Addressing Resource Conservation Issues in Rice-Wheat Systems of South Asia

A Resource Book

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Rice Wheat Consortium for Indo-Gangetic Plains
Convening Center: CIMMYT

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The Indo-Gangetic Plains (IGP) is the breadbasket of South Asia. The region witnessed higher growth rates for food grain production compared with other regions of the world. Most of this area is under rice-wheat cropping systems covering a total of 13.5 million hectares in Bangladesh, India, Nepal and Pakistan. Extensive irrigation infrastructure, mechanization and easy access to production inputs and marketing and grain procurement services have contributed to these increases, especially in the western parts of the IGP. However, growth rates have decreased even as there is a wider recognition of environmental issues arising from the intensive and sometimes excessive use of inputs. The long-term sustainability of these systems is now a subject of attention of the Rice-Wheat Consortium for the Indo-Gangetic Plains (RWC).

There is a general consensus that quality of natural resource base needs to be improved for enhanced productivity in the northwest IGP. Also, it is believed that future productivity growth would come about through better risk management strategies in the drought-flood prone marginal tracts of the eastern Gangetic plains. Targeting the resource conserving technologies offers newer opportunities to provide for better livelihoods for the resource poor, densely populated, small and marginal farmers of eastern Gangetic plains.

This book is a rich collection of resource-conserving opportunities and new approaches for anyone wanting to tackle complex natural resource management and environmental issues and produce more at less costs within the Green Revolution tracts of South Asia.

The Editors

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Foreword

Can South Asia Eat Without Consuming its Natural Resources?

The rice-wheat zone of South Asia may be regarded as a laboratory for the future of world agriculture. Consider, for example, the case of Bangladesh: every square centimeter of arable land is cropped 1.9 times per year. As in many parts of the developing world, increases in population, income, and market competition in South Asia are pushing agriculture to the limit, and one result is the degradation of natural resources. Fueled by policies designed decades ago to foster self-sufficiency in basic food grains, current rice-wheat systems pull more nutrients, organic matter, and water from the earth than are being put back. Because puddling for rice essentially obliterates the soil structure, farmers who sow wheat after rice harvest typically spend up to two weeks plowing, representing an average seven or eight tractor passes, hundreds of liters of diesel fuel consumed, and hundreds of kilograms of CO_2 added to the atmosphere. In addition, the current systems require the application of several million liters per hectare of irrigation water, along with the requisite pumping of groundwater to supplement flagging supplies from dam-fed canals. Millions of tons of crop residues are burned each year, polluting the air in many zones for a month or more and adding yet more greenhouse gases to the air. Finally, continuous high-intensity farming has brought on problems that include the appearance of new, herbicide-resistant strains of weeds.

On the plus side, the Indo-Gangetic Plains are home to some of the developing world's most innovative and enterprising farmers. In addition, the region is arguably among the best "studied" agro-ecological environments, and relevant knowledge and products are on the shelves ready for application. The problem has been to get technologies off the shelf and onto farmers' fields.

For this reason, the recent achievements of the Rice-Wheat Consortium for the Indo-Gangetic Plains (RWC) in testing and promoting resource-conserving technologies such as zero-tillage are particularly gratifying. Their experience suggests certain keys to success in achieving the adoption of such practices:

- A multi-stakeholder approach.
- A strong reliance on farmer experimentation and farmer interaction, with important back-stopping and follow-up roles for research.
- Identifying and supporting "champions" in local research and extension organizations to promote resource-conserving practices.
- Accessing and facilitating use of outside expertise.
- Developing and making available essential machinery and implements for farmers to test; later, promoting the development of local manufacturers and suppliers.
- A continued emphasis on long-term trials and monitoring to anticipate and deal with undesirable consequences that may arise.

I am proud of the International Maize and Wheat Improvement Center's (CIMMYT) role in the RWC and of our partnerships with its members and its many, generous supporters. Over the years a consortium of generous partners have supported the RWC, including the following:

- The Asian Development Bank (ADB).
- The Directorate General, International Cooperation of the Government of the Netherlands (DGIS).
- The Consultative Group on International Agricultural Research (CGIAR) Finance Committee (support obtained with help from the World Bank).
- The Australian Centre for International Agricultural Research (ACIAR).
- The Department for International Development, UK (DFID).
- The International Fund for Agricultural Development (IFAD).
- The United States Agency for International Development (USAID).
- The New Zealand Overseas Development Agency (NZODA).

National research systems of the participating countries have also provided funding and significant in-kind support for RWC activities, and international centers like CIMMYT have drawn on their own unrestricted funds to ensure that work goes forward. The Food and Agriculture Organization of the United Nations (FAO-UN) provided supplementary funding towards the development of this resource book.

The information in this publication should prove invaluable for those who wish to learn of the Consortium's work and scale out its successes.

Where do we go from here? There are many ideas, but the challenge now and in the future is how to sequester more carbon in agricultural lands. Permanent planting systems based on the use of reduced tillage must be used. Planting will more likely be undertaken into crop residues left on the surface (rather than burnt). Rice will have to be grown using some of the resource conserving technologies evolved for wheat. Much of this work is already underway and will hopefully be reported in future revised versions of this resource book.

Larry Harrington
Director, Natural Resources Group (NRG)
The International Maize and Wheat Improvement Center (CIMMYT)

Introduction

Rice-wheat systems are critical to South Asian food security. Over a billion people depend on these systems for their food. More than 150 million people support themselves by growing rice in rotation with wheat in 13.5 million hectares of land in the Indo-Gangetic Plains (IGPs) of India, Pakistan, Nepal and Bangladesh. Indeed the livelihoods of millions of farmers and workers are dependent on these systems. The pressures on natural resources are immense: soils are less able to sustain crops as a result of continuous and intensive cropping and reduced organic matter levels. The development of sodicity and salinity on irrigated land and the depletion of groundwater in areas irrigated by tubewells and water quality concerns have brought about heightened awareness of the need for the judicious use of water. Tillage costs are rising, which accentuates the already serious labor shortages during peak periods of land preparation and harvest. For these and other reasons, the sustainability of these systems is in question. The Rice Wheat Consortium for the Indo-Gangetic Plains (RWC), an initiative that puts national agricultural systems in the above-mentioned countries at the forefront of efforts to address these issues, has supported the development of a wide range of resource-conserving technologies.

Improved tillage and crop establishment practices, especially for rice, show real potential for sustainably improving the productivity and profitability of rice-wheat systems. Reduced and zero tillage can improve yields, raise input-use efficiency, reduce the intensity of machinery use and lower production costs. Zero-tillage allows farmers to establish a wheat crop almost immediately after rice harvest, thereby improving yields and input use efficiency. Surface seeding technologies can increase the use of underutilized 'rice fallows' in the eastern Indo-Gangetic Plains. Scientists are working jointly with farmers to find ways to manage rice and wheat residues that typically amount to as much as 7-8 tons per hectare each year. When burnt during land preparation, the residues instantly generate as much as 13 tons of carbon dioxide per hectare, contaminating the air, depriving soils of organic matter, and constraining supplies of fodder for livestock. Because zero-tillage involves the direct seeding of wheat and several other crops in rice residues, residual moisture use is increased and as much as 10 cm-hectares (approximately 1 million liters per hectare) of irrigation water is saved. It is thus no wonder that farmers have been quick to adopt zero tillage and other resource conserving technologies. From a modest 3,000 hectares of zero-till wheat in India and Pakistan in 1998-99, area surpassed 200,000 hectares in 2001.

Another innovation being tested and promoted with farmers is the planting of wheat and rice on raised soil beds, where the furrows facilitate the movement of mechanized equipment and serve as a waterway. Water requirements are 50% less than those under conventional tillage systems. The major savings in water use will come from planting the rice on raised beds, and early results from tests with farmers suggest this system improves both yields and water use efficiency. Bed planting can also be used for legumes, maize, potato, vegetables, and other crops that would normally not be raised in a rice field. Good opportunities exist for better integration of ruminant livestock, with profitable conversion of crop by-products, increased use of manure and treatment of straw, among other benefits. Such intensification and diversification both offer opportunities to boost food security and incomes among the smallholders.

The RWC is also working on new options for efficiently synchronizing nutrient management with crop nitrogen demands to reduce the use of chemical fertilizers. Thus, a "tillage revolution" is sweeping across the Indo-Gangetic Plains of South Asia, and may be one of the best opportunities to foster sustainable improvements in productivity and livelihoods for vast numbers of people in one of the poorest regions on earth.

Because national research systems are at the forefront of this work and because it is done with farmers in their fields, adoption is accelerated. The RWC is pleased to share this collection of field-tested and farmer-proven, resource-conserving technologies. Local governments, NGOs, the private sector, extension agencies and research centers are encouraged to test and adapt these approaches and feature them in rural development strategies. Policy makers will benefit from these short summarized discussions of problems and tested solutions. Hopefully, policy implications can also be derived to promote the efficient use of land, water and other inputs. While the countries in the region currently have adequate quantities of grain stocks, demands are expected to increase dramatically within the next 2-3 decades, increasing pressures on the resource base. New problems and new challenges in South Asia's breadbaskets require new approaches that are sensitive to concerns about food security, resource use and the environment in general.

Raj K. Gupta
Regional Facilitator
Rice-Wheat Consortium for the Indo-Gangetic Plains

How this Resource Book was Produced

Rice-wheat systems by far are the most intensively studied agricultural production system yet valuable information has remained underutilized by practitioners, policy makers and development administrators who, often, have difficulty with documentation generated primarily for the research or academic community. The Rice-Wheat Consortium undertook upon itself the task to identify and repackage existing research studies.

Authors of shorted-listed papers and reports were contacted and informed about plans to produce a resource book. A team of professional editors (Dr. P.N. Mathur, Ms. Sheila Vijaykumar, Ms. Elizabeth Chacko, Mr. Miguel Braganza) and illustrators repackaged the papers, added illustrations and improved the layout. These papers were posted on a website accessible to all those involved in the production effort. Authors had an opportunity to provide feedback directly to the editors or through the facilitation unit. Authors' feedback initiated the second cycle for revision of the papers in which editors, illustrators and graphic artists were involved. This constituted the first set of 42 papers. The production team (professional editors, consultants, RWC staff and two resource scientists) met face to face in New Delhi, India for three days in August 2002 to review the progress and identify set of new papers mainly to fill in the gaps that became apparent after the review. A total of 25 papers were identified for repackaging in this second round. The same process of contacting the authors, repackaging, seeking feedback on revisions, etc. was pursued to assemble a total of 68 papers.

The whole process relied heavily on the use of internet for exchanges between the authors and production staff and consultants. Dr. Prabhakar deserves my compliments for his tireless efforts in corresponding with the production team, the authors and the reviewers involved in the process. The lead consultant who helped design and develop the approach was Dr. Julian Gonsalves. Ms. Joy Rivaca-Caminade took charge of the final editing, design, layout of articles and for the preparation of the camera-ready version of the resource book.

RWC acknowledges the immense contributions and support of numerous scientists who authored and gave concurrence for the simplified versions of their scientific papers, the editors, peer reviewers and the production team for their help in the publication of this resource book. Dr. Julian Gonsalves deserves a special mention for demonstrating how the potential of information technology can be harnessed for generating relevant and usable materials to disseminate information as public goods. Readers are encouraged to use these materials and disseminate them as widely as possible. There is no copyright but the Consortium would appreciate it if due acknowledgments are provided whenever materials from this resource book are used.

Thanks are due to the Members of the Regional Steering Committee for their encouragement to undertake this challenging assignment of putting together pertinent information that will serve a quick reference for non-specialists in particular. I am indebted to all my colleagues in NARS, Centers, advanced institutions and the Facilitation Unit for their invaluable support in bringing out this Resource Book.

Raj K. Gupta
Regional Facilitator
Rice-Wheat Consortium for the Indo-Gangetic Plains

The Rice-Wheat Consortium for the Indo-Gangetic Plains:
Vision and Management Structure

In Asia, the rice-wheat system was practiced nearly 1000 years ago and it has since expanded and is now estimated at 24 million ha. This includes China with about 10 million ha, and South Asia with about 13.5 million ha. During the last few decades, the rice-wheat region witnessed higher growth rates for food grain production (wheat 3.0%; rice 2.3% and maize 4%,) compared with other regions of the world. Growth rate in yield per hectare for cereals in developing countries and the world as a whole have declined since early 1980s and the prognosis for further increases vary widely. In case of rice and wheat, countries in South Asia have done very well in maintaining the pace of food production in tune with population growth. However, there is growing realization that the agriculture of the Post-Green Revolution will be guided by the need to produce more of quality food at less costs and from more of marginal quality land and water resources.

High productivity rice-wheat systems, are thus fundamental to employment, income and livelihoods for hundreds of millions of rural and urban poor in the Indo-Gangetic Plains (IGP) of South Asia. These systems, however, are showing signs of fatigue. Even though yields (slowly) continue to increase, factor productivity is declining in some areas, driven by soil fertility decline, an increase in weed problems and localized problems of groundwater depletion and salinity/sodicity. Food security and livelihoods for hundreds of millions of rural and urban poor are at stake because of sustainability issues concerning rice-wheat systems of the IGP.

Evolution of the Consortium Concept

In India, the largest National Agriculture Research System (NARS) participating in the Consortium, the organization of agricultural research evolved over the past 40 to 50 years through networking arrangements in its coordinated research programs and several commodity and system perspective based project directorates. Similar evolutionary changes have occurred in the NARS of Bangladesh, Nepal and Pakistan. There are considerable variations across countries in the maturity of the NARS. In spite of this, Consortium countries have established multidisciplinary teamwork within their institutions, though links between institutions are still weak, and often reporting is to different lines of management. While the commodity-mandated institutions looked at cropping-system interactions for their particular commodity, they tended to remain isolated from related research on similar themes in other institutions. Social science and policy sector was, and often still is, relatively weak. Concern about the sustainability of the rice-wheat system arose from diagnostic work initiated at different sites in the region. Analysis of data from field experiments conducted by scientists provided evidence of a sustainability problem.

Facts in Figures...

- South Asian countries, comprising of Bangladesh, India, Nepal and Pakistan with a geographical area of 401.72 million ha, holds nearly half the world population of 3.1 billion. Of which, 59% depends for livelihoods on agriculture. Nearly half the land area is under agricultural crop production. It is estimated that nearly 60% of the farming households live on less than 30% of global agricultural lands.
- Rice-wheat systems meet the food needs of approximately 1.3 billion people in the region. Both contribute nearly 70%-95% of the daily calorie intake.
- In South Asia, rice and wheat occupy 59.16 and 42.55 million ha respectively.
- The annual grain output of the rice and wheat crops individually in the region is around 181.35 million tons for rice and 109.07 million tons for wheat.
- Rice-wheat system occupies 13.5 million ha in four Consortium countries of India, Pakistan, Bangladesh and Nepal with areas 10.0, 2.2, 0.8, and 0.5 million ha respectively. Another 10 million ha of rice-wheat area is in China. Taking all the five countries (China, India, Pakistan, Bangladesh and Nepal) together, RWC covers 28% of the total rice area and 35% of the total wheat area in these countries.
- These RWC countries are not just only five of the more than 200 countries of the world; they represent 43% of the world's population on 30% of total land including 20% of the world's arable land.
- In absence of the system productivity figures, the average yield of rice and wheat together in the region are 5.2 tons per ha (5.6, 5.8, 4.4 and 5.5 t/ha for Bangladesh, India, Nepal and Pakistan respectively).

The Rice-Wheat Consortium (RWC) was established in 1994 to address issues of this intensively-cultivated and irrigated cropping system adopted by millions of farmers located in the semi-arid agro-ecoregion of the IGP in South Asia. Establishment of the RWC only confirms that this learning process is still continuing. The ecoregional approach is the latest and most comprehensive of the evolving concepts of how agricultural research should be structured for more effective performance.

The RWC has its origin in many years of collaborative research between CIMMYT, IRRI and the national research centers for rice and wheat in South Asia. These arrangements were formalized in 1989 by an agreement between IRRI, CIMMYT and the NARS of India, Pakistan, Bangladesh and Nepal. Funding from IFAD and other donors supported the groundwork to formalize the establishment of the RWC in 1994. This facilitated collaboration among the NARS, IARCs and the ARIs. A central Facilitation Unit was also established to help coordinate research across the four member countries, and sharpen the focus on long-term system sustainability issues. RWC work has continued with local and international funding such as from DGIS, of the Netherlands, ADB, DFID, IFAD, USAID, ACIAR, and World Bank (CG-administered funds). Various advanced research institutions such as Cornell University, Ohio State University, IACR, Rothamsted, AVRDC, IAC, Wageningen, CABI-UK, CISRO Australia, Melbourne University, CIRAD, DMC and IAEA have since joined the association of rice-wheat experts.

History of the Rice-Wheat Consortium

Conception

In January 1993, the World Bank arranged a meeting between the heads of the national agricultural research systems (NARS) of the four countries in the Indo-Gangetic Plains and the Directors General of two international agricultural research centres (IARCS), i.e., CIMMYT and IRRI. The idea of a collaborative research management mechanism was conceived at this meeting of four heads of NARS and the heads of two IARCS.

Gestation

The International Maize and Wheat Improvement Centre (popularly known by the acronym of its Spanish version, Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) and the International Rice Research Institute (IRRI) helped establish the structure and research plan along with the four NARS of Bangladesh, India, Nepal and Pakistan. The International Crops Research Institute for Semi-Arid Tropics (ICRISAT), the International Water Management Institute (WMI) the International Board for Soils Research and Management (IBSRAM), the Australian Centre for International Agricultural Research (ACIAR) and Cornell University (USA) became partners in the effort to manage collaborative research in rice and wheat. The Regional Steering Committee began to take shape and move.

Birth

In May 1994, the Steering Committee commissioned ICRISAT as the Convening Center and a Facilitation Unit of the Rice-Wheat Consortium (RWC) was set up at the 23, Golf Links, Delhi, office of ICRISAT. The physical presence of RWC was at this address while it initiated interactions with the NARS and IARCs.

The First Steps

RWC was born with a mission to promote sustainable productivity growth in rice-wheat systems and help produce food for the growing populations in the region. In its very first year, RWC identified four areas that needed attention:

- Declining rice and wheat yield growth rates
- Water-induced land degradation
- Gradual loss of soil fertility
- Increasing crop losses due to insects, diseases and weeds

It set about its mission with a systems perspective and an integrated collaborative approach involving national, regional and international agencies. That was 1994.

Growing up

A number of universities and research institutes around the world associated with the RWC for research and training. Universities of Melbourne and Adelaide (both in Australia) Michigan (USA) and Rothamsted (UK) joined along with CABI-UK, IAC (Netherlands) and other institutes. The number of donor agencies funding RWC activities also increased. The priorities and research themes also increased, moving on from five to eight themes.

CIMMYT was given the responsibility of being the Convening Center in 1998. The Facilitation Unit shifted to the CIMMYT office in the old NBPGR building, and in 2002 from there to its current office in the new National Agricultural Science Centre Complex Building at Dev Prakash Shastri Marg, New Delhi. The research themes have expanded, from six in 2000 to eight in 2002, to meet the growing challenges.

Consortium Members

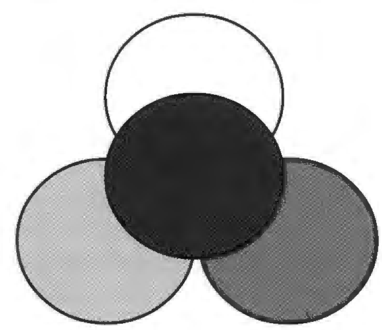
A consortium of South Asian National Agricultural Research Systems (Bangladesh, India, Nepal and Pakistan), International Centers (CIMMYT, CIP, ICRISAT, IRRI and IWMI), Advanced Research Institutions (ARIs), NGOs, and private enterprise and farmers groups was formed to address the sustainability concerns of the rice-wheat systems. This consortium, known as the Rice-Wheat Consortium for the Indo-Gangetic Plains (RWC), is convened by CIMMYT and is one of the Ecoregional Initiatives of the CIGIAR. As such it brings together research and extension services of the region to interact and mobilize resources.

The focus of the Consortium is on the interface between the dimensions of the problems being addressed through a partnership of farmer organizations, NARS, NGOs, ARIs and CG centers. Success of the Consortium is based on participation of stakeholders. Private entrepreneurs and other stakeholders are encouraged to take up corporate memberships.

RWC Structure and Operational Mechanisms

RWC structure is like a tetrahedron with three partners IRRI, (CIMMYT/CG centers) and the ARIs at the base of the pyramid and NARS at the top of the base structure. The RWC resides in the centre of the pyramid structural cavity that glues the partners and facilitates closer links between them and helps coordinate activities of the rice-wheat production systems.

Figure 1. Linkage of Rice-Wheat Production System Programs of the Consortium with Programs of the Centers and other Stakeholders

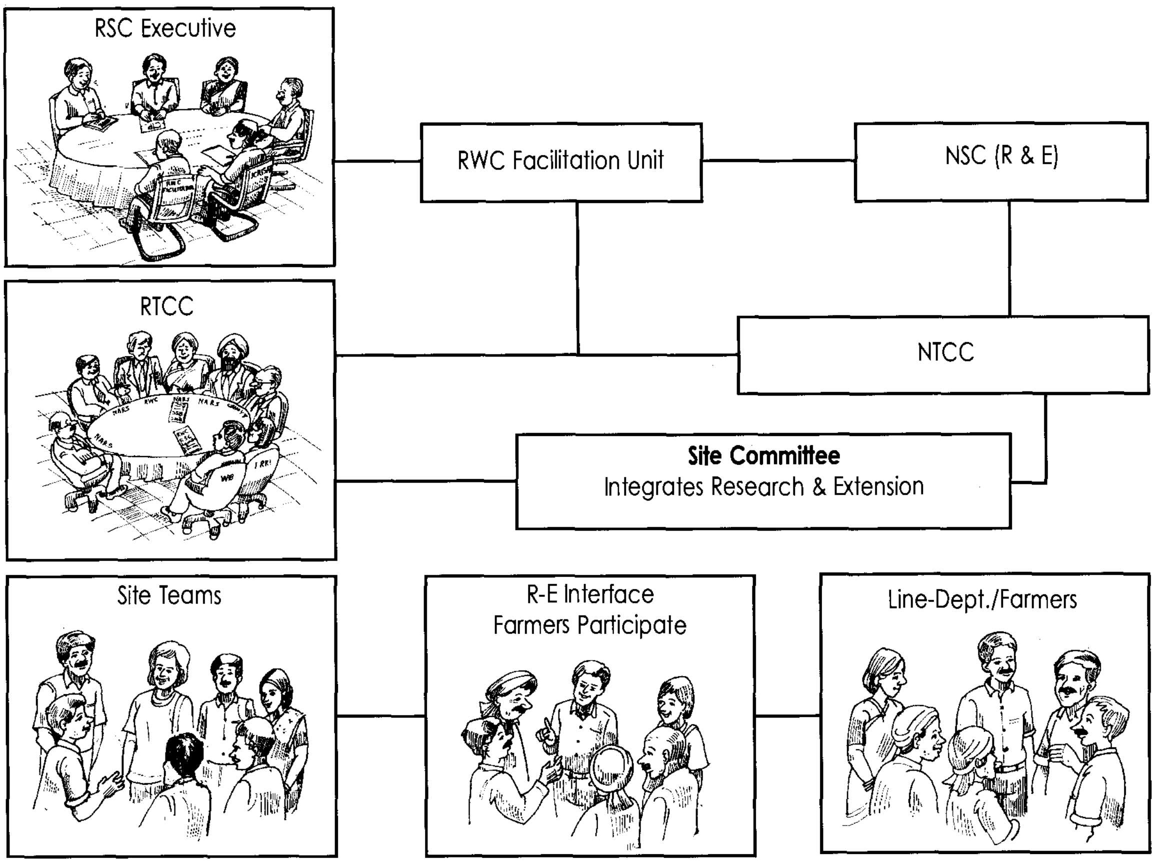


- Rice-wheat systems being handled by IRRI
- Wheat systems being handled by CIMMYT
- Other centers & ARIs programs
- NARS led rice-wheat programs facilitated by RWC in collaboration with CG centers

It needs to be made very clear that the RWC is truly a consortium (a special kind of research network). It is not a Research Programme in its own right in the sense that the word 'program' is generally used in the CGIAR. Apart from any studies, the Facilitation Unit carries out on ecoregional methodologies, the RWC is not structured to conduct research in its own name. The research programs and projects directed at the problems of rice-wheat production systems, and carried out under the aegis of the RWC, all reside with one or more of the participating research organizations (Figure 1). The fact that the RWC has sometimes been described by the CGIAR as an eco-regional program, e.g., in TAC's (1994) Review of System-wide and Ecoregional Initiatives, has added to the confusion.

The RWC has a Regional Steering Committee, which is chaired by one of the chief Executive of NARS from the four member countries in rotation annually. Membership comprises the Directors General of the four NARS, and of IRRI and CIMMYT from the International Agricultural Research Centres (IARCs), and a donor representative. The Consortium Facilitator/and Co-facilitator act as Secretary/and Co-secretary. A Regional Technical Coordination Committee (RTCC), made up of the national rice-wheat coordinators, focal scientists from the participating CGIAR Centres, and the advanced institutions and NGOs, assist in formulating programs for the RWC. There are national steering and technical coordinating committees in each of the four countries and the site teams to coordinate programs at the site. These have now been formalized and are a favored mechanism for coordinating and monitoring the cooperative research in all four countries. The Organogram of the RWC as it has evolved over the years is shown in Figure 2.

Figure 2. Structured Mechanism of Coordinated Research in the Consortium



Responsibilities within the Consortium

NATIONAL

- Identification and prioritization of research problems.
- Organization of multi-disciplinary teams to conduct research on location-specific problems.
- Identification and procurement of funds for national activities.
- Identification of ways to solve research problems through collaborative Consortium activities.
- Constitution of a national rice-wheat research committee and designation of a senior scientist as national program Convener.

REGIONAL

Regional Steering Committee (RSC)

Mandate

- Provide policy guidance and direction.
- Endorse research priorities, work programs and budgets for collaborative work.
- Monitor effectiveness of the Consortium.
- Commission an international research agency to provide logistic support to the Facilitation Unit.

Membership

- Senior executive of each participating NARS.
- Senior executive representing participating IARCs.
- Donor representative.
- Consortium Facilitator as an ex-officio member and Secretary.

Regional Technical Coordination Committee (RTCC)

Mandate

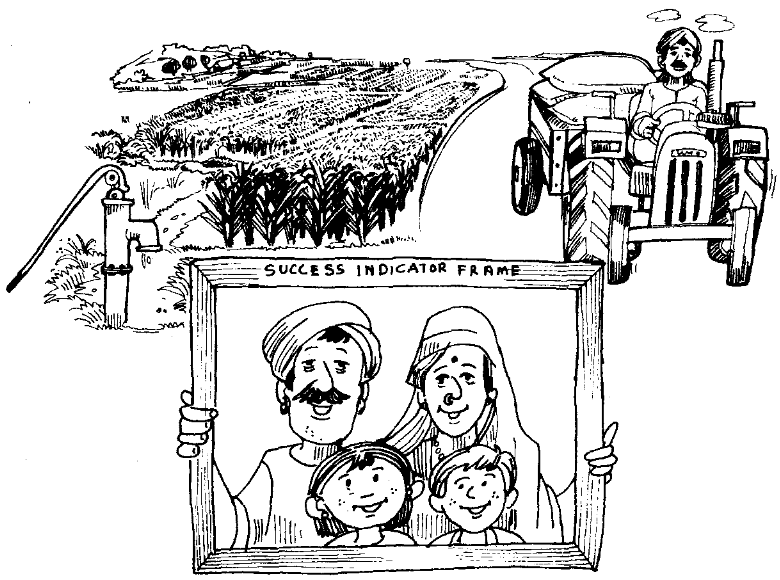
- Develop work plans and budgets for such collaborative activities as research, training and networking.
- Promote and strengthen linkages between national programs.
- Serve as a forum for information exchange.
- Provide feedback to the RSC.

Membership

- Senior representatives from each participating NARS.
- Representative from each participating IARC.
- Consortium Facilitator as a memebr.

The Goal and Objectives

The goal of the Consortium is to reverse the declining trends in factor productivity by promoting research on issues that are fundamental to enhance the productivity and sustainability of rice-wheat systems in South Asia.



This is achieved through:

- Setting priorities for focused research on problems affecting many farmers.
- Promoting linkages among rice-wheat specialists at the local, national and regional levels with technical backstopping from the IARCs and ARIs.
- Encouraging inter-disciplinary team approach to understand and find solutions to complex problems of natural resource management in system ecology perspective.
- Promoting farmer participatory mode of research.
- Improving the skills and excellence among scientists, entrepreneurs and farmers.
- Enhancing the transfer of improved technologies to farmers through established institutional linkages.

The RWC research themes focus on rice-wheat system interactions and the attendant issues related with production research of rice-wheat systems in areas such as:

- Resource-conserving technologies with tillage and crop establishment at the center stage of soil, water and crop management practices
- Crop improvement and management
- Integrated soil nutrient management
- Integrated weed, insect and disease management
- Integrated water management
- Socioeconomics and policies
- Knowledge management
- Human resource development

The financial support for the Consortium's research agenda currently comes from many sources, including the Asian Development Bank, Government of Netherlands, the New Zealand, Department for International Development, UK (DFID), US Agency for International Development (USAID), International Fund for Agricultural Development (IFAD), ACIAR, CGIAR, The World Bank and other donors.

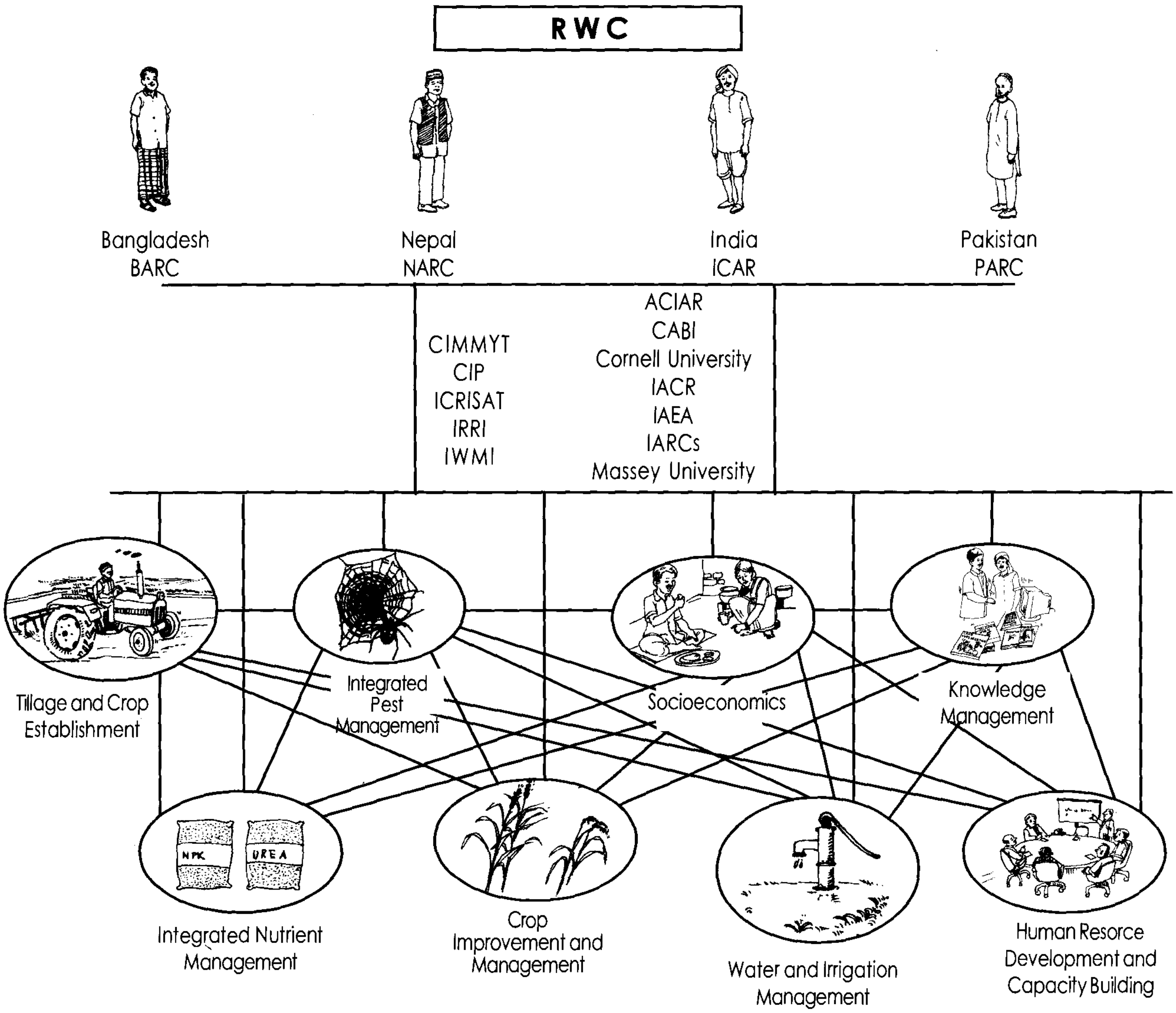
RWC: A Successful NARS-Driven Initiative

In a recent review of Ecoregional Programs within the CGIAR, the RWC was listed as one of the two best such programs in the CGIAR system. The TAC-commissioned review of Ecoregional Programs noted that, "The RWC is clearly a NARS-driven initiative with the Centers largely having roles defined by the Consortium . . ." The review goes on to say that, ". . . there is clearly a strong commitment to [the RWC] at the highest levels of leadership in the national systems . . . [the RWC] has raised awareness of the benefits of a systems perspective, raised awareness of the importance of integrating NRM with production research . . . and fostered the use of new research tools . . .. Some of the greatest achievements of the RWC have been in fostering partnerships and strengthening stakeholder participation... The aim is not only to draw on their experience and knowledge in order to set more relevant priorities, but more importantly, to develop a sense of ownership of the research and development process and to improve the 'goodness of fit' of its expected products. It is hard to see how the CGIAR can play any useful role in testing and developing these partnership approaches unless it is through a mechanism such as the RWC."

In recognition of its efforts, RWC has been cited for numerous achievements. Some feel that the RWC is the best Ecoregional Program in the CGIAR system. It has accomplished much in governance and partnerships, in science and the use of new research methods, and in impacts in farmers' fields. APAARI, the association of NARS from the Asia-Pacific region, chose the RWC as their "best example of an effective research partnership" for presentation at GFAR, and was awarded the CGIAR Chairman's 'Award for Outstanding Scientific Partnerships'.

Contributed by:
Raj K. Gupta, G. Michael Listman and **Larry Harrington**

Rice-Wheat Consortium (RWC):
Linkages and Operations



An organization that collaborates, cooperates and coordinates with international, regional and national agencies for the all-round and sustainable development of crops in rice and wheat based systems, the Rice-Wheat Consortium (RWC) looks beyond just the crops to the livelihoods of the people in the communities with which it interfaces. The RWC began as a forum for the four South Asian countries to work together to do research on some common problems in crop cultivation. Originally, the farmer-defined researchable issues gathered by the National Agriculture Research Systems (NARS) were combined together into themes. Then these themes were assigned to the various International Agriculture Research Centers (IARC) working in the region to collaborate with the NARS and address these issues.

The RWC is composed of the four NARS stretching across the Indo-Gangetic Plains of South Asia. Though the RWC attempts to introduce and foster diversity within the rice-wheat cropping pattern, it recognizes the importance of rice-wheat to the livelihoods and cereal sustainability of the region. Currently, two out of the four countries (India and Bangladesh) are self-sufficient in cereal grains with the other two (Nepal and Pakistan) close to becoming so.

Each partner brings to the consortium its unique talents and experiences, e.g., the advance institutions with their emphasis on upstream and more academic research coupled with the more applied nature of the NARS and IARCs (Table 1). These research efforts under various thematic areas are funded by different donors (Table 2). What joins these partners together is the goal of tackling grower-defined problems they face in maintaining sustainability of the rice-wheat cropping pattern.

Table 1. Existing Organizational Responsibilities for Various Thematic Activities in the Consortium

Thematic areas and organizational responsibilities	Activities within thematic areas	NARS	CIMMYT	IRRI	IWMI	ICRISAT	CP	IAC/Wis. Int.	Cornell University	IACR	IAEA	CABI	Massey Univ	ACIAR/CSIRO,QU/MU	CRAD/DMC	AVRDC	GCTE/GECAFS/APN
1. Tillage and crop establishment	1. Tillage and crop establishment	✓	✓	✓						✓			✓	✓	✓		
	2. Residue management	✓	✓	✓					✓					✓	✓		
	3. Machinery development	✓	✓	✓									✓	✓			
2. Crop improvement and management	4. Germplasm screening and GxE, GxT interactions, cultivar choices	✓	✓	✓		✓	✓						✓	✓			
	5. Legumes in rice-wheat systems	✓		✓		✓			✓							✓	
	6. System diversification and intensification	✓	✓				✓										
	7. Modeling and climate change	✓	✓	✓		✓			✓					✓			✓
	8. Seed quality, priming and storage			✓					✓								
3. Integrated pest and disease management	9. Crop protection – IPM, IDM	✓	✓			✓			✓			✓					
	10. Weed management	✓	✓	✓										✓	✓		
4. Nutrient management (IRRI)	11. Integrated nutrient management	✓		✓					✓	✓	✓		✓	✓		✓	
	12. SOM, long-term fertilizer trials, nutrient enrichments	✓		✓					✓	✓	✓						
5. Water management (IWMI)	13. Water use efficiency, land leveling	✓		✓	✓						✓		✓	✓			
	14. Water (field, farm and system level)	✓			✓												
	15. Water quality, salinity/sodicity issues	✓															
6. Knowledge management	16. GIS/ country almanacs	✓	✓	✓		✓		✓	✓	✓							
	17. Database management - RWC-PRISM, RWIS and Webpage	✓	✓					✓							✓		
	18. RWC paper series and publications	✓	✓	✓		✓		✓	✓								
	19. Annual meetings in regional and international research fora	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
	20. Multi-stakeholder meeting events-traveling seminars, workshops and conferences	✓	✓	✓		✓				✓		✓		✓			
	21. Technology dissemination/ adaptive research	✓	✓	✓		✓				✓				✓			
7. Socioeconomics	22. Impact analysis	✓	✓		✓		✓							✓	✓		
	23. Policy issues	✓	✓														
	24. PR & GA	✓											✓				
	25. Community group working	✓				✓				✓			✓				
8. Human resource development and capacity building	26. Specialized training in advanced institutions for scientists and farmers	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓			

Other organizations to include or integrate are Adelaide (weeds), Long Ashton (weeds), NGOs (eg., LIBIRD in Nepal, Catalyst Management Services in India) and Monsanto.

Table 2. Donor Support for Various Activities of the Consortium

Thematic areas and organizational responsibilities	Activities within thematic areas	DGIS, Netherlands	ADB	NZODA	IFAD	DFID	ACIAR	FAO/IAEA	WB Projects-FAO	USAID SM-CRSP	APN
1. Tillage and crop establishment	1. Tillage and crop establishment		✓	✓		✓	✓		✓		
	2. Residue management		✓	✓			✓	✓	✓		
	3. Machinery development	✓		✓	✓	✓	✓		✓		
2. Crop improvement and management	4. Germplasm screening and GxE, GxT interactions, cultivar choices		✓	✓		✓	✓		✓		
	5. Legumes in rice-wheat systems		✓			✓			✓	✓	
	6. System diversification and intensification	✓	✓			✓	✓		✓		
	7. Modeling and climate change	✓					✓			✓	✓
	8. Seed quality, priming and storage	✓				✓				✓	
3. Integrated pest and disease management	9. Crop protection – IPM, IDM		✓			✓			✓	✓	
	10. Weed management		✓	✓		✓	✓		✓		
4. Nutrient management (IRRI)	11. Integrated nutrient management		✓			✓	✓	✓	✓	✓	
	12. SOM, long-term fertilizer trials, nutrient enrichments		✓			✓		✓	✓	✓	
5. Water management (IWMI)	13. Water use efficiency, land leveling		✓			✓	✓	✓	✓		
	14. Water (field , farm and system level)		✓			✓			✓		
	15. Water quality, salinity/sodicity issues	✓							✓		
6. Knowledge management	16. GIS/ country almanacs	✓	✓	✓						✓	
	17. Database management- PRISM and Webpage	✓	✓								
	18. RWC paper series, RWIS and other publications	✓	✓				✓		✓		
	19. Annual meetings in regional and international research fora	✓	✓	✓		✓			✓	✓	
	20. Multi-stakeholder meeting events- traveling seminars, workshops and conferences	✓	✓	✓		✓			✓	✓	
	21. Technology dissemination/ adaptive research	✓	✓				✓	✓	✓		
7. Socioeconomics	22. Impact analysis		✓			✓			✓		
	23. Policy issues		✓			✓			✓		
	24. PR & GA			✓		✓	✓				
	25. Community group working			✓		✓			✓	✓	
8. Human resource development and capacity building	26. Specialized training in advanced institutions for scientists and farmers	✓	✓	✓			✓		✓	✓	

This is a mixture of NARCs, IARCs, donors, NGOs, and private companies, with a common goal shared by all-sustainable rice-wheat systems for cereal and food security for the region. The six simple themes grew to more than 26 sub themes, woven into a matrix of working groups that function under the umbrella of the RWC.

Slowed growth of productivity in agriculture, and negative impacts of intensive agriculture on environmental quality, particularly in the northwestern parts of the Indo-Gangetic Plains (IGP), suggested for infusion of a complementary set of new agricultural technologies to boost productivity growth. The need is to re-orient strategies for enhancing and sustaining productivity gains of the Green Revolution era. As a part of the strategy, the paradigm shift focuses on the way agricultural research is prioritized, conducted, coordinated and managed as also how knowledge-intensive technologies for establishment and management of rice-wheat systems are transferred to farmers.

The RWC is an umbrella organization under which the talents, resources and efforts of participating agencies are combined and channeled in a way one would conduct an orchestra to produce one harmonious product. Significantly, RWC has no "Director". It is headed by a facilitator who truly facilitates the work of many to achieve the objective of sustained growth and socioeconomic, equitability in the rice-wheat system of the IGP spread over four countries.

Operations

Research conducted by the RWC through various agencies targets site-specific national and regional sustainability problems of rice and wheat. National systems (NARS) identify and prioritize problems and suggest potential RWC interventions and research sites. A national rice-wheat research coordinator designated by each country monitors the national institutions. Rice, wheat and other commodity programs are being linked to provide a systems perspective in research.

Multidisciplinary research efforts that address system-level biologial and socioeconomic problems are being encouraged and supported. The National Technical Coordination Committee (NTCC) and National Steering Committee (NSC) are responsible for overall program management in a member country. Finally, each country is encouraged to form a site-level committee to coordinate activities and strengthen interactions between different programs operating at each site.

Activities of the Consortium

The RWC objective is not merely to raise production of rice and wheat, but also to help improve livelihood and reduce poverty through more sustainable agro-ecosystems based on the rice-wheat rotation, and to conserve natural resources devoted to these systems. Resource-conserving tillage practices have been found to contribute substantially to this objective. The activities of the RWC in its ecoregional mode basically includes the following:

- Development of priorities and strategies for research on rice-wheat production systems through diagnostic surveys at key sites.

- Provision of a forum where scientists in the region can meet to discuss common problems and to exchange ideas and material (also through a newsletter (RWIS) traveling seminars and a web site: (www.rwc-prism.cgiar.org).
- Foster the development of crop varieties, water and nutrient management, integrated pest management as well as soil and crop management practices and their interaction with resource-conserving tillage technology breakthroughs.
- Encourage widespread use of farmer experimentation and farmer participatory research methods among RWC scientists.
- Facilitate the governance and management of all of this through recurrent meetings of the Regional Steering Committee (RSC) and the Regional Technical Coordination Committee (RTCC). Facilitate coordination of activities through national coordinating committees and site teams, including the submission of joint funding proposals on behalf of stakeholders.
- Organize and participate in technical conferences and training seminars.
- Publication of conference proceedings and training materials and encourage scientists to publish relevant research in a Consortium research paper series.
- Organization of traveling seminars to see farmers' problems and field experiments at first hand.
- Development of a regional project information system (www.rwc-prism.cgiar.org) and regional GIS-based country almanacs for cross-site synthesis of data.
- Promotion and acceleration of the use of new methodologies.

A good example is the promotion of the farmer participatory research process. Traditionally, in the region, research and extension had been a top-down process. The results of research are provided to extension workers and the recommendations are then demonstrated to farmers; farmer participation is minimal. The Consortium, with the support of the IARCs and national agricultural research institutes in NARS, is encouraging improved farmer participation in diagnostic work to setup and develop the research agenda, for experimenting with new technologies. The success of the new resource conserving technologies (RCTs) has ushered an era of a new "Tillage Revolution", the term coined by Prof. Timothy Reeves, to describe the changes taking place in South Asia that provided options to the farmers to allow faster adoption and benefit from these of new technologies.

Dr. Paroda, former Director General of ICAR and Secretary (DARE, GOI) credits the ecoregional approach with having heightened awareness in South Asia of the benefits of a whole system perspective in agricultural research and of the importance of integrating NRM research with production research.

At present, these activities are taken up at various priority levels. However, there is an urgent need to push the low priority activities to a higher level (Table 3).

The Method

The RWC has successfully applied participatory approaches and expanded partnerships among a range of stakeholders, encouraging all to collaborate on system-level problems at specific sites and targeting different social groups.

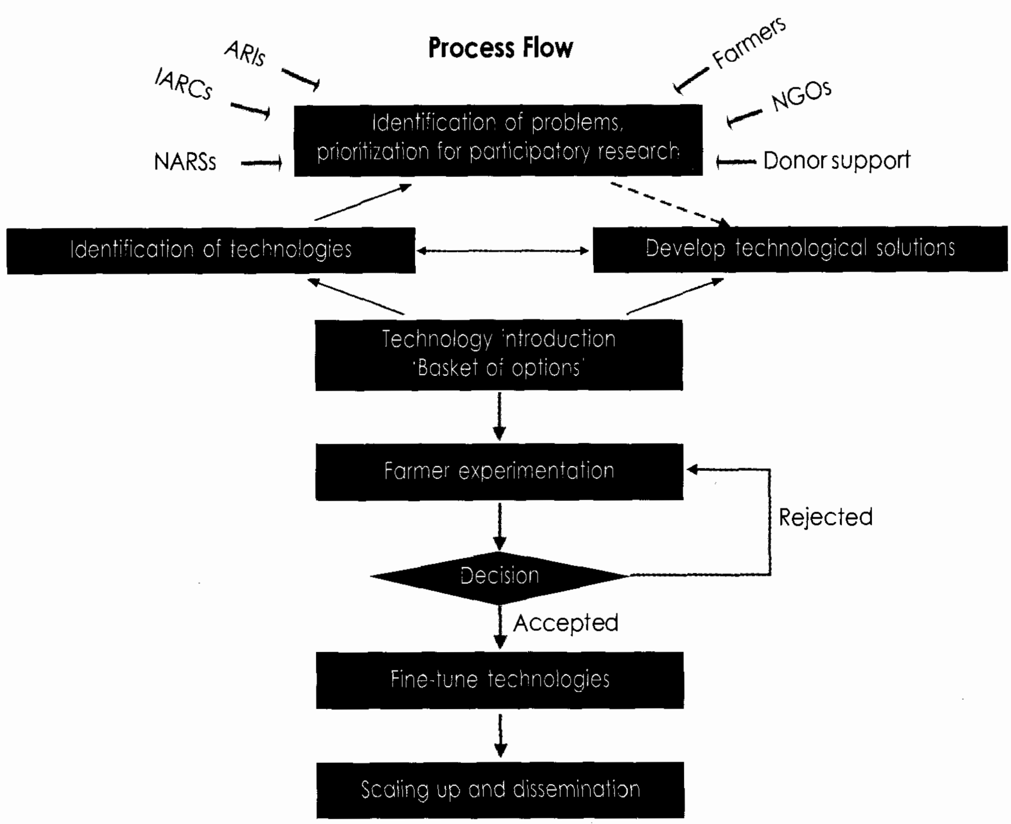
In recent years, the Consortium has focused strongly on reduced tillage as a platform for a suite of options to lower costs, increase productivity, and improve soils. These feature a range of conservation tillage practices, such as zero-tillage for wheat and sowing crops on raised beds. The practices reduce costly and time-consuming cultivation and save water, among many other benefits, and are being adopted rapidly in South Asia (they are used in 2002-03 on an estimated more than 500,000 hectares, and adoption continues).

Table 3. Consortium Activities in Thematic Areas (with Priority Ranking)

Thematic areas and organizational responsibilities	Activities within thematic areas	Low	Medium	High
1. Tillage and crop establishment	1. Technology targeting (preparatory/ planting) - ZT and surface seeding, rotavator drill, permanent bed planting system			H
	2. Residue management - retention, incorporations, microbial decompositions, animal fodders			H
	3. Machinery development and improvement 4- and 2-wheel tractors, animal-drawn machine, sprayers/ nozzles, laser machines, hoes, attachments, USG applicators, rotavator blades			H
2. Crop improvement and management	4. Germplasm screening and GxE, GxT interactions, cultivar choices		M	
	5. Legumes in rice-wheat systems			H
	6. System diversification and intensification			H
	7. Modeling and climate change		M	
	8. Seed quality, priming and storage	L		
3. Integrated pest and disease management	9. Crop protection – IPM, IDM		M	
	10. Weed management			H
4. Nutrient management (IRRI)	11. Site-specific nutrient management			H
	12. SOM dynamics, C sequestration, long term fertilizer trials, nutrient enrichment			H
5. Water management (IWMI)	13. Water use efficiency, land leveling, rainwater use			H
	14. Water (field, farm and system level)		M	
	15. Water quality, salinity/sodicity issues, nitrate pollution monitoring	L		
6. Knowledge management	16. GIS/ country almanacs		M	
	17. Database management- RWC-PRISM, RWIS and webpage			H
	18. RWC paper series and other publications			H
	19. RWC annual meetings in regional and international research fora		M	
	20. Multi-stakeholder meeting- traveling seminars, workshops and conferences		M	
	21. Technology dissemination/adaptive research in participatory mode			H
7. Socioeconomics	22. Impact analysis		M	
	23. Policy issues	L		
	24. PR&GA	L		
	25. Community group working/farmer groups/manufacturer groups		M	
8. Human resources development and capacity building	26. Specialized trainings in advanced institutions for scientists and farmers		M	

To convince farmers, extension workers, and even other scientists that this radically-different technology had any benefit, the RWC had to use an approach different from the classical one of perfecting the practice over many years of on-station research. Consortium participants essentially took the practices directly to the field for farmers to test under their own conditions. In this process, the role of the Consortium was one of support: researchers and extensionists had to check back regularly with farmers to advise and help identify and solve problems. Farmers had to be shown how a zero-tillage seed drill worked and then allowed to experiment with the equipment. Local manufacturers had to develop and produce conservation tillage equipment of high quality yet affordable to farmers, something which also required RWC input and monitoring. As these practices became widely viewed as acceptable, farmers themselves began to serve as extensionists and resource persons. The RWC then focused on scaling out, further backstopping, and capitalizing on the trust gained to promote and test other potentially useful practices. Meanwhile, RWC scientists continue to monitor fields where these technologies are being adopted, collecting data on soil, life forms, and resource use, to elucidate the benefits and identify any problems that require further technical input.

Methods used by RWC in Finding Solutions and their Dissemination Among the Target Farming Community



Joint Efforts of CGIAR Centers and Funding Partners on Rice-Wheat Systems

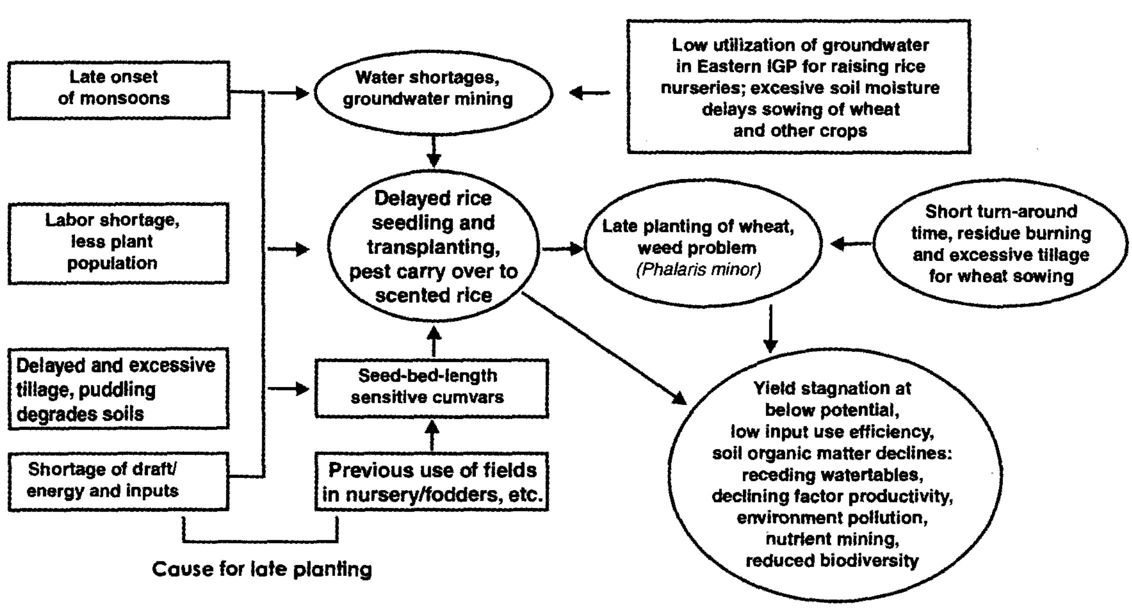
As part of the RWC, several centers of the Consultative Group on International Agriculture Research (CGIAR) and partners have recently launched a series of collaborative projects on issues central to rice-wheat cropping systems and agriculture in South Asia. Topics include the following: salt and water balances; the cultivation of rice on raised beds; nutrient, weed, and soil management in rice-wheat systems; crop diversification, including potatoes; and the introduction of legume crops in rice-wheat systems. The focus is on farmer participatory research, although some of the work also involves more basic research. The key issues like crops, soil, water and crop diversification are covered in order to bring about sustainable growth in productivity in the area of operation i.e., the IGP of South Asia. Productivity and production of rice-wheat systems in the IGP keep increasing through exchange and transfer of technology by international research agencies and NARS. Technology for urea placement developed in Indonesia or for bed planting developed in Mexico, a rice transplanter developed by IRRI in the Philippines or a no-till wheat drill developed in India in collaboration with CIMMYT are just some of the innovations that are widely used in South Asia today.

Contributed by:
Craig Meisner and **Raj K. Gupta**

Rice-Wheat System: Problem Analysis and Strategic Entry Points

Though most rice-wheat cropped area is under irrigation, soil and crop management undergoes drastic changes from flooded rice to wheat in both favorable and unfavorable regions of the Indo-Gangetic Plains (IGP). Crops with contrasting edaphic needs continuously practiced by numerous farmers, suffer from increasing pest pressure and yield decline in some areas in the South Asia, questioning the sustainability of the system (Tran and Marathe, 1994). Some sustainability dimensions of the rice-wheat system ecology are illustrated in Figure 1. Here, we discuss some crop management practices that have a bearing on rice-wheat system productivity.

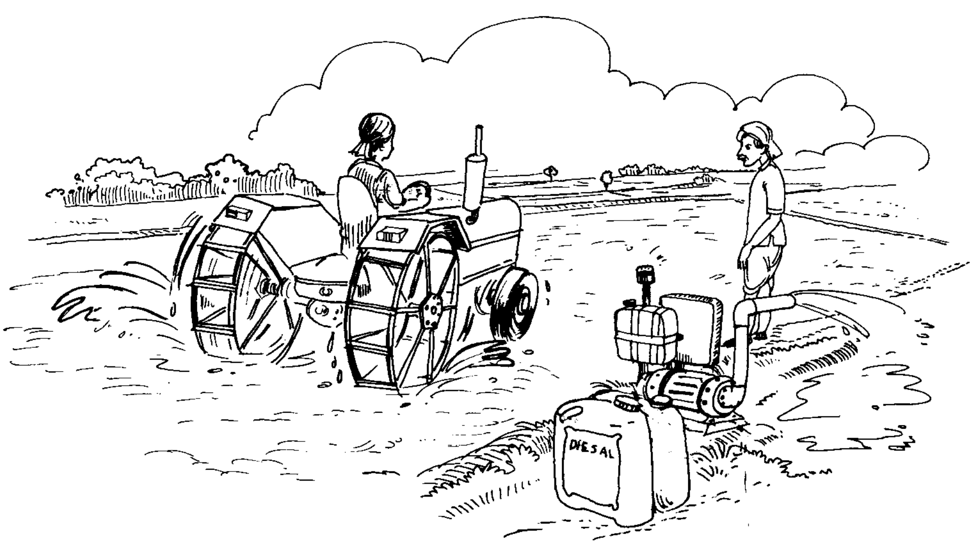
Figure 1. Sustainability Dimensions of Rice-Wheat Systems of the Indo-Gangetic Plains



Crop Establishment: A Strategic Entry Point

In rice-wheat dominated IGP, the system of transplanting 3-5 week old seedlings into puddled fields is mostly used to grow the rice crop. Puddling is a traditional soil management operation used to reduce soil permeability to water and preserve the aquatic, anaerobic conditions suited for the growth of wetland rice (Sanchez, 1973). It also helps control weeds, improve water and nutrient availability and facilitate transplanting of rice seedlings. Repeated puddling destroys soil aggregates, breaks capillary pores, disperses fine clay particles which settle in the bottom of the plow layer to form a compacted layer (plow pan) that restricts percolation of water and reduces recharge of groundwater aquifers and/or soil profile. Puddling may influence the irrigation water requirement of succeeding crops. Therefore, to overcome ill effects of puddling, either manage the system to maximize the overall system productivity or do away with the puddling in rice culture.

Long-term rice-wheat cropping system experiments at Pantnagar (India) and Bhairahawa (Nepal) showed that there was no difference in yield of rice crops grown on puddled or non-puddled soils. A shift in weeds, from mainly sedges in puddled soils to grasses and broadleaf weeds in non-puddled situations, however, has been reported. Also, weed control was more difficult in non-puddled situations. It is not necessary to puddle soils for transplanting the young seedlings. It can be done on flat as well as on permanent beds by placing young seedlings in narrow slits opened with point openers of the zero-till drill as well.



Dispensing with Rice Transplanting

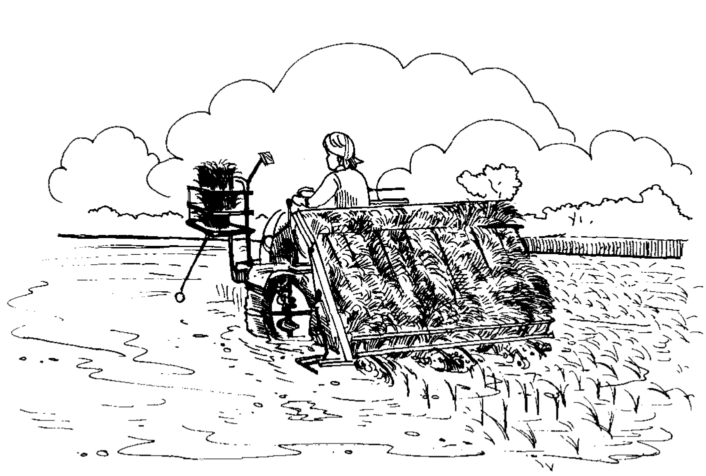
Rice transplanting which has an element of peak seasonality is very often done into puddled soils. For transplanting, the workers are paid by the area planted, rather than by quality, and so plant population remains lower than what is optimally required. Alternate methods of establishing rice that require less labor and water without sacrificing productivity are needed. Considering water availability and opportunity cost of labor, Pandey and Velasco (1999) hypothesized that dry seeding of rice is an appropriate alternative for South Asia. Whenever the watertables *(as in tarai soils or the chor, tal and diara lands)* were close to the surface in the wet monsoon season, puddling may not be needed to hold water and transplanting can be dispensed with as long as weeds are controlled. Interestingly, deepwater rice, an important rice crop in very low-lying areas of Bangladesh, Eastern India and Nepal, is grown like wheat and planted onto non-puddled soils. Rising water during flooding helps control weeds for this crop (Catling *et al.* 1983). Preliminary results suggest that in areas prone to flooding, full basal application of fertilizer is best for higher productivity.

Direct seeded rice (DSR) crop matures early by 2-3 weeks and has higher number of tillers and panicles per meter-square mainly due to higher seed rate. However, total yields were similar as transplanted crops had more grains per panicle. This suggests that higher fertilizer doses are needed for DSR system to enable better grain filling if it does not result to higher incidence of brown planthopper. Use of resistant cultivars or wider spacing or reduced seed rates may be needed to realize the full potential of this system. In DSR, seed depth and emergence, and effective weed and water control in the initial 2-3 weeks have profound effects on growth and yield of this crop.

Direct seeding of sprouted rice seeds on puddled or unpuddled moist soils is another option. This is commonly used in Malaysia, Thailand and other Southeast Asian countries. This requires more exact water management than for transplanted rice for which laser levelling is very helpful.

Reducing the Drudgery of Manual Transplanting

On the issue of high costs of labor for transplanting, there are several options. In northwest India and Pakistan, scientists are experimenting with mechanical rice transplanter to overcome the problems of labor shortages and poor transplanting techniques and spacing. Problems related to growing mat-type nursery on plastic sheet have to be resolved to some extent. Other problems include local manufacture of quality transplanter so that more farmers can access them. As seedling density is higher in this system, increased nutrient applications may be needed to ensure high yields.



Yet another option is broadcasting of young rice seedlings in fields flooded with water. In China, establishing rice using bubbled plastic trays, saves on labor and removes the drudgery of transplanting and is gaining greater acceptance from the farmers. The benefits include fast timely transplanting, good initial growth, less drudgery and lower production costs.

Reducing Tillage Requirements for Wheat

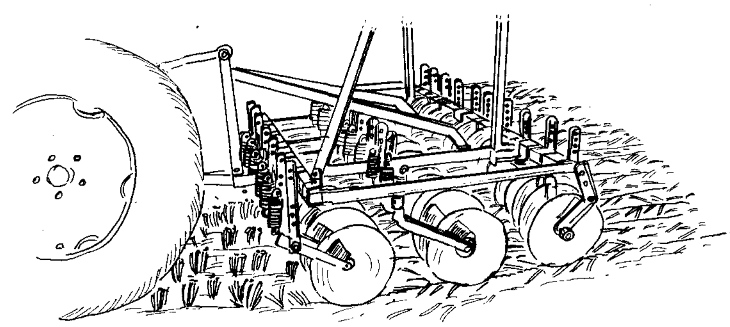
Repeated traditional tillage operations escalate the cost and reduce the farmers' profits margin (Harrington *et al.,* 1993). It is generally believed that if tillage operations prior to wheat sowing were not performed, crop yield would suffer because of poor crop stand and also due to poor soil aeration following an irrigation or rainfall. However, Aslam *et al.,* (1993) has shown that zero-tillage establishment of wheat after rice gives yields that are equal or even superior to when planted under normal tillage. This was mainly explained by timely planting in the zero-till plots.

On the basis of the results of 132 farmer participatory trials conducted across the wheat-growing belt in Haryana, Mehla et al. (2000) concluded that zero-till systems gave higher yields, saved at least a week's time, and could be used for both early and late wheat planting situations.

Farmers were impressed with this resource-conserving technology enough that about 300,000 ha were planted with reduced zero-tillage in the 2001-02 wheat season in the IGP compared to 50,000 ha the year before. The main constraint to adoption at the moment is the production of good quality drills in sufficient numbers for the farmers to experiment and purchase.

Better Management of Crop Residues

Traditionally this was not an issue. Residues of rice and wheat crops were often fed to the animals or removed. Many farmers now use combines for harvesting rice and this creates a problem of anchored rice stubbles and of loose residues for planting. Farmers tackle this problem by either burning rice stubbles partially or chop the straws and burn them completely resulting in air pollution, loss of nutrients and potential soil organic matter. Indeed, loss of soil organic matter is one of the recognized threats to rice-wheat sustainability (Timsina and Connor, 2001). Using drills fitted with coulter and disc type openers or with the use of Zimbabwe star-wheel openers, it is possible to avoid burning and still be able to seed into loose residues. Efforts are also underway with support from the ACIAR for developing zero-till and bed planting implements which facilitate seeding and mulching in just one operation.



Surface Seeding

Surface seeding of winter crops, in excessively moist, finer textured soils commonly found in low-lying areas of the eastern IGP, is another option for eliminating tillage in wheat. Primed wheat/lentil/peas seed is broadcast onto the wet saturated soil surface either before or after rice harvest. Seeds germinate and roots follow the saturation fringe as water recedes. Surface seeding options have been evaluated in longer-term studies in Nepal and Pantnagar and Bihar in India (Verma, 1999). Farmers in Kustia District in Bangladesh and Yangtze River valley area of China also use this system. There is a need to adapt the drum seeding equipment with 4-wheel and 2-wheel tractors and animal power systems to popularize this technology to eliminate need for tillage altogether to reduce costs of production and fuel use, allow earlier planting, reduce weed growth and avoid rice-fallows.

Crop Diversification

The raised bed planting system is being promoted in the region to overcome temporary waterlogging stress commonly experienced by crops during monsoon season or in irrigation cycles. Bed planting system greatly facilitates diversification of the rice-wheat system, ameliorates the adverse effects of seasonality on family incomes and peak labor demands, reduces risk due to fluctuating monsoonal patterns, helps in asset improvement on the farms, facilitates easier weed and nitrogen management, and often results in better yield. Bed planting system conserves rainwater and improves irrigation water use to save as much as 40% of the total irrigation water. In bed planting systems, intercrops such as mint, peas, Indian mustard or wheat with sugarcane and winter maize with potato, onion or garlic, etc. can be grown. Intercropping in bed systems offers great opportunities for rehabilitation and sustaining maize/sugarcane in favorable ecosystems and to serve as alternate source of productivity growth for wheat and other pulse crops. Using one of the several crop establishment techniques including the surface seeding, it is now possible to grow legumes and reduce acreage of rice fallow lands in eastern parts of the IGP which occupy nearly 14 million ha out of total 50.4 million ha of kharif rice in South Asia (Subbarao *et al.,* 2001). A major challenge is to make the beds permanent and drill each succeeding crop, year after year, on the same beds even in the presence of crop residues.

Nutrient Management

Continuous cropping with the rice-wheat system on the calcareous, illitic alluviums of the IGP have shown signs of fatigue and deficiencies in nitrogen (N), phosphorus (P) and micronutrients like zinc (Zn), iron (Fe), manganese (Mn) and sulfur (S) are emerging. In many high rainfall areas, soils are acidic in nature and crops respond favorably to N, P, Zn and boron (B) applications. Recent evidences also suggest that even micaceous soils in several areas now need external applications of potassic (K) fertilizers for enhanced productivity. Nitrogen is a key fertilizer input in rice-wheat systems on most soils. In the puddled rice system, any N left over from the previous crop would be lost through leaching with the onset of monsoons. There is a need to examine the use of legumes to mop up residual N, during the dry-to-wet transition period to conserve and recycle soil-N.

Application of urea before pre-sowing irrigation, or deeper drilling of urea super granules at sowing could increase yields of wheat. This may also be a good strategy for dry-seeded rice, as the nitrogen would be placed in the wetter, lower depths, and not be leached, making the nutrient available for early rice establishment. Deep placement of urea super granules (USG) improves fertilizer N uptake by rice and reduces N losses, particularly from ammonia volatilization.

> A major bottleneck in the use of deeper prilled urea placement and/or urea super granules (USG) and other urea formulations such as with neem admixtures has been the absence of a reliable mechanical applicator under ponded water conditions. This may now be possible with the new zero-till and bed planters available for rice-wheat

The optimum use of nutrient comes from matching the supply with crop demand. This can be achieved through improved fertilizer formulations coupled with deep and band placement. Use of chlorophyll meter (SPAD meter) or leaf color charts (LCC) to determine the right time of nitrogen top dressing for rice and wheat crops has been found quite useful (Balasubramanian *et al.,* 2002). The concept is based on results that show a close link between leaf chlorophyll and leaf N contents.

The time has come when farmers have to switch over from the concept of fertilizing individual crops to a strategy of nutrient management for the cropping system, and taking into account the residual value of fertilizers, contributions from legumes and green manures, use of organic manures, compost and bio-fertilizers. Field experiments have clearly shown that integrated conjunctive use of nutrient sources coupled with good management practices increase soil productivity and biological activity as compared to use of chemical fertilizers alone.

Water Management

Long distance inter-basin transport of surface waters is a common feature of the supply-driven canal irrigation systems in the IGP. There is also an increasingly heavy reliance on groundwater for irrigation. Future food security in this region is severely threatened by unsustainable groundwater use, receding watertables, and waterlogging and secondary salinization in many parts of the irrigation commands. Poorly-levelled lands, practice of night irrigation and flood irrigation methods lead to overuse of irrigation water. In the absence of quality irrigation systems, canal water supplies remain unreliable and hence the strategy of irrigating crops as per irrigation schedules has not paid much dividends. Farmers continue to irrigate crops according to crop phenology. Land levelling, known to improve water-use efficiency through uniformity in water application, better crop stand, improved nutrient-water interactions combined with bed planting and zero-tillage, etc. will help improve water use efficiency and save on irrigation water. A watershed approach to conserve rainwater in many rainfed regions is yet to be introduced in many irrigation commands.

The strategy of raising the rice nursery with groundwater to advance transplanting of rice with the onset of monsoons has been observed to enhance productivity of not only the main season (*a m a n*) rice but also of the rice-wheat system.

Integrated Pest Management

Injudicious use of chemicals leads to development of pesticide resistance, reduced diversity and abundance of natural enemies of the pests. Poor quality sprayers and spraying techniques and lack of technical know-how on integrated pest managements are some of the main reasons for use of insecticides in heavy doses. RWC scientists have to give more emphasis on above issues beside work on pests, host and environment interactions for designing new Integrated Pest Management (IPM) modules.

Enabling Policies and Socioeconomic Conditions

Agricultural production boom in South Asia is a product of small and marginal size farms and is not a shift from small to larger farms. This is in spite of medium-size and large farmers accounting for 30% of the total farmholdings, but tilling nearly 70% of the arable lands. Policy reforms to seize new opportunities for the majority of farmers belonging to small farmholding category would, therefore, remain a top priority for revitalization and infusion of new RCTs in the region.

To enhance efficient use of inputs and the development and use of resource conserving technologies, certain policy reforms concerning pricing, incentives, research, agricultural education, and funding are needed. It is difficult to promote technologies that promote efficient use of inputs unless subsidies are properly rationalized and made more production-protection oriented. Land levelling is a simple case to save on water and improve productivity, yet subsidies are assigned to energy and to canal water supplies. The same applies to pricing of fertilizers and other inputs. The subsidy instrument in fertilizer sector has to be used to correct the imbalanced fertilizer N:P:K use ratio; switch over from prilled urea to urea super granule (USG) and for developing machines that help proper placement of these costly inputs. Deep placement of urea (with or without neem formulations/slow release materials) in rice reduces ammonia volatilization losses and leaching losses to save more than 2 million tons of nitrogen in rice alone. Fertilizer saved is fertilizer produced.

Knowledge Management and Partnership-Oriented Approaches

Consortium countries have accepted the concept of agro-ecological zoning to put together basic variables of soil-scapes and bio-climates for producing land inventory maps. In order to move forward along this concept, advances would relate to improvement in Geographic Informaton System (GIS) based national and regional databases for use in models for crop growth and crop suitability and risk assessment. Another use of these databases would be in targeting and scaling up the resource conserving technologies. Project research information systems, such as PIMSnet and PRISM help in the dissemination of technologies, availability of information in simple formats, help avoid repetitions and save scarce resources.

The RWC is putting a strong emphasis on developing these new methodologies and tools for use by Consortium partners. The RWC cannot do justice to extending the new resource-conserving technologies and influencing policy without the help of the many stakeholders in the national programs. There is also a need to develop a public-private interface in the area of input supply (seed, fertilizer, credit and machinery) and manufacture of equipment. The RWC acts as a catalyst to promote more efficient paradigms within national programs for extension of new technologies and improvement in policies that result in more efficient agriculture, improvement in natural resource management and helps farmers improve livelihoods. The RWC promotes this change through use of expanded stakeholders and participatory approaches and thereby hopes to make an impact on agricultural production in a positive way and helps maintain food security in the region, improves livelihoods and reduce poverty.

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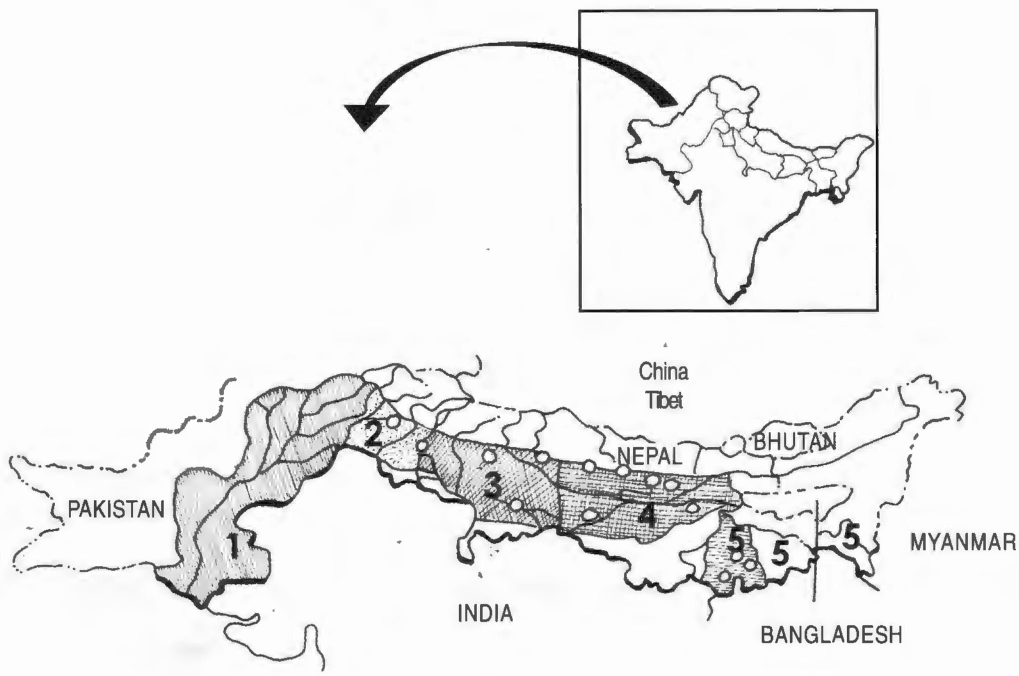
Contributed by:
Raj K. Gupta, Peter R. Hobbs, Larry Harrington and **J. K. Ladha**

Characteristics of the Indo-Gangetic Plains:
The Rice-Wheat Bowl



o = LTE sites

The Indo-Gangetic Plains (IGP) in South Asia are the main cradle of rice-wheat production system in Asia. This system has fed millions of people for over a thousand years. Still, over 30% of rice and 42% of wheat are grown in the IGP of India, Pakistan, Bangladesh and Nepal covering about 13.5 million ha.

Characteristics of the Indo-Gangetic Plains

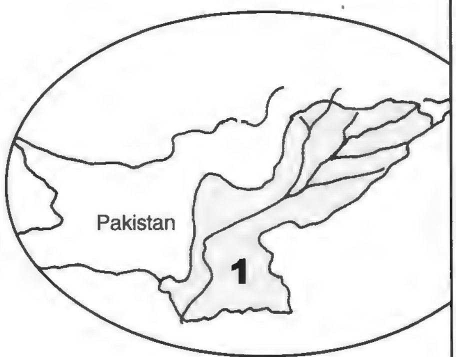
The IGP is a relatively homogenous ecological region in terms of vegetation. While in the western part wheat is the dominating crop, rice is the dominant crop in the eastern part. It is important to know the characteristics of the IGP as this region is largely influenced by the rice-wheat system.

Based on physiographic and bio-climatic considerations, the IGP can be subdivided into five transects which cover the areas as shown next page.

Rice-Wheat System Covers 24 million ha in Asia

• India	10 million ha
• Pakistan	2.2 million ha
• Bangladesh	0.8 million ha
• Nepal	0.5 million ha
• China	10 million ha
• Other countries	0.5 million ha

Transect 1. Trans-Gangetic Plains in Punjab (Pakistan)



Climate
- Semi-arid
- 400-800 mm annual rainfall
- 85% rainfall received between June and September

Physical features
- Alluvial, coarse to medium fine textured calcareous soils
- Gently sloping with good drainage
- Alkali soils exist in stretches
- Low groundwater quality in pockets
- Some of the marginal lands have been reclaimed

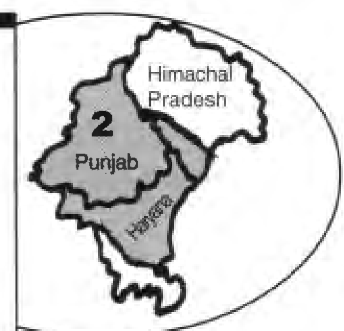
Cropping systems
- Intensively irrigated rice-wheat system
- Mostly basmati type of rice grown

Transect 2. Trans-Gangetic Plains in Indian Punjab, Himachal Pradesh and Haryana

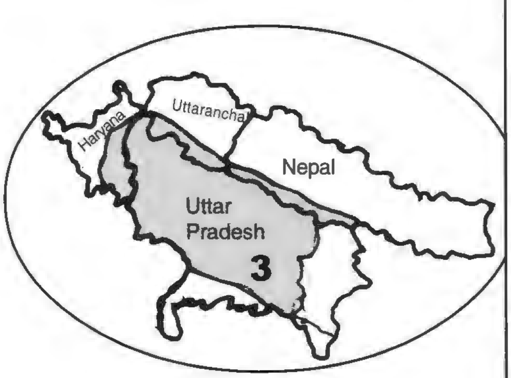
Climate
- Semi-arid
- 400-800 mm annual rainfall
- 85% rainfall received between June and September

Physical features
- All physical features are the same as in Transect 1 except topography which is saucer-shaped

Cropping systems
- Rice–Wheat–Maize+Cowpea (fodder)
- Rice–Wheat–Cowpea (fodder)
- Rice–Wheat–Green manure
- Rice–Potato–Wheat
- Rice–Wheat–Mungbean
- Rice–Sugarcane–Ratoon–Rice–Wheat
- Rice–Wheat–Sunflower



Transect 3. Parts of Haryana, Uttaranchal, Western and Central Uttar Pradesh, Tarai Regions of India and Nepal

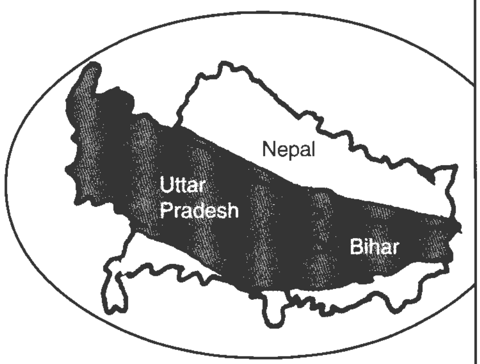


Climate
- Hot, subhumid climate
- Annual rainfall up to 1000 mm
- 75% to 78% rainfall received during monsoon season

Physical features
- Topography is saucer-shaped
- Acidic soils are found in hills
- Changing river courses affect farming and livelihood of the people
- Other features as in Transects 1 and 2

Cropping systems
- Rice–Sugarcane–Ratoon–Rice–Wheat
- Maize–Wheat
- Pigeonpea–Green gram/Wheat
- Soybean–Wheat
- Maize–Potato–Wheat
- Cotton–Wheat

Transect 4. Eastern Uttar Pradesh, Bihar and Eastern Parts of Nepal



Climate
- Hot, sub-humid climate
- Annual rainfall up to 1000 mm
- 75% to 78% rainfall received during monsoon season
- Annual rainfall less than 1500mm

Physical features
- Alluvial, medium fine-textured calcareous and acidic soils
- Gently sloping
- Low-lying, flood-prone, drainage congestion
- Low-quality groundwater in pockets due to fluorides and arsenic
- Changing river courses affect farming and livelihood of the people

Cropping systems
- Rice-Potato-Wheat/Sunflower
- Rice-Jute
- Rice-Wheat-Rice
- Rice-Potato-Maize
- Rice-Rice
- Rice-Potato-Rice (Boro)
- Rice-Potato-Onion
- Rice-Lentil-Onion

Transect 5. West Bengal and Bangladesh

Climate
- Hot sub-humid
- Annual rainfall up to 1800 mm
- 70 to 78% rainfall received during monsoon season

Physical features
- Farmholdings are fragmented and relatively small in size
- Farms are highly diversified and flood-prone
- Other physical features are similar as in Transect 4

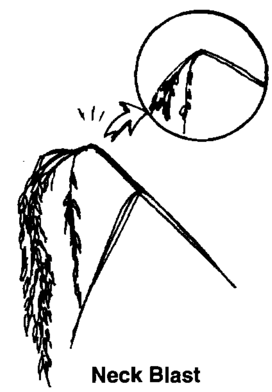
Cropping systems
- Rice-Jute
- Rice-Potato-Rice (Boro)
- Rice-Potato-Onion
- Rice-Rice (Boro)

Other Features

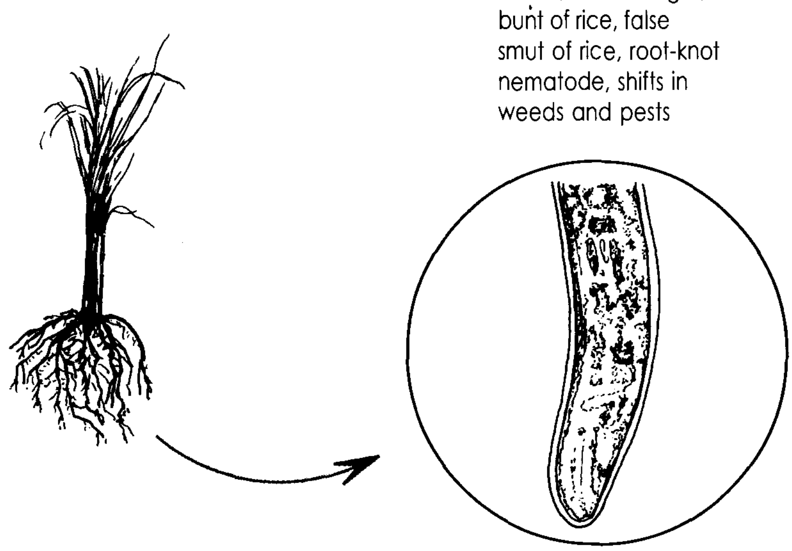
In the IGP transects, irrigation is mainly practised in winter season. Life-saving irrigation is given only during monsoon season if there are long dry spells. Groundwater development is inadequate across transects. In Transects 1, 2 and 3, tractors are frequently used for performing farm operations and rice farming is partially mechanized. However, in Transects 4 and 5, the use of tractor in rice-wheat system is very limited and farmers mainly depend on animal power or the two-wheel tractors. In the Indian part, farmers have recently started using small tractors.

Pest and Disease Profile in the IGP

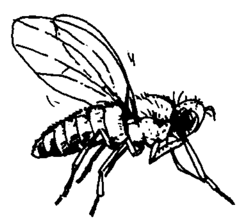
Transects 1&2	Transect 3	Transects 4&5
Rusts, leaf minor, leaf streaks,	Same as in Transects 1&2	Blast disease, brown spot, bacterial leaf, shifts in weeds and pests
Blasts, false smut, stem borers, leaf minor	Root knot nematodes	Streak, sheath blight, bunt of rice, false smut of rice, root-knot nematode, shifts in weeds and pests



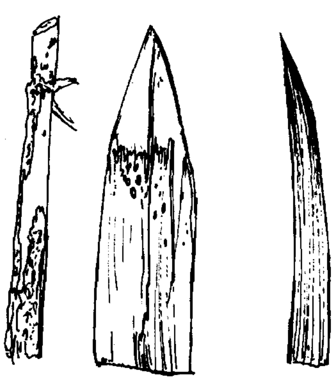
Neck Blast



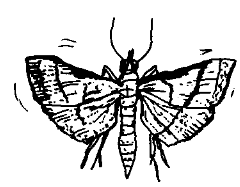
Rice Nematode



Rice Leaf Minor
(Hydrellia griseola)



Wheat Streak Mosaic



Rice Leaffolder
(Cnaphalocrosis medinalis)

Spotted Stem Borer
(Chilo partellus)

Socioeconomic Profile of Farmers in the IGP

- Farmers in Transects 1 and 2 are more enterprising than in other transects.
- Except in Transect 4, farmers, on an average, are educated up to middle level. In Transect 4, they are mostly educated up to primary level.
- Farmers in Transects 1, 2 and 3 have higher risk-taking capacity. They are more affluent.
- Farmholdings are more consolidated in medium size holdings in Transects 1, 2 and 3. The holdings in these transects are less diversified.
- Peri-urban agriculture is more developed in Transects 1, 2 and 3.
- Private agro-industries are less conspicuous in Transects 4 and 5.

Common Problems in the IGP

- Delayed harvesting and low plant density of rice in Transects 1, 2 and 3 are important problems.
- Untimely rains and excessive moisture are problems in Transects 4 and 5.
- Nutrient mining and multiple nutrient deficiencies are common problems in all transects.
- Grains produced in all transects are low in quality.
- Water shortages and poor management of irrigation water are common problems in all the transects.
- Waterlogging during rainy season prevents crop diversification in all the transects.
- Lodging of rice and wheat crops is common.
- Productivity of inter-crops is low with current technologies.
- Cultivars are sensitive to heat/cold stresses.

Site-Specific Management in the IGP Transects

Natural resource profile and socioeconomic environment of the farmers vary between farms within and between transects in the IGP. Complex ecological problems of rice-wheat systems can be resolved through site-specific management of technological innovations embedded in appropriate policy environments. Technology and policy options must act in harmony for interactive effects.

Farmers and Precision Technology

Knowledge transfer among farmers about precision agriculture in IGP is a prerequisite for resource conservation and their higher productivity. Farmers have the broad awareness and knowledge about the nature and behavior of their land, water and plant resources. This enables them to harness the resources to ensure higher productivity. For this purpose, a cadre of trained manpower of subject matter specialists from public institutions, government agencies and non-government organizations (NGOs) can be tapped. This seems a better option than to provide subsidies that do not improve quality of natural resources.

For promoting precision agriculture, time seems ripe for encouraging large-scale farm industries to manufacture good quality farm implements and small-scale manufacturers to provide services.

Adapted from:

Gupta, R.K., R. K. Naresh, P. R. Hobbs, Z. Jiaguo and J. K. Ladha. 2003. Sustainability of Post-Green Revolution Agriculture: The Rice-Wheat Cropping Systems of the Indo-Gangetic Plains and China. *In:* Ladha, J.K. (ed). Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts. ASA Special Publication, American Society of Agronomy/Crop Science Society of America/Soil Science Society of America. Madison, Wisconsin, USA. (In print).

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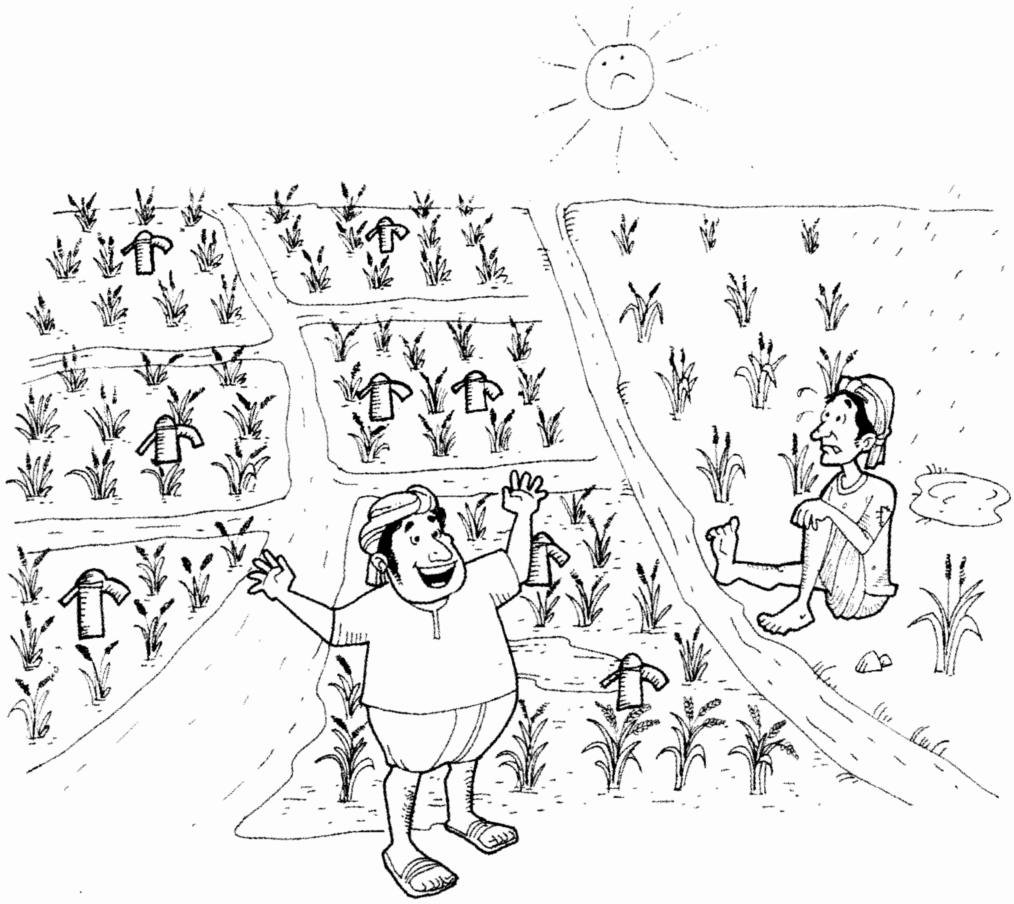
Rice-Wheat Environment



Rice-wheat systems occupy 24 million hectares of cultivated land in Asia. Of this, 13.5 million hectares are in South Asia extending from the Indo-Gangetic Plains to the Himalayan foothills. Rice-wheat systems cover about 32% of the total rice area and 42% of the total wheat area in these four countries: India, Pakistan, Bangladesh and Nepal. Although most rice-wheat cropping is fully irrigated, substantial areas are rainfed. Identifying the processes that govern the sustainability of rice-wheat systems in both irrigated and rainfed conditions, and distinguishing these from site-specific causes of decline in productivity, is crucial for developing sustainable production technologies. Predominantly rainfed rice-wheat environment is more unfavorable than the fully irrigated one. The characterization was done at district level using secondary data.

Rice-Wheat Environments

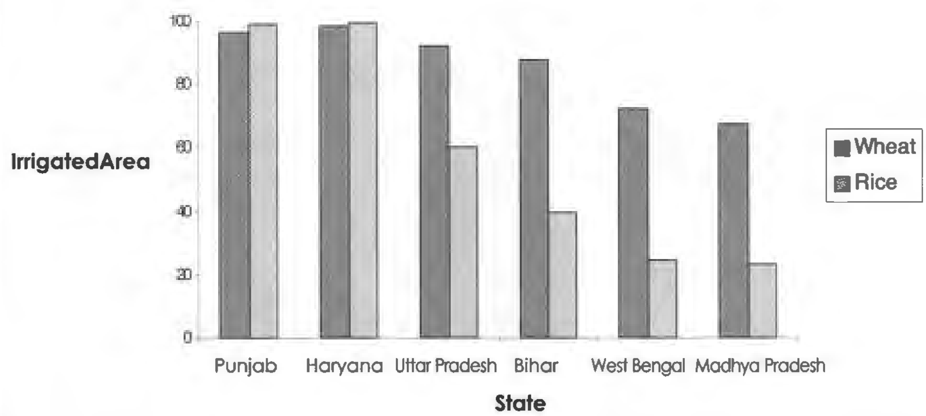
Geographically, the favorable rice-wheat environments in the Indo-Gangetic Plains are located in the western part, where winter environmental conditions are suited for wheat, irrigation infrastructure is good, marketing facilities are available, and both rice and wheat yields are high. The less favorable rice-wheat environments occur in the eastern part and are associated with partially irrigated and rainfed systems, and a shorter growing period for wheat. More detailed agroclimatic analysis would provide an in-depth understanding of environmental constraints (e.g., drought stress and flood proneness) for geographical targeting of varietal and crop management strategies in both the favorable and less favorable rice-wheat environments.

Wheat and Rice Yields Under Two Different Conditions (1990 -93) in India

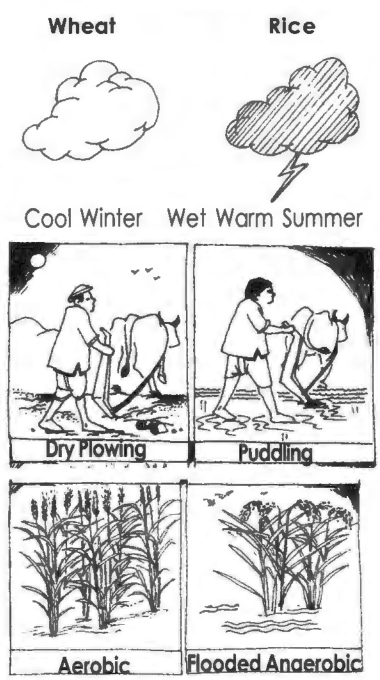
State	Wheat yields (t/ha)[a]		Rice yields (t/ha)[b]	
	Favorable	Unfavorable	Favorable	Unfavorable
Punjab	3.7	-	4.8	-
Haryana	3.6	-	4.3	-
Uttar Pradesh	2.3	2.0	3.0	2.5
Bihar	1.8	1.7	2.3	1.6
West Bengal	-	2.0	-	2.7
Madhya Pradesh	-	1.0	-	1.2

Sources: (a) Centre for Monitoring Indian Economy. India's Agricultural Sector, July 1996
(b) Huke and Huke, 1997

Percentage of Rice and Wheat Area Under Irrigation



Contrasting Requirements of Rice and Wheat Crops



Favorable Rice-Wheat Environment

The western part of the rice-wheat belt, where wheat is the predominant crop, provides a favorable environment through assured irrigation for both rice and wheat crop. Pakistan's Punjab province and India's northwestern states of Punjab and Haryana as well as the western part of Uttar Pradesh are included in this category. Yields of both rice and wheat are the highest in the states of Punjab and Haryana where an extensive, high-quality irrigation infrastructure of canals and tubewells exist, more than 97% of rice and wheat cropped area is under irrigation in these two states. The overall wheat and rice yields here are almost twice the yields obtained in the eastern states of Bihar and Madhya Pradesh. The wheat yields in the rice-wheat systems are not substantially different from the overall yields for wheat grown in the other systems (wheat-mungbean, wheat-cotton) in these states.

Unfavorable Rice-Wheat Environment

The eastern part of the Indo-Gangetic Plains, where rice is the dominant crop, provides the less favorable environment for rice-wheat systems due to its dependence on rainfall in the absence of irrigation facilities. Bangladesh, Terai region of Nepal and the Indian states of West Bengal, eastern Uttar Pradesh and northern parts of Madhya Pradesh and Bihar fall in this category which is characterized by predominantly rainfed rice and either irrigated or rainfed wheat.

The irrigation systems were developed to provide supplementary, life-saving irrigation during periods of droughts in this region which basically depends on rainfall for production of both the crops. The yields of rice and wheat under such conditions of irrigation are substantially lower than those obtained in Punjab and Haryana. Yields are the lowest in Madhya Pradesh, where climatic conditions also restrict the growth of wheat.

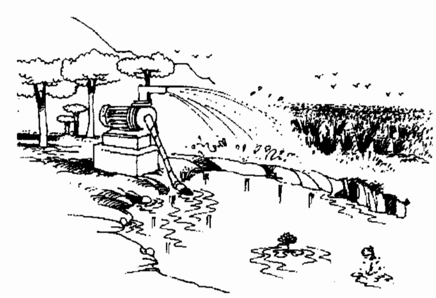
Effect of Land Ownership

In Bihar State of India, the skewed distribution of land and the insecure crop-sharing tenancy has a negative influence on crop yields even under irrigated conditions. Bihar has a larger area under irrigation for both rice and wheat than West Bengal, yet yields of both crops are lower than those in West Bengal.

Influence of Climate on Choice of Crop

The duration of the season favorable for wheat production is shorter in the eastern part of the Indo-Gangetic Plain than in the western part. The temperature in the dry season also tends to be higher. When reliable irrigation systems such as tubewells and pumps are developed in this region, the farmers show a distinct preference for *boro* rice over wheat, specially in West Bengal and Bangladesh.

Boro Rice



Boro rice is a special system of rice cultivation in waterlogged areas of the delta region taking advantage of residual soil moisture after kharif harvest and using surface water stored in shallow ditches canals, etc. for supplementary irrigation during dry, spells. This system gets the benefit of low night temperature in the early stages of crop growth to accumulate photosynthates and a higher temperature at harvest time to promote ripening. Yields of boro rice are three to four times that of kharif rice and boro ratoon crop can yield an additional 2 to 2.5 t/ha in six weeks if irrigation water is available.

Thakur, R and V.S. Singh. 2000. Boro Rice Cultivation. *In:* Singh, V.P. and R.K. Singh, (eds). 2000. Rainfed Rice: A Sourcebook of Best Practices and Strategies in Eastern India. International Rice Research Institute, Los Banos, Philippines. pp292.

Adapted from:

Ladha J.K., K.S. Fisher, M. Hossain, P.R. Hobbs and B. Hardy (eds). 2000. Improving Productivity and Sustainability of Rice-Wheat Systems of the NARS-IRRI Partnership Research. IRRI Discussion Paper Series 40. IRRI, Los Banos, Philippines.

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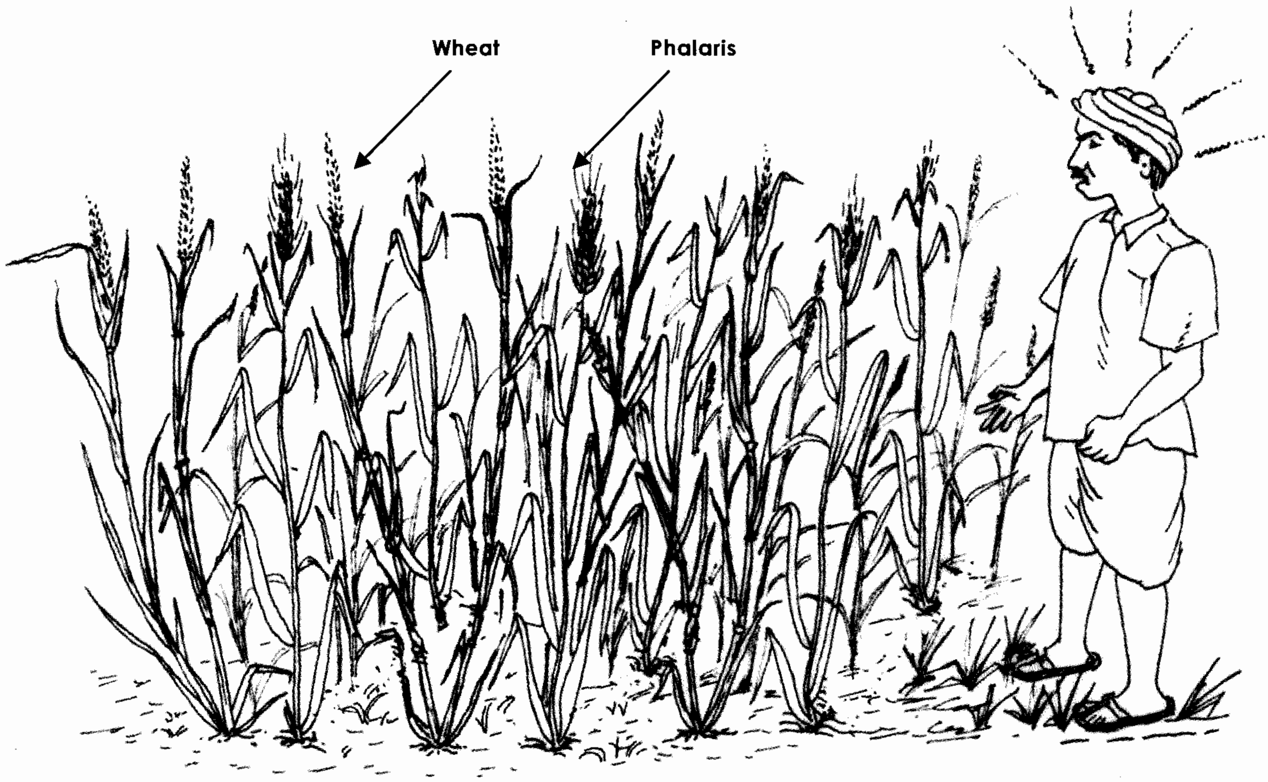
Production Constraints of the Rice-Wheat System

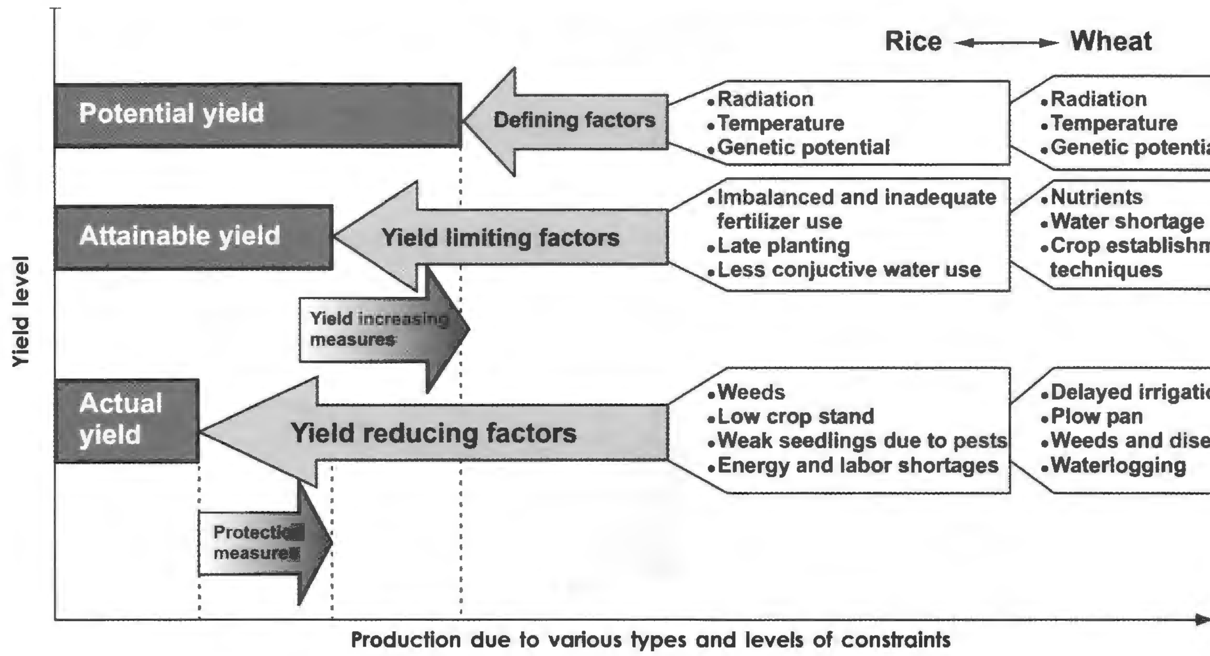


The rice-wheat system has been practiced by farmers in Asia for more than 1000 years. It has since expanded and is currently estimated at 23.5 million ha. The rice-wheat system covers 13.5 million ha in South Asia: India (10.0), Pakistan (2.2), Bangladesh (0.8) and Nepal (0.5). It represents 32% of the total rice area and 42% of the total wheat area in these countries. In the Indo-Gangetic Plains (IGP), which stretches across these four countries, rice is usually grown in the wet summer (May/June to October/November) and wheat in the dry winter (November/December to February/March). Although rice-wheat cropped area in the IGP is irrigated or has assured rainwater in sub-humid regions, the soils and crop management undergo drastic changes during the two cropping seasons. Several yield-reducing and yield-limiting factors, together with delayed planting of wheat and transplanting of rice; energy, labor, and other input shortages; resistance of the weed *Phalaris minor* to isoproturon; and crop residue burning have contributed to the stagnating or declining production, productivity and sustainability of this system.

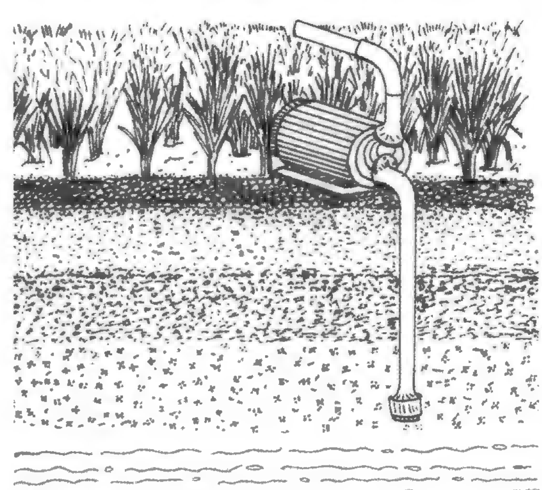
Production Trends

In eastern India and Bangladesh, where rice is the predominant crop and wheat has unfavorable production environments, rice-wheat system expanded during the 1970s in response to the foodgrain shortage and the availability of high-yielding wheat varieties. By 1980, the expansion of wheat plateaued at 5% of the area in Bangladesh and West Bengal. In northwestern India and Pakistan, where wheat has a favorable growing environment and rice can be grown only with full irrigation, the system expanded after the early 1970s in response to market opportunities and the availability of high-yielding rice cultivars. Rice gradually emerged as a commercial crop while wheat remained the principal staple food.

Production Constraints: Sustainability Dimensions



Continuous cropping of rice-wheat system for several decades as well as contrasting edaphic needs of these two crops have resulted in increased pest pressure, nutrient mining, and decline in yields in some areas. In many areas, yields have stagnated at below potential level. The input use efficiency is low. Soil organic matter content has reduced. This can be improved by incorporating crop residue into the soil. But burning of crop residue is common and has increased environment pollution. Nutrients are being mined and transported long distances and lost permanently for the subregion. The water table has receded at several places in the region. Also, there is a reduction in biodiversity due to large area coverage by a single cultivar. Therefore, agronomic research related to rice-wheat system ecology and its environment must be directed at enhanced and sustained productivity of this important farming system at reduced costs.



Adapted from:

Gupta, R.K., P.R. Hobbs, J.K. Ladha and S.V.R.K. Prabhakar. 2002. Resource Conserving Technologies: Transforming the Rice-Wheat Systems of the Indo-Gangetic Plains. Rice-Wheat Consortium – A Success Story. Asia Pacific Association of Agricultural Research Institutions. Bangkok, Thailand. 42 pp.

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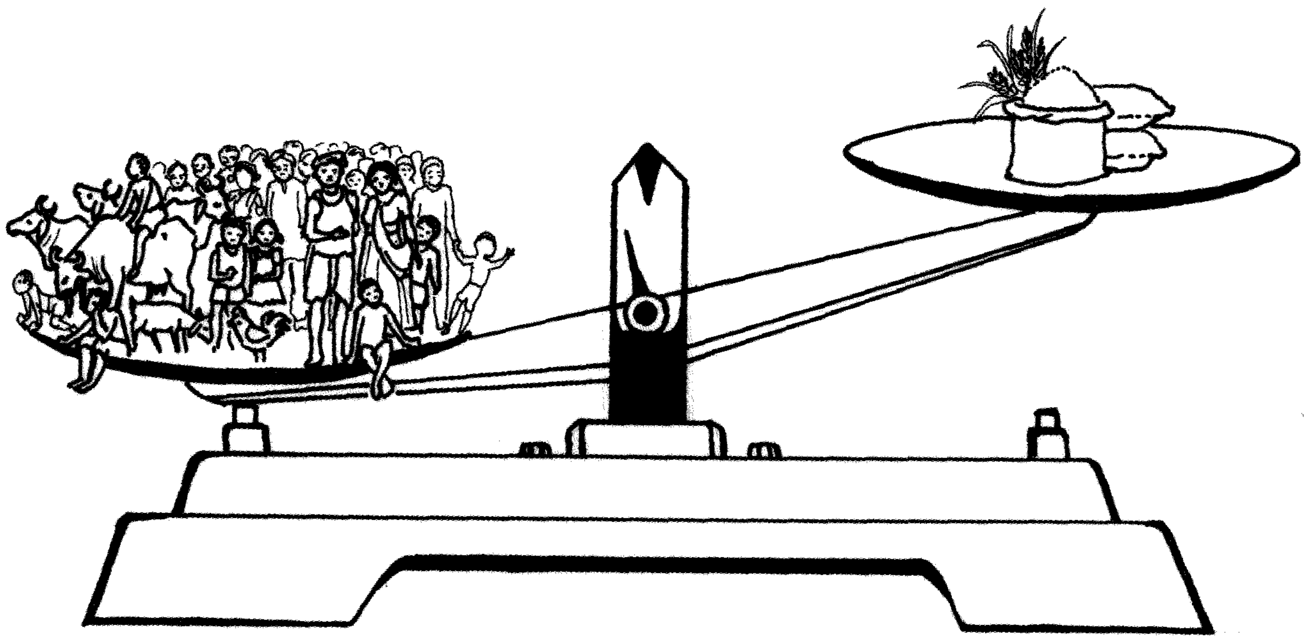
Rice-Wheat Productivity and Population Increase: A Challenge



Scenario 2020?

India has a population of one billion people. If the current growth rate estimated at 1.8%-2.0% per year continues for the next 20 years, the population of India will be between 1.4 and 1.5 billion in 2020, close to 50% greater than today, requiring 50% more food. Today, the biggest threat to sustainability and conservation of natural resource is the human population.

Over the last 30 years, India's production growth for wheat and rice has matched population growth. This production growth rate is made up of increases in area and yield. Area growth has been maintained for rice and wheat at 0.5% and 1.2%, respectively. The area growth has mainly resulted from double cropping or intensification of the cropping system.

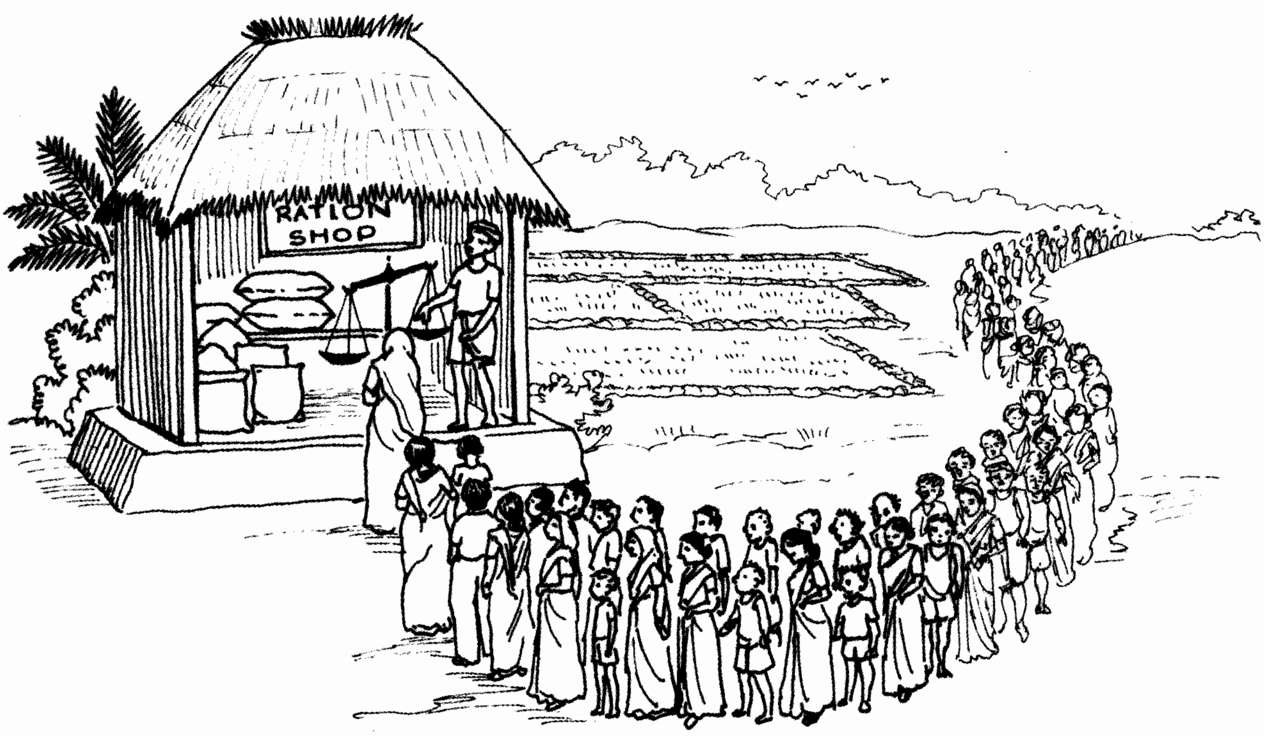
As urban areas grow and land is increasingly used for non-agricultural purposes in the next 20 years, area growth for rice and wheat is expected to slow or even decline. Therefore, any future production growth will have to come from yield increases.

Today, more than 10 million hectares of land are under rice-wheat cropping patterns in India. In this system, rice is grown in the wet, warm, monsoon summer, and is followed in the same field in the same calendar year by wheat in the cool, dry, winter season. Increasing system productivity is key to the success of the rice-wheat system.

Rice and wheat yield growth will have to increase by 2%-2.5% per year over the next 20 years to match the anticipated growth in population and to provide sufficient grain to meet a dramatic increase in the demand for animal feed. This level of growth was obtained in the last 30 years for rice (2.3%) and wheat (3.0%) through the use of improved seed, fertilizer and increased irrigation. In the next 20 years, other yield-enhancing factors will have to be tapped if growth is to continue. Even at a 2% growth rate, yields for rice and wheat will have to reach 4.7t/ha and 4.2 t/ha, respectively, in the year 2020.

What Needs to be Done?

Opening land to agriculture will no longer be a feasible way to increase production; scientists must increase the yield per unit area. New and innovative management systems that optimize input use, increase natural resource use efficiency, provide environmental benefits and cut production costs will be needed.



Adapted from:

Hobbs, P. R. and R. K. Gupta. 2000. Sustainable Resource Management in Intensively-Cultivated Irrigated Rice-Wheat Cropping Systems of the Indo-Gangetic Plains of South Asia: Strategies and Options. *In:* Singh, A.K. (ed). Proceedings of the International Conference on Managing Natural Resources for Sustainable Agricultural Production in the 21st Century. February 14-18, 2000. Indian Society of Soil Science, New Delhi, India.

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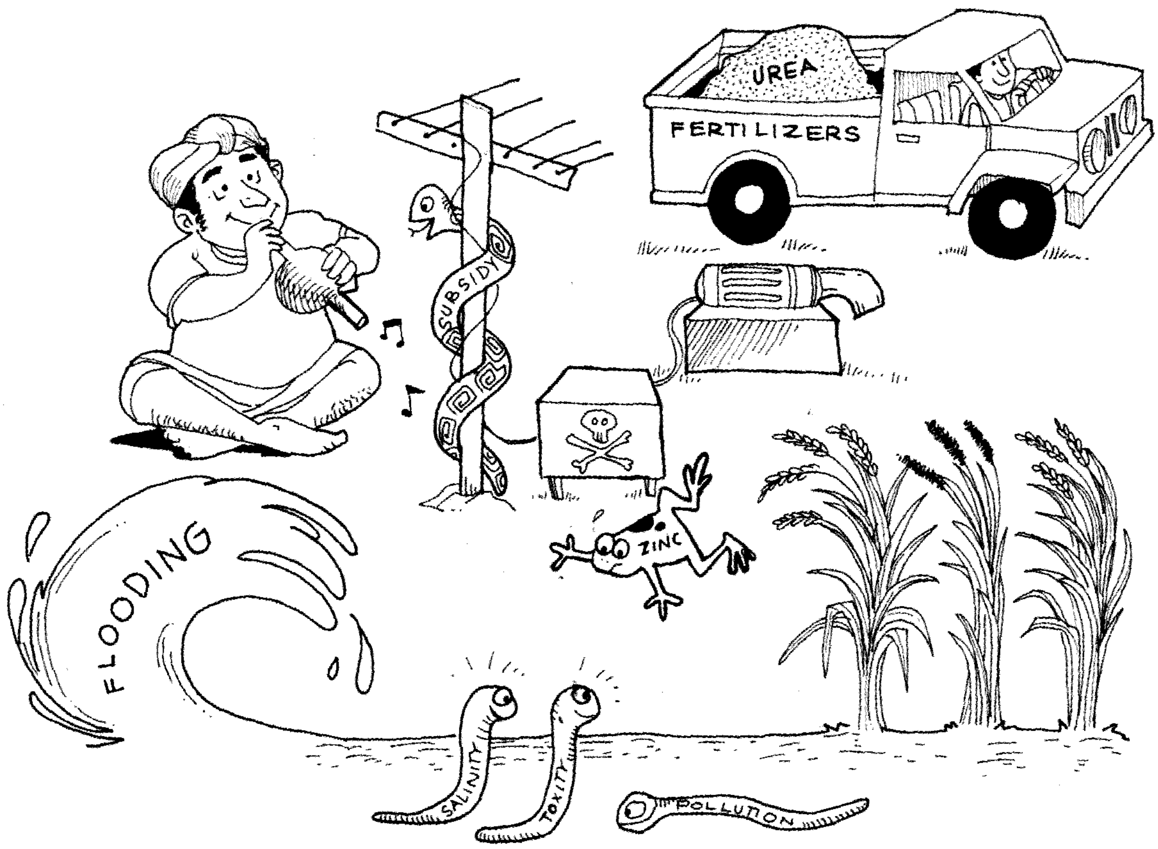
Peter R. Hobbs

Ecological Consequences of Intensification



Intensive rice-wheat crop rotation is an obvious outcome of an assured irrigation facility and short-duration varieties becoming available in the Indo-Gangetic Plains of South Asia. This crop rotation results in the following changes:

- seasonal wet and dry crop cycles over a long term;
- increased use of, and reliance on inorganic fertilizers;
- asymmetry of planting schedules; and
- greater uniformity in crop varieties cultivated and hence their susceptibility to the same pests.

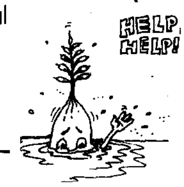
The most common environmental consequences of crop intensification in lowland areas are:

- waterlogging and salinity buildup;
- depletion/pollution of (ground) water resources;
- hardpan formation (or subsoil compaction);
- toxicities or deficiencies of nutrients in the soil; and
- pest buildup and pest-related yield losses.

ALERT!

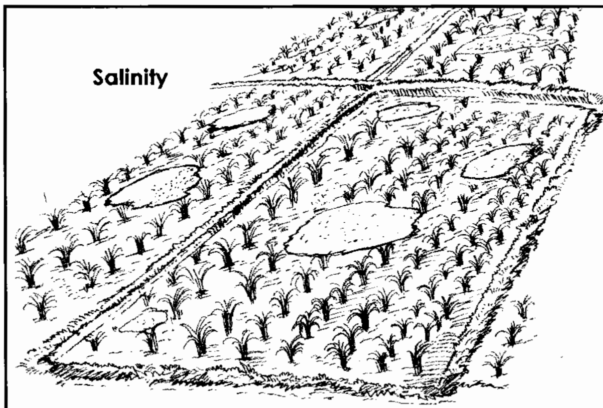
W-a-r-n-i-n-g S-i-g-n-s

At the farm level, long-term changes in the biophysical environment are manifested in terms of declining total factor productivity, input efficiencies and profitability.



Salinity, Waterlogging and Groundwater Degradation

Intensive use of irrigation water in areas with poor drainage leads to buildup of salinity in arid and semi-arid zones, and waterlogging in the humid zone. In canal irrigated fields, the watertable may rise due to the continuous recharge of groundwater. On the other hand, it can also lead to falling water tables and groundwater depletion in tubewell irrigated areas where the pumping rates exceed the rate of natural recharge of the aquifer.



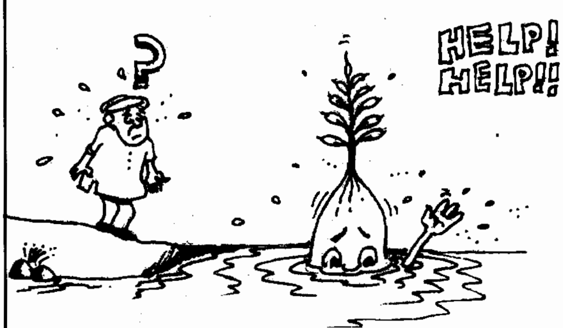
The groundwater itself need not be saline for salinity to build-up; it can occur due to the long-term evaporation from a soil surface continuously recharged with water of low salt content.
(Moorman and Van Breeman, 1978)

Salinity

Poor irrigation system design and management are the primary factors leading to salinity problems. Salinity in semi-arid zones is induced by an excess of evapotranspiration over rainfall causing a net upward movement of water through capillary action bringing with it salts that are then concentrated on the soil surface. Salinity problems are aggravated by seepage from unlined irrigation canals.

Waterlogging

Excessive water use and poor drainage in high rainfall areas cause problems of waterlogging resulting in low productivity levels due to poor aeration and lower rates of organic matter decomposition and mineralization, lower nitrogen availability and accumulation of soil toxins. Waterlogging early in the growing season can also lead to lower plant population and yield in wheat.



Waterlogging is reported to have reduced wheat yields by half a ton per hectare in Nepal's Terai region.
(Hobbs, et al., 1996)

Groundwater

Overdrafting of groundwater through power operated tubewells is a universal phenomenon. The resultant falling water tables have negative environmental and productivity consequences. Laws to regulate silting and use of tubewells are either absent, inefficient or their enforcement is abysmal.

Soil Characteristics

Soil physical characteristics and nutrient status over a long-term are adversely affected by seasonal cycles of tillage, flooding and drying due to intensive crop rotation.

Hardpan

Due to wet tillage or puddling operations for rice, the subsoil at a depth of 10-40 cm from the soil surface gets compacted. This 5-10 cm thick layer of sub soil, or hardpan, has less number of medium to large-sized pores and hence a higher bulk density. Water cannot move through this layer to the deeper soil and the water holding capacity of the overlying topsoil layer is increased. While this is ideal for rice, it has an adverse effect on the plant population and productivity of wheat. However, if the hardpan is broken by deep tillage, it has a negative effect on the yields. Flexibility is lost due to crop rotation.

Toxicity

Toxicities are not inherent to most irrigated lowlands but may build up in some soils due to continuous flooding, increased reliance on poor quality irrigation water and impeded drainage, especially on soils with hardpan. Iron toxicity is the most common. Farm level diagnosis of toxicity is complicated and corrective actions are not straightforward.

Nutrient Status

The most commonly observed effect of intensive rice-wheat system is the decline in partial factor productivity of nitrogen fertilizer. Fertilized rice and wheat obtain 50%-80% of their nitrogen requirement from the soil, mainly through mineralization of organic matter (De Datta, 1981). Continuous flooding for rice cultivation reduces the soil's capacity to provide nitrogen to the crop. Using long-term experimental data, Cassman and Pingali estimate the decline in yields in rice-sequence to be around 30% over a 20-year period at all nitrogen levels. Deficiencies of two other macronutrients, phosphorus and potassium are becoming widespread in areas not previously considered to be deficient.

Pest Incidence

Weeds, insects and disease-causing microorganisms like fungi and bacteria reduce crop productivity and quality of yield. The situation is aggravated by inappropriate crop management and pesticide use practices. Intensive crop rotation and susceptible crop varieties continuously provide sustenance to the pests. Prophylactic or preventive pesticide application has actually resulted in the contrary due to the disruption of pest-predator balance and a resurgence of the pest populations later in the crop season (Heong *et al.*, 1992). Relatively, minor pests of rice like caseworm, army worm and cutworm have started to cause noticeable losses.

Some diseases like Spot blotch of wheat are on the rise while others like Karnal bunt, for which the flooded conditions of rice are unfavorable, are on the decline. Insect and disease resistant varieties of rice and wheat have now been developed to reduce the need for pesticides.

Deficiency A-L-E-R-T

The deficiencies of macronutrients like nitrogen, phosphorus and potassium are directly related to the increase in cropping intensity and the predominance of year-round irrigated production systems. Two thirds of the agricultural land in China and nearly one-half of the districts in India are now classified as low or deficient in phosphorus (Stone, 1986; Tandon, 1987)

The micronutrient zinc has also become deficient in the tropics and is the limiting factor for rice in 2 million hectares in Asia alone. Drainage increases zinc availability (Lopes, 1980). Quite often, micronutrient deficiencies are misdiagnosed as pest-related damage.

Adapted from:

Pingali, P.L. and M. Shah. 1999. Rice-Wheat Cropping Systems in the Indo-Gangetic Plains: Policy Re-Directions for Sustainable Resource Use. pages 1-12. *In:* Pingali, P.L. (ed). 1999. Sustaining Rice-Wheat Production Systems: Socioeconomic and Policy Issues. Rice-Wheat Consortium Paper Series 5, Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

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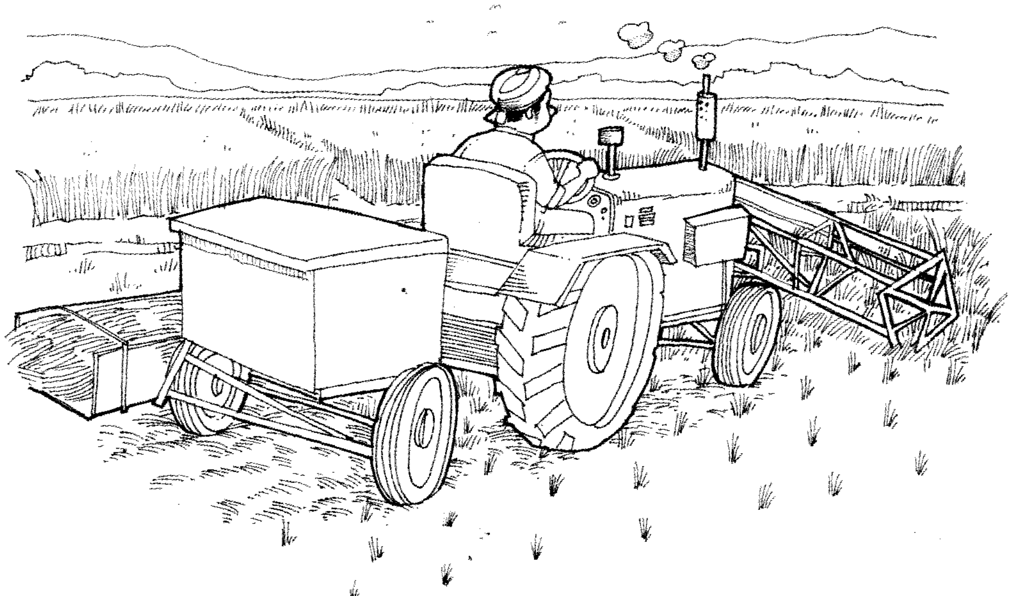
Prabhu L. Pingali

Farm-level Sustainability of Intensive Rice-Wheat System:
Socioeconomic and Policy Perspectives



The rice-wheat system (RWS) is one of the widely practiced cropping systems in India and covers about 9.5 million ha. About 90% of this area is concentrated in the Indo-Gangetic Plains (IGP) comprising the states of Punjab, Haryana, Uttar Pradesh, Himachal Pradesh, Bihar and parts of Rajasthan, Madhya Pradesh and West Bengal. Almost 90% to 95% of rice area in Punjab, Haryana and western Uttar Pradesh is under intensive RWS.

The favorable resource-base, availability of suitable modern technologies, and expansion of irrigation infrastructure complemented by the attractive macro- and micro-policy environments facilitated increase in rice and wheat outputs and yields tremendously in the intensive RWS over the past three decades. But recently, several causes have been reported for the decline in productivity of RWS. Some of these causes are declining soil fertility due to continuous and intensive monocropping, increasing soil salinity and alkalinity, declining partial factor productivity to fertilizer use, increasing pest and disease incidences, and deteriorating quality of water. The magnitude of yield decline is higher for rice than for wheat; rather there is an increasing trend for wheat yields under intensive RWS.

Most of the currently-available knowledge on these issues is based on data from long-term experiments (LTE) on research station or on-farm adaptive trials. But there is limited information on how farmers perceive these issues in terms of the yield losses. Therefore, the changes that occur in RWS under controlled environment at research sites (also in adaptive trials) may not be the same under real farm environment in farmers' fields.

The Transformation of the System

The agricultural production system has been transformed under RWS over the past thre e decades in several states in India in relation to micro- and macro-policy changes.

Is the sustainability of intensive RWS under threat in farmers' fields in India as it was reported from research sites? Farmers adjust their farm operations over the period to cope with the changing production and micro-policy environments.

Shift in Cropping Pattern

Total food grain production in India increased from 142 million tons in the triennium ending (TE) 1985/86 to 203 million tons in TE 2000/01. This was possible because of area expansion and productivity improvements in rice and wheat crops during this period. The area of coarse cereals and pulses has reduced due to crop diversification in favor of rice and wheat crops in RWS-dominant states. Cultivation of pulses in Punjab has almost disappeared over the period.

Shifts in Cropping Pattern and Composition of Food Grain Production in Punjab, India

Year (TE*)	Total area of food grain crops (million ha)	Share (%) in total cropping pattern				Total food grain production (million tons)	Share (%) in total food grain production			
		Rice	Wheat	Coarse cereals	Pulses		Rice	Wheat	Coarse cereals	Pulses
1971/72	3.9	10.5	58.0	20.4	11.2	6.8	10.7	76.1	8.1	5.1
1984/85	5.2	28.5	59.5	8.1	3.9	15.0	30.5	63.9	4.7	0.9
1995/96	5.9	37.8	57.9	3.6	0.8	21.1	34.9	62.5	2.5	0.2
2000/01	6.2	41.8	54.7	3.2	0.3	25.0	34.8	62.8	2.4	0.1

*TE = Triennium ending

Trends in Input Use Levels

Adoption of Modern Varieties

Farmers especially in irrigated environment found the modern or high-yielding varieties (HYVs) of rice and wheat more profitable and suitable for their production system, when these new varieties emerged in the 1960s and 1970s. Therefore, adoption of modern rice and wheat varieties eventually took place rapidly in Punjab, Haryana, and Uttar Pradesh. Nearly 95% to 98% rice and wheat area was planted to modern varieties by 1981/86. By 1992/97, nearly 100% wheat area was planted to HYVs while interestingly, rice area under HYV dropped in Punjab and Haryana between 1981/86 and 1992/97. Farmers in these states are substituting HYVs of rice with exportable and traditional rice varieties whose yields are quite low but higher priced.

Expansion of Irrigation Infrastructure

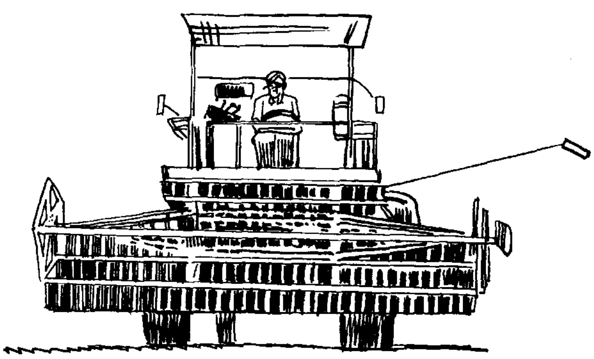
About 95% to 98% of the RWS had assured irrigation sources by the 1980s in Punjab and Haryana. Irrigated area under rice and wheat in other states also increased in the 1990s. Irrigation infrastructure is essentially required to adopt modern rice/wheat varieties. Thus, lack of assured irrigation is the major cause for non-adoption of modern rice and wheat varieties in eastern India. However, 68% and 78% of wheat area in Bihar and West Bengal respectively were covered by irrigation sources.

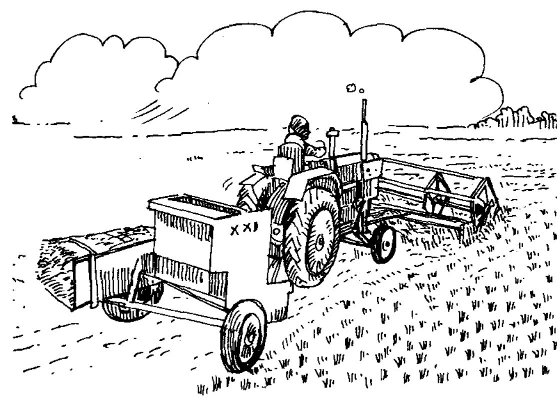
Increase in Use of Chemical Fertilizer

Modern rice and wheat varieties are highly responsive to chemical fertilizers. Therefore, use of fertilizers has increased tremendously for rice and wheat in the intensive rice-wheat belts. Use of chemical fertilizers is still low in Bihar as adoption of HYVs is low with less proportion of area under irrigation. In West Bengal, fertilizer use increased after the 1980s as modern varieties started spreading.

Labor Use

Intensification of RWS in Punjab and Haryana has increased demand for labor. Agricultural commercialization in this region has led to diversion of labor force from farm sector to non-farm sector leading to mechanization of RWS in this region. Thus, labor use in rice-wheat crops has significantly dropped between 1971/76 and 1992/97 in the intensive rice-wheat states of Punjab, Haryana and Uttar Pradesh. To cope with the increasing labor demand, labor-saving machinery such as combine harvester, power tiller, sprayers, dusters, threshers, balers, etc. have been widely adopted in these states.





Availability of labor in time is a major constraint in Punjab and Haryana. Farmers in these states bring contract labor from eastern states especially Bihar during March/April for wheat harvesting. To cope with the labor demand mainly for paddy transplantation, farmers in these states have changed sowing time from May/June to March/April so that paddy transplantation could be done with the same labor brought from Bihar after wheat harvesting season.

Use of Organic Manure

Intensification and mechanization of RWS in Punjab, Haryana, and some parts of Uttar Pradesh had reduced cattle population. This is due to lack of demand for animal power and conversion of pastures and other areas under fodder crops into agricultural lands. As a result, use of organic manure for rice and wheat crops has drastically reduced over the period in these states as well as in eastern India. Further, availability of chemical fertilizers at subsidized cost is also a principal factor for the negligence of conventional organic manures under intensive RWS.

On-farm Assessment of Long-term Productivity Trends

Are Rice and Wheat Yields Declining Under Farmers' Fields Over the Period?

The productivity growth of rice in farmers' fields declined but there was no negative growth during 1982/83 to 1995/96 under RWS in Punjab, Haryana and Uttar Pradesh. Thus, there was no yield decline in absolute terms in farmers' fields during this period. On the other hand, wheat yields in these states increased significantly at 1.8% to 2.6% per annum in the late Green Revolution Period. This increase has sustained the system productivity.

Changes in Productivity Levels of Rice and Wheat in India

State/Crop	Yield (tons/ha)				% change in yield		
	1971/72 (TE)	1984/85 (TE)	1995/96 (TE)	2000/01 (TE)	1984/85 over 1971/72	1995/96 over 1984/85	2000/01 over 1995/96
Punjab							
Rice	1.8	3.1	3.3	3.4	75.3	8.1	0.3
Wheat	2.3	3.1	4.0	4.6	35.7	28.5	15.8
Haryana							
Rice	1.7	2.5	2.6	2.4	43.4	2.7	-8.5
Wheat	2.1	2.5	3.7	4.1	22.9	44.4	12.6
Uttar Pradesh							
Rice	0.8	1.2	1.9	2.1	54.5	52.5	10.0
Wheat	1.2	1.9	2.4	2.7	50.5	29.9	17.2
Bihar							
Rice	0.8	0.9	1.3	1.5	9.6	45.1	18.6
Wheat	1.3	1.5	2.1	2.2	20.6	35.3	6.8
West Bengal							
Rice	1.3	1.6	2.1	2.3	22.3	32.7	12.6
Wheat	2.1	2.4	2.3	2.4	16.6	-4.6	2.6

*TE = Triennium ending

Has Instability of Yields Increased Under Farmers' Fields?

Instability indices for system productivity have declined between the early and late Green Revolution Periods and the productivity levels of RWS have stabilized by reducing yield variations over the period. However, instability of rice productivity in West Bengal has substantially increased during 1982/83 to 1995/96. This may be due to rapid coverage of HYVs.

The total factor productivity (TFP) for rice and wheat crops has increased significantly between 1971/72 and 1981/82 in intensive RWS of North India. During this period, TFP growth was higher for rice than for wheat and later it was vice-versa.

Yield Trend in the IGP

In eastern India and Bangladesh, where rice is the predominant crop and wheat has unfavorable production environments (shorter duration of winter, heavy soils and scanty rains during the winter season), rice-wheat systems expanded during the 1970s in response to the food grain shortage and the availability of higher-yielding wheat varieties. By 1980, the expansion of wheat stagnated at 5% of the area in Bangladesh and West Bengal in India. Since the mid-1980s, wheat yield has stagnated at around 2.0-2.5t/ha in Bangladesh and West Bengal, whereas rice yield continues to increase. In northwestern India, however, rice yield has stagnated and wheat yield increased. In northwestern India and Pakistan, rice yield is already the highest in the region. In other regions, the yields of both rice and wheat are steadily increasing.

Insights from Farmers' Experiences

Sample Farmers

Survey data was collected during 1999-2000 for a collaborative study of the Directorate of Rice Research (DRR) of the Indian Council of Agricultural Research (ICAR) and the International Rice Research Institute (IRRI), Philippines. Ten high productive rice-growing villages in each state of Andhra Pradesh, Karnataka, Punjab and Uttar Pradesh were selected. Ten progressive farmers were randomly selected from each village. These farmers had more than 10 years experience in rice cultivation.

Does Yield Gap Still Exist Under Intensive Rice System?

Only 30% of the sample farmers reported a decline in yield by 0.6 to 0.8 tons per ha while 60% stated yield stagnation between 1990 and 1999 under intensive RWS. Decline in yield of 0.8 tons per ha in rice-rice system was reported by only 40% of sample farmers during wet season while about 0.8 to 1.0 ton per ha of yield increase was mentioned by 60% farmers during dry season. Thus, the magnitude of 'yield decline' in RWS over the past 10 years was not as serious as earlier perceived by the researchers.

Are There Significant Losses Caused by Biotic and Abiotic Stresses that Could be Recovered Through Further Development of Technologies?

Based on farmers' perceptions over the past 10 years (1990-99), the annual yield loss is estimated at 536 kg/ha. This is equivalent to the total annual loss of about 5 million tons of paddy under the intensive rice system of which nearly 60% is due to biotic stresses (insect pests and diseases). The remaining 40% is due to resource (soil and water) degradation. The total yield loss accounts for only 8.5% of average yields obtained by farmers.

Insect pests have caused more yield loss than diseases in rice system. The total yield loss due to all major insect pests, after all possible plant protection measures was only 2% (125 kg/ha) and 3% (116/ha) of average yields obtained by farmers in Punjab and western Uttar Pradesh respectively. Stem borer, brown plant hopper, green leaf hopper, and leaf folder were the major yield-reducing insect pests while bacterial leaf blight and blast were major disease-causing yield losses.

As intensive RWS is concentrated under assured irrigation sources in Punjab and western Uttar Pradesh, the annual yield losses due to water-related stresses was minimum, i.e., less than 1% of average levels. However, soil-related problems have caused yield loss of about 2% (about 100 to 120 kg/ha) of average rice yields obtained by farmers under intensive RWS. Zinc deficiency, alkalinity, and iron deficiency are major yield limiting soil-related stresses under intensive RWS.

Estimated Annual Yield loss of Paddy Due to Biotic and Abiotic Stresses Under Intensive Rice Systems in India

System/State	Annual yield loss (kg/ha)				
	Insect pests	Diseases	Water-related stress	Soil-related stress	Total
Rice-rice system					
Andhra Pradesh	180	140	120	124	564
Karnataka	160	170	40	80	450
Rice-wheat system					
Punjab	125	65	40	102	332
Western Uttar Pradesh	166	91	48	119	424
Average*	**181**	**140**	**84**	**131**	**536**

*Proportion of rice area in each state was taken as weight for computing 'average' figures.
Data source: Survey data collected for an IRRI-ICAR (DRR) collaborative study "Constraints to increasing rice production in the irrigated rice systems in India", 1999-2000.

Implications

The introduction of modern varieties or HYVs of rice and wheat in the 1960s and 1970s complemented with supportive macro-policy environment made these two crops more attractive to farmers. The expansion of irrigation infrastructure, almost free electricity, subsidized input supply, minimum support pricing, procurement, etc. are major macro- and micro-policies that induced farmers to expand the area under rice and wheat at the cost of pulses and coarse cereals in the rice-wheat region.

Changes in Macro-Policies to Ensure Farm-Level Sustainability

- There is a need to withdraw gradually all protective policy support for rice and wheat crops.
- Subsidized input supply policy should be reviewed and public investments should be allocated for resource conservation activities instead of direct production subsidies.

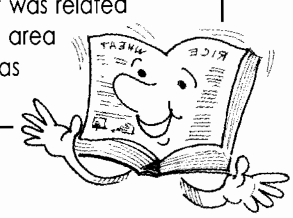
The incidence of poverty was low in Punjab, Haryana and western Uttar Pradesh where there was high adoption rate of HYVs and irrigation coverage. Thus, increase in rice and wheat supplies through the Green Revolution era significantly brought down real prices of rice and wheat to reducing poverty in India from about 56% in 1973 to 26% during 1999-2000.

Although the rate of decline in real prices per ton was higher than the rate of decline in real cost of production per ton for both rice and wheat, overall real profitability for production of these crops has increased at farmers' level due to tremendous yield improvements over the period. Therefore, under current policy environment with available technologies, production of rice and wheat crops is more profitable than other alternative crops in the intensive RWS dominant states. Although these micro-policies have played a greater role in boosting food supplies during chronic deficit era, continuation of the same policies even in the 1990s has brought in market distortions for other crops that prevented the farmers to diversify agricultural production systems under RWS leading to several of today's environmental concerns.

Price Trend in the IGP

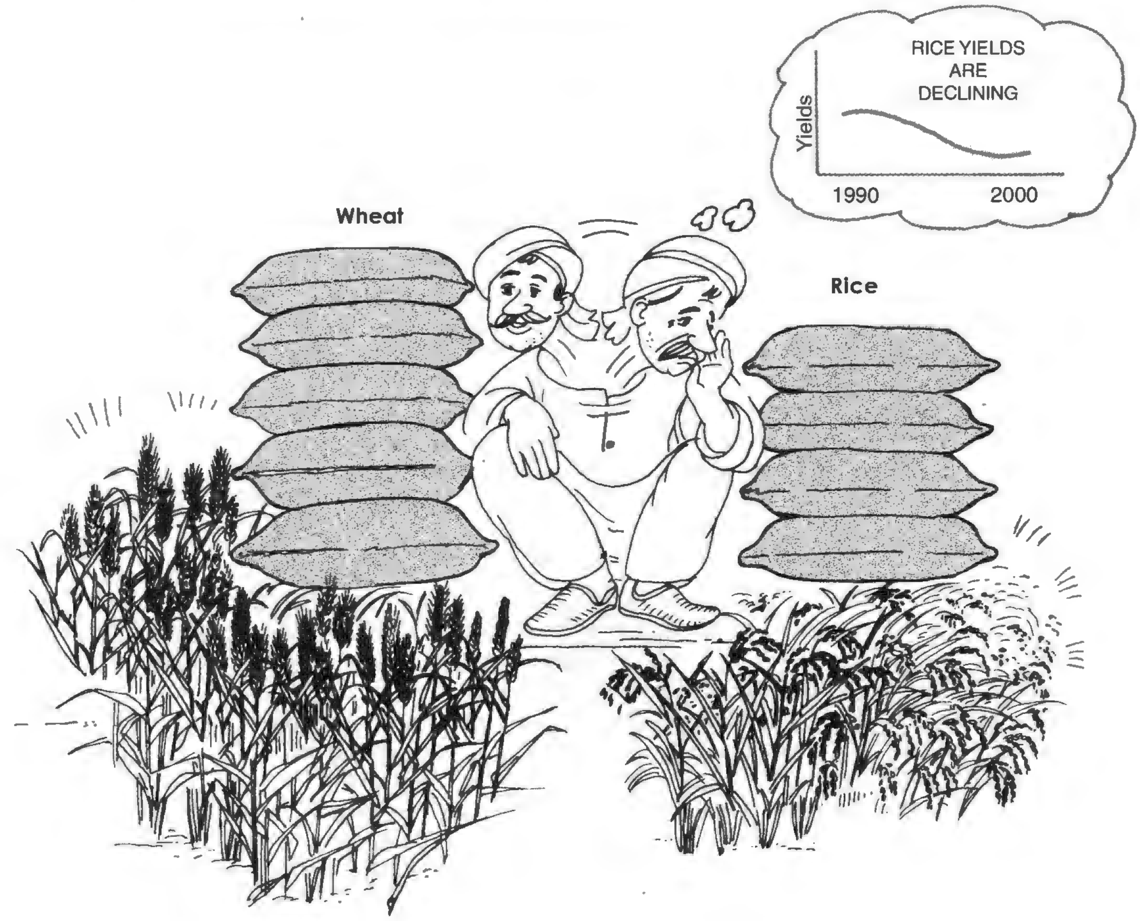
In northwestern India and Pakistan, where wheat has a favorable growing environment and rice can be grown only with full irrigation, the rice-wheat system expanded after the early 1970s in response to market opportunities and the availability of high-yielding rice varieties. Rice gradually emerged as a commercial crop while wheat remained the principal staple food. Bangladesh receives a large quantity of wheat (1.0-1.5 million t/yr) as food aid from wheat-surplus donor countries such as the United States, Australia, and Canada. This should have depressed the prices of wheat in the local market and provided disincentives to the growth of wheat production. But there has been a faster decline in the real price (adjusted for inflation) of rice compared with that of wheat. The price of both rice and wheat generally remained above the world market price. The data indicate that the price trend was not a dominant factor in the unfavorable system where the productivity growth of wheat was slow.

Information generated on costs and returns shows that boro rice has higher financial and economic returns than wheat. Where the production environment is favorable for both crops (availability of assured irrigation), wheat cannot compete with dry-season rice. Wheat, however, has a comparative advantage in areas with a longer duration of winter and light soils. The year-to-year variation in area under wheat was related to the price of wheat relative to that of the competing crop. But the long-run variation in area under both wheat and rice was price-inelastic. For Nepal, the price response for wheat was higher in areas with assured irrigation and access to developed infrastructure.



Contributed by:
Aldas Janaiah and **Mahabub Hossain**

How Extensive are Yield Declines in Long-Term Rice-Wheat Experiments in Asia



Long-term experiments (LTEs) provide opportunities for monitoring long-term changes in crop yields and soil nutrient balances and identifying factors associated with such changes. They also provide data on which to base rational judgments about the bio-physical aspects of sustainability. Analysis of the yield trends of 33 LTEs at different sites has successfully investigated the extent and causes of yield declines of rice and wheat in South Asia and China.

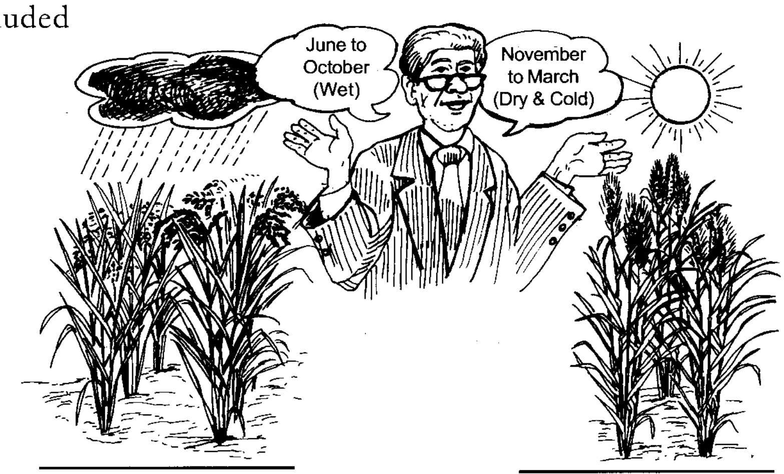
The LTE sites are located within subtropical to warm temperate climate. These areas have cool and dry winters, and warm and wet summers.

Soil fertility varies widely across these LTEs in terms of organic carbon (3 to 19 g/kg), Olsen P (0.005 to 0.26g/kg) and available K (0.036 to 0.225g/kg). Organic carbon content is generally higher in the soils of the lower IGP than in those of the upper IGP.

Crop Management in LTEs

Most of the experiments included **two crops per year:**

- Rice grown in the months of June to October under monsoon conditions.
- Wheat grown during cooler and comparatively dry winter months (November to March).



All the LTEs used semi-dwarf high-yielding cultivars of rice and wheat. During the experiments, the varieties were even changed in favor of the best available in the region.

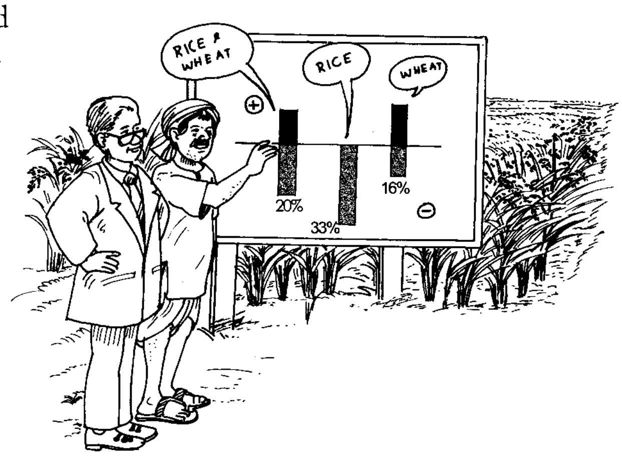
Trends in Rice and Wheat Yields

Rice-Wheat

Yields of wheat were more stable over time as they declined at only two sites and increased at four sites. However, yield trends in rice-wheat systems were mainly dominated by the trends in rice yields.

Wheat

Of the 33 LTEs, 16 showed negative yield trends. However, wheat yields were more stable than rice yields as is evident from the fact that only two LTEs showed significant declining trends as compared with eight LTEs in rice. Positive trends were observed in 17 LTEs, four of which were significant. It has been found that rice yields are less stable than wheat but the optimal conditions for rice lead to poor soil condition for growth of wheat. Thus, although wheat yields are stable, they probably are still lower than potential yields.



Rice

Region-wise averages were negative in all except one of the transects of the IGP, but no significant decline was observed at sites outside the IGP and in China.

It was interesting to note that the rice yields were similar in the IGP 2 and China but wheat yields were higher in the IGP 2 than in China. Sites in the non-IGP (excluding China) showed the lowest average system yield at 7t/ha.

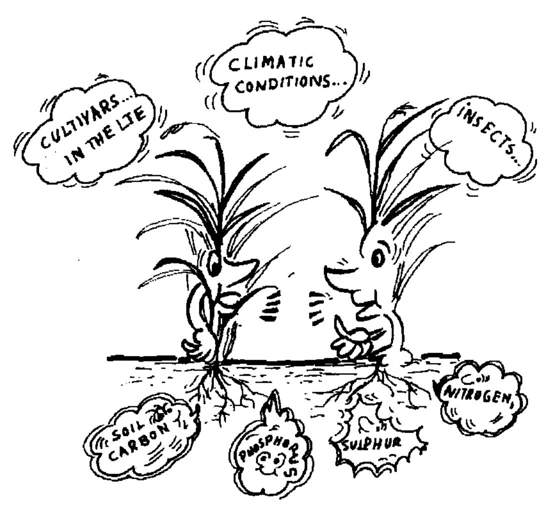
The analysis of yield trends of 33 LTEs in Bangladesh, China, India and Nepal suggest that though significant yield decline is not widespread, yields of both rice and wheat are **stagnating** in 72% and 82% of the LTE respectively. In other 22% and 6% of the LTE, the yields of rice and wheat respectively are **declining.**

Why Yields Decline?

Increases at some sites have been attributed mainly to improved varieties that were grown in place of the normally recommended varieties. Stagnation and reduction in yields may be because of negative changes in any of the following factors:

- soil organic matter and associated nutrient supply;
- exogenous supply of balanced nutrients;
- cultivars used in LTE;
- adverse or unsuitable climatic conditions;
- pressure of insects, diseases and weeds; and
- inadequate crop and soil management.

As all the experiments were conducted on research farms where crop and soil management and insect and disease control measures were done as per pre-determined schedule, these could not be the reason for stagnation and decline in yields. Likewise, rice and wheat varieties were constantly exchanged for cultivation of improved germplasm, a breakdown in crop genetic potential was not likely. Therefore, the remaining soil-related factors and gradual depletion of some nutrients, a downward shift in nutrient response function and changes in the climate may be the possible reasons for the declining yields.



Why yields decline?

Does Wheat Suffer After Rice?

Data indicate that in the rice-wheat system, rice yields, particularly in the IGP, have more disturbing trends than wheat yields. Scientists have given a hypothesis that this happens mainly due to puddling done in growing the rice crop. The soils in the rice-rice and rice-wheat systems differ vastly in texture. The rice-rice soils have much higher clay content with low bulk density compared with the alluvial soils which are sandy loam to silt loam with high bulk density. It is hypothesized that continuous puddling in light soils can cause soil compaction because of crystallized ferric oxides making the soils shallow. These shallow soils do not allow roots of the rice plant to penetrate in the soil resulting into lower yields.

Rice crop, as against wheat crop, suffer more because of this phenomena of soil compaction because rice is a shallow-rooted crop and mainly depends on 30 cm surface layer for all the nutrients. Naturally, in such a situation, rice crop suffers early due to nutrient deficiency as compared to wheat crop. In addition to its deeper root system, wheat is a longer duration crop and has 30-35 days more to mine soil nutrients.

Nutrient Depletion and Imbalance

There have been significant decreases in the rice-wheat yields when no fertilization was done. Yields of rice at various sites ranged from 1.6 to 5.8 t/ha because of varying fertility levels and other constraints. The mean yields of rice dropped from 2.8 to 1.6 t/ha, a 45% decrease. The mean wheat yields dropped from 1.2 to 0.9 t/ha, a 21% decrease.

Possible Causes of Decline in Rice and Wheat Yields in Various LTE

Causes	LTE
1. Decline in soil carbon	Ludhiana 1, Pantnagar 1 and Bhairahwa 2
2. Decline in soil N	Ludhiana 1, Pantnagar 1 and Bhairahwa 1
3. Decline in availability of P	Bhairahwa 1, Bhairahwa 2, Tarahara and Pantnagar 4
4. Decline in soil K	Ludhiana 1, Karnal 1, Pantnagar 4, Pusa, Bhairahwa 1, Bhairahwa 2 and Tarahara
5. Decline in available Zn	Pusa, Bhairahwa 1
6. Delay in planting	Bhairahwa 1 and Bhairahwa 2
7. Decrease in solar radiation	Ludhiana 1
8. Increase in minimum temperature	Ludhiana 1

Decline in Soil Carbon

Carbon, the soil conditioner, source of nutrients and substrate for microbes, appears to have declined in some of the LTEs. Total soil carbon declined due to continuous cultivation in Bhairahwa 1, Ludhiana 1, Pantnagar 1 and other LTEs in the IGP. Even when supplied with the recommended NPK, there was corresponding decline in yields of rice and wheat. In the major rice-wheat regions of northwest India, soil C has decreased from 0.05% in the 1960s to 0.02% in the late 1990s. Such a decline is prevalent throughout rice-wheat systems in India.

However, scientists have found a positive role for organic matter along with NPK.

Does Soil Organic Matter Increase Yields?

Scientists say, soil organic matter (SOM) does not necessarily maintain or increase yield. For instance, SOM content was increased in the rice-wheat in Tarahara, LTE but yields declined in both the crops. In Bhairahwa LTE, continuous application of FYM did increase the SOM but not yields. The data suggest that SOM and crop productivity are not linked. Perhaps total size of SOM is not as important as the size of the active fraction involved in nutrient cycling. While high SOM is critical in attaining yields close to potential yields, other factors should also be optimal.

In Bhairahwa 1 LTE, where SOM increased but yield declined, it was found that gradual depletion of soil K and its insufficient application caused the yield decline. Therefore, there is a need to understand and quantify the role of SOM in relation to crop productivity and sustainability.

Depletion of Soil Nitrogen

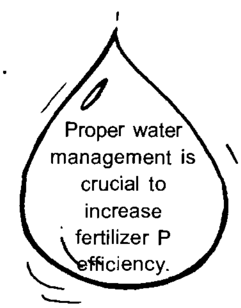
Three possible reasons have been identified for yield decline in rice-wheat systems:

- soil nitrogen supply;
- nitrogen uptake efficiency; and
- fertilizer N-use efficiency because of biotic or abiotic constraints.

To achieve higher yields in rice-wheat systems, time of N application is important. This is more important in sandy rice-wheat soils having high pH. Such soils are common in the IGP areas where nitrogen losses by leaching and volatization are high.

Reduced Soil P Availability

Total P was not a limiting factor in influencing yields of rice-wheat systems. However, unfavorable soil conditions can reduce its bio-availability contributing to decline in yields.



The differential availability of P for rice and wheat could be due to the following:

- Changes in the oxidation-reduction status of soil resulting from continuous submergence in late rice.
- Intermittent wetting and drying in early rice and aerobic conditions during wheat cultivation.
- Reduced soil conditions because of reduction of ferric iron phosphate compounds and increased solubility of Ca-P compounds. This happens mainly in alkaline soils due to decreased pH. Use of gypsum to ameliorate sodic soils reduces P availability as calcium phosphate species are formed.
- Increased absorption during the drying phase and differences in soil P diffusion in submergence and dry soils.

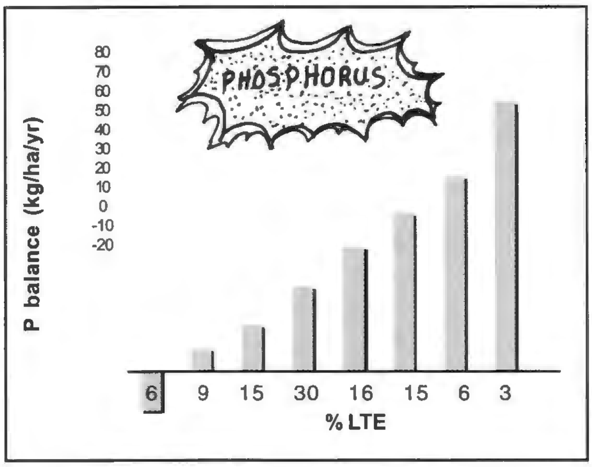
Depletion of Soil K

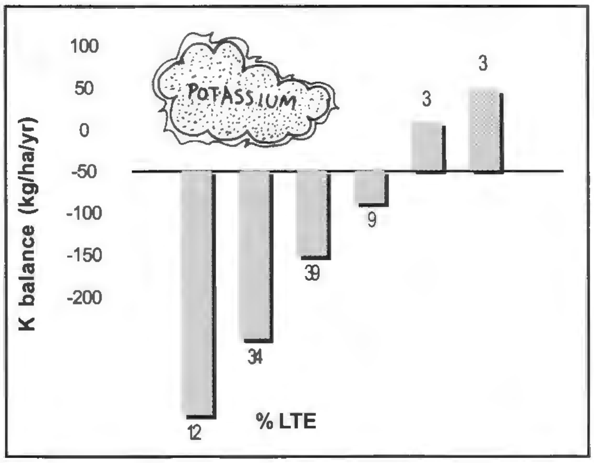
All the LTEs with a significant yield decline had large negative K balance. However, P balance was positive in most LTEs. In 90% of the LTEs, the fertilizer K rates used were not sufficient to sustain a neutral K input-output balance.

The following suggestions have been made to keep the K balance in the soils:

- Higher doses of K application are needed to increase the yield levels of both rice and wheat.
- Incorporate straw into the soil to replenish K to some extent. Identify other sources of animal feed than straw.

Potash deficiency reduces the yields in rice and wheat even in most of the soils of the alluvial flood plains of Asia which are normally considered to be rich in K. It may also be a misplaced perception that irrigation water supplies enough K to the crops.

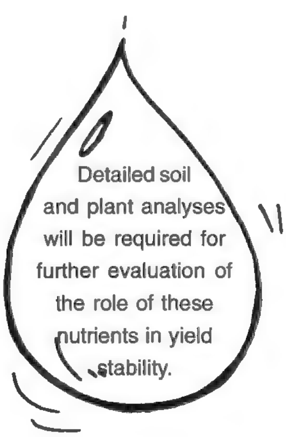




Depletion of Micronutrients

Micronutrient deficiency exists in the IGP, especially in the calcareous soils. More stable yields were obtained with farmyard manure (FYM) treatment as against NPK treatment.

As for other micronutrients, the deficiency was not widespread. Soils are not normally deficient in S because application of single superphosphate supplies the needed levels of this nutrient. For meeting the requirements of other micronutrients, blanket application once in three years should be done or in case deficiency symptoms appear.

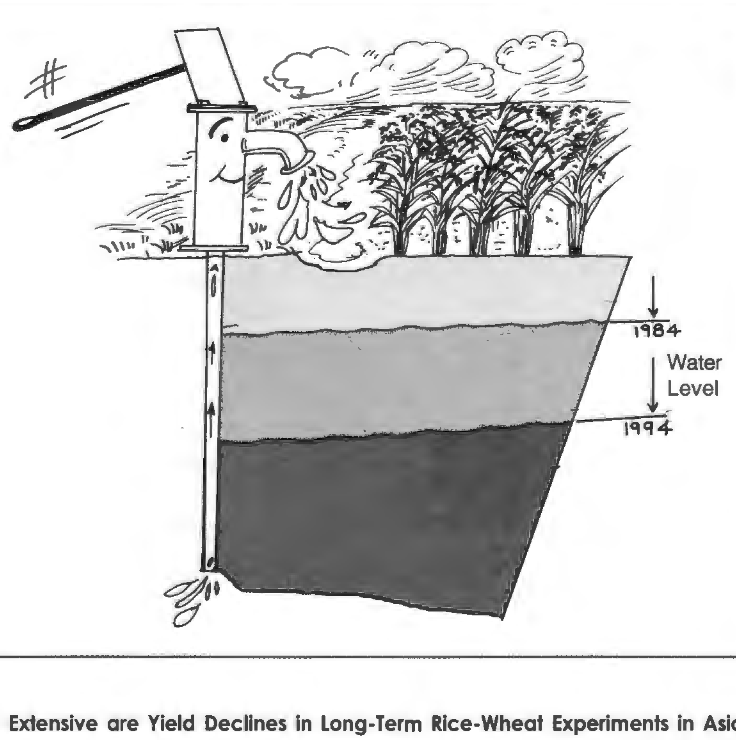


Soil Salinity and Depleting Groundwater

Soil salinity is perceived as a cause of declining yields in farmers' fields in the rice-wheat system of the IGP, particularly in Transects 1 and 2. Frequent irrigations in these highly porous and light-to medium-textured soils cause salinity.

Groundwater Decline

In Haryana, India, the rice-wheat growing areas in the districts of Ambala, Kaithal, Karnal, Kuruhkshetra, Panipat and Yamunanagar, show a considerable groundwater decline. In Punjab, India, a 2-5 m decline in the water table has been recorded from 1984 to 1994.



Delay in Crop Planting

Another cause of yield decline, especially for wheat, is delay in sowing. It results to decrease in yield because of rise in temperature at grain filling stage. This yield loss was noticed in Bhairahwa 1 because of delay in sowing. Sowing wheat after 15-20 November resulted in decrease of yield by 1% every day! Late planting not only reduces yield but also reduces efficiency of inputs applied to the wheat crop.

Reasons for Late Planting of Wheat in Rice-Wheat System

- Late planting of preceding rice crop.
- Growing long-duration, photo-sensitive, high quality basmati rice that matures late.
- Long turn-around time between rice harvest and wheat planting is required.
- Growing of a short-duration crop planted after rice

Summary

Yield stagnation has set in the rice-wheat system in all the LTEs and decline in some LTEs, particularly in rice. It is difficult to attribute any single reason for this decline. The reasons may be more location-specific. Depletion in soil nutrients, reduced availability of P, delay in planting, decrease in solar radiation and higher temperatures may be the causes of the decline in some locations. Depletion of soil K seems to be a general cause.

The main bottleneck in the identification of specific reasons for declining yield trends can only be identified if historical soil and plant samples are available for analysis. Therefore, more detailed data collection and archives of soil and plant samples should be determined to find out this cause-and-effect relationship.

- Greater stability in wheat yields does not mean conditions are favorable for wheat. Yields are still below potential.
- Assessment of pest and disease pressures and interactions with nutrient management is essential.
- Greater attention should be given to the role of organic matter in rice-wheat system.
- New experiments to assess long-term effects of zero-tillage and reduced tillage practices are required to probe further to this phenomenon.
- Accurate assessment of nutrient budgets is required. Non-nutritional benefits of some of the nutrients need further study.
- More experiments with residue management are needed.

Adapted from:

Ladha, J.K., D. Dawe, H. Pathak, A.T. Padre, R.L. Yadav, B. Singh, Yadvinder Singh, Y. Singh, P. Singh, A.L. Kundu, R. Sakal, N. Ram, A.P. Regmi, S.K. Gami, A.L. Bhandari, R. Amin, C.R. Yadav, E.M. Bhattarai, S. Das, H.P. Aggarwal, R.K. Gupta and P.R. Hobbs. 2003. How Extensive are Yield Declines in Long-term Rice-Wheat Experiments in Asia? Journal of Field Crops Research. Article in press. Available at: http://www.sciencedirect.com.

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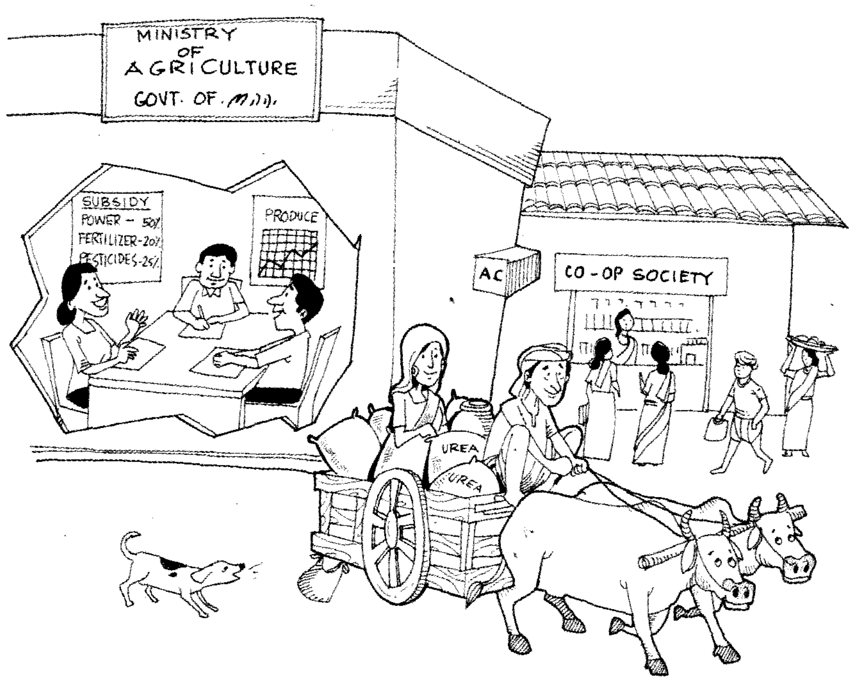
Policies Influencing Productivity and Sustainability



The last three decades have witnessed a phenomenal growth in cereal crop productivity in the developing world, particularly in rice and wheat in Asia. The commitment to achieving food self-sufficiency was the driving political force that made Green Revolution happen in South Asia. High levels of investments in research and infrastructure development, especially irrigation facilities, resulted in rapid intensification of the lowlands.

Contributory Factors

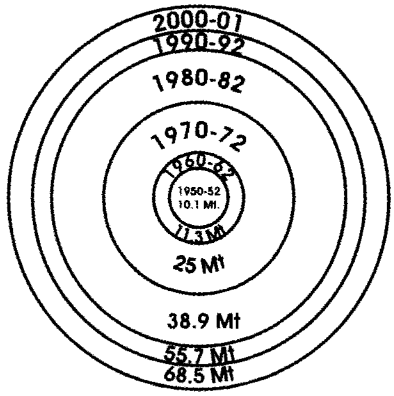
The major factors that contributed to the dramatic increase in production and the initial success of the Green Revolution are the following:

- Introduction of semi-dwarf, high-yielding varieties (HYV) of rice and wheat increased investments in infrastructure, especially irrigation systems and policy support and political commitment to accelerated food grain production.
- Policy support and political commitment were critical to the rapid dissemination and adoption of modern technologies for rapid growth in food production.
- Supply of free irrigation water and free or subsidized power supply for tubewells.
- Provision of fertilizers at subsidized prices.
- Disbursement of farm credit at low interest rates.
- Provision for price support.

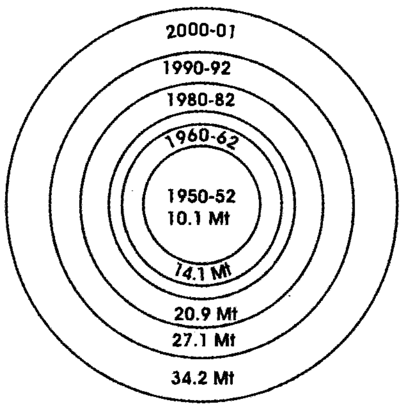
Revolving Door Effect

During the Green Revolution period, subsidies motivated the farmers to adopt new technologies to increase productivity and production of food crops.

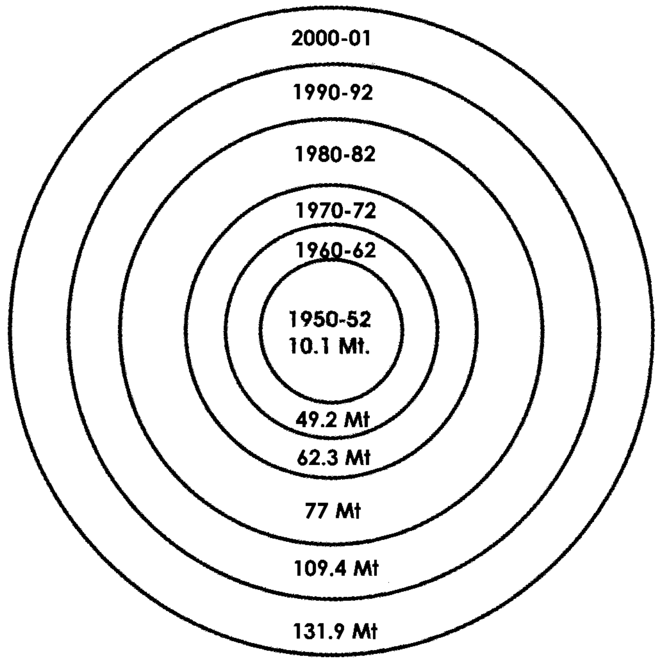
Prolonging the policies of input price subsidies into the post-Green Revolution period has resulted in a distortion of farm-level incentives for efficient input use and has led to much of the resource base degradation observed today.



Wheat production growth
(in million tons) in India



Rice production growth
(in million tons) in Bangladesh



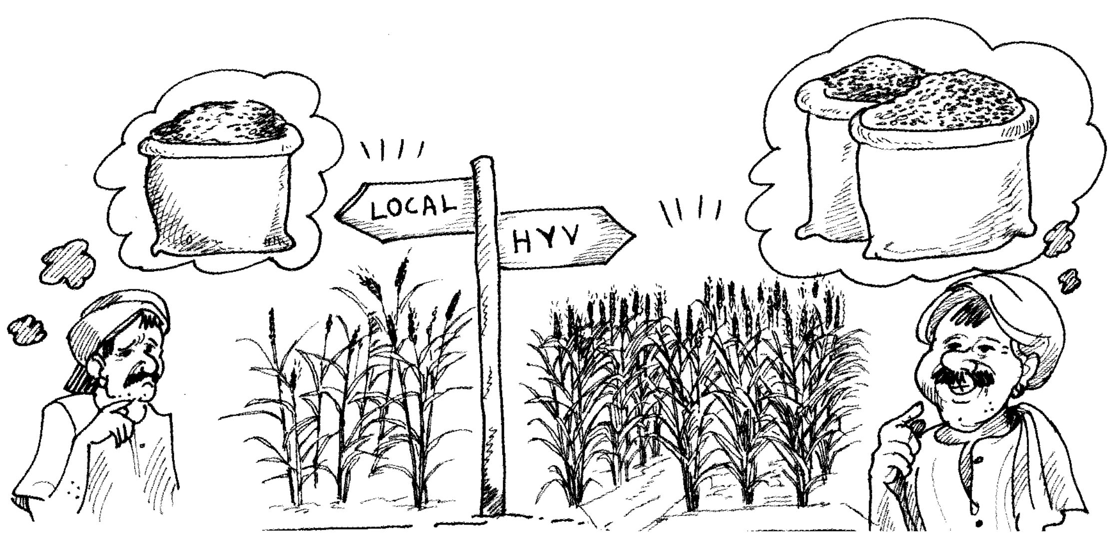
Rice production growth (in million tons) in India.

Source: P. L. Pingali, 2002

Crucial Policies

Subsidized HYV Seeds

The average wheat yield in Indian Punjab doubled from 2 tons/hectare in 1970-71 to over 4 tons/hectare in 1993-94. By 1979, almost 100% of wheat planted in Punjab was of modern HYVs, thanks to subsidies on HYV seeds.



Support Prices

To encourage domestic food grain production, macro-economic policies were put in place to artificially maintain grain prices at high levels. Rice and wheat became 'safe' crops which would get farmers assured prices at subsidized input costs. As self-sufficiency in food grain production was the motivating factor for many of the policy measures during the 1970s and 1980s, the grain prices were also protected through import restrictions and tariffs.

Tubewell Deregulation

The most successful tubewell development has been through small-scale private investment. Bangladesh triggered a tubewell revolution in early 1980s by deregulating private tubewell imports and markets. Subsequent restrictions on tubewell siting slowed down the growth in tubewell adoption during 1985-87. However, nearly 1.5 million hectares of additional land was irrigated and this stimulated rapid agricultural growth in the 1980s and early 1990s (Rogers *et al.,* 1994).

Changing Trends

Recent signs, however, indicate a slowdown in productivity growth of primary cereals, particularly in intensively cultivated rice-wheat zones of South Asia. Degradation of the lowland resource base, specially land, due to intensive use over a long term, slackening of investments in research and infrastructure as well as reduced policy support explain the current sluggish growth in productivity. Intensification *per se* is not the root cause of resource base degradation, but rather the policy environment that encouraged inappropriate land use and injudicious input use, especially water and chemical fertilizers.

Policy Needs

Ecological degradation is often the consequence of ill-conceived policy. Free or very low-cost irrigation facility promotes its over use thereby resulting in salinity or waterlogging and groundwater pollution. Promotion of nitrogenous fertilizer use through subsidies and year-round cropping with irrigation has reduced the mineralization for the natural supply of nitrogen from soil and has also upset the balance of macronutrients. This imbalance also impacts on insect pest incidence. Policies and incentives can induce inappropriate and inefficient use of land, water and other input use practices.

Cropping pattern choices at both farm and national levels continue to be made on economic grounds rather than on sustainability grounds. Policies designed for achieving food self-sufficiency, which was of utmost importance to the hungry millions in Asian countries thus far, tend to undervalue goods like land and labor resources which are not traded internationally. The dual goals of food self-sufficiency and sustainable resource management are often mutually incompatible. As a result, food self-sufficiency in countries with an exhausted land resource, particularly the countries of South Asia, came at a huge ecological and environmental cost.

Policy Re-Directions

Appropriate policy reform, both at macro as well as sector level, will go a long way towards arresting and possibly reversing, the current resource base degradation trends. Severe environmental degradation in intensified agriculture mainly occurs when incentives are incorrect due to bad policy or a lack of knowledge of the underlying processes of degradation.

Input subsidies that keep prices of certain inputs at lower levels directly affect crop management practices at the farm level. The low prices ensure that the farmer has no need or desire to improve input use efficiency or to learn to use it judiciously. South Asian farmers have for long 'benefited' from subsidies on irrigation water, fertilizers, pesticides and credit. Existing evidence on intensification induced degradation in rice-wheat systems of the Indo-Gangetic Plains of South Asia has been extensively reviewed to arrive at possible policy re-directions and corrections that can ensure sustained productivity growth to meet the future food requirements of this region.

Water

Irrigation water is by far the most critical factor for intensive crop rotation. Its indiscriminate and excessive use is responsible for extensive resource base degradation through waterlogging, salinity, iron toxicity, macro and micronutrient deficiencies and changes in soil physical properties. To create incentives for efficient and more environment-friendly water use, water subsidies (and power subsidies for operation of tubewells) should be phased out, with more realistic water charges for all sectors. In the long-term, markets in tradable water rights should be established where feasible.

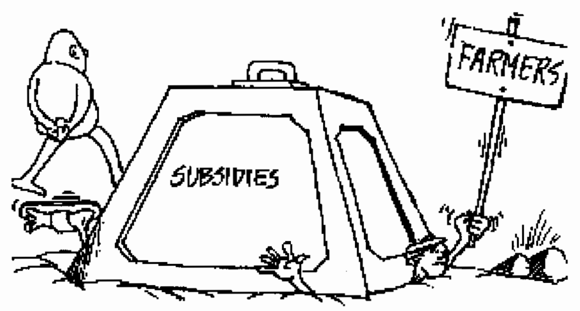
Establishment of secure water rights for water users is an important foundation for the establishment of economic incentives for efficient water allocation. Responsibility for irrigation water management should be devolved to autonomous local institutions with use representations and/or joint ownership.

Fertilizers

Excessive and imbalanced fertilizer application is a direct consequence of the subsidy regime. In Asia, the deficiency of the micronutrient zinc has become a major limiting factor in rice productivity. Subsidies on macro nutrients, specially nitrogen, should be phased out to promote greater fertilizer use efficiency.

The Fertilizer Story

Improving input (fertilizer) use efficiency often requires the farmer to invest in learning about the technology and how best to use it. Techniques for improving fertilizer use efficiency are available but will only be viable at the farm level when fertilizer subsidies are removed. South Asian farmers can get "cheap" fertilizers and hence, there is no incentive to change. The reduction and eventual removal of fertilizer price subsidies can substantially improve fertilizer use efficiency and help reduce fertilizer-related environmental degradation. The funds saved from subsidies can be used for alternative investments.



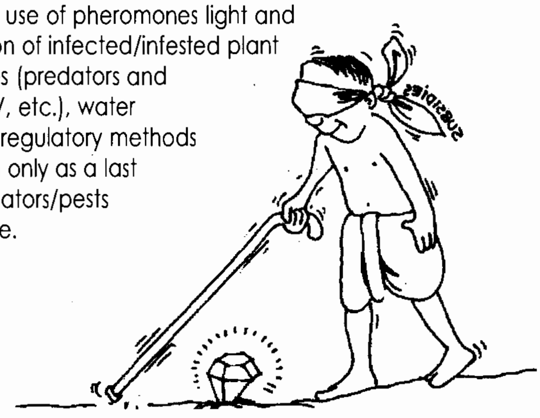
Pesticides

The integrated pest management (IPM) program seeks to reduce pest damage by fostering an appropriate predator-pest ratio at the farm and sector level. Prophylactic pesticide application, on the other hand, disrupts the natural predator-pest balance and causes a resurgence of the pest population later in the crop season (Heong *et al.,* 1992). However, policymakers commonly, and mistakenly, perceive that modern crop varieties are more susceptible to pest-related crop losses and, therefore, that their cultivation is not possible without high levels of chemical pest control. Subsidies are provided for pesticides and pesticide application equipment due to this misconception. To make IPM attractive to the farmers, it is important to remove all explicit and implicit subsidies on pesticides, as otherwise the farmers have no incentive to invest time in acquiring IPM skills.

Integrated Pest Management

Integrated pest management (IPM) is a strategy combining physical, mechanical, biological and chemical methods for managing the pest population at levels below those causing economic loss. IPM is both cost effective and less damaging to the environment than use of pesticides alone.

IPM involves use of insect/disease resistant crop varieties, use of pheromones light and mechanical traps for insect pests, removal and destruction of infected/infested plant parts, conservation and enhancement of natural enemies (predators and parasites) population, use of microbial pesticides (BT, NPV, etc.), water management, reduction of nitrogenous fertilizer use and regulatory methods including plant quarantine. Chemical pesticides are used only as a last resort. This requires investment in learning to identify predators/pests and to estimate their population through field surveillance.
(Figueiredo and Braganza, 1992)



Research and Extension Services

Continued high levels of investments in research and infrastructure development as well as institutional and policy reforms are necessary to reverse the current trends in resource base degradation. Location-specific research on soil fertility constraints and agronomic practices, development of improved fertilizer supply and distribution systems and improvement of farm extension services are important. The policy must provide for these.

With the progression towards global integration, competitiveness can only be maintained through dramatic reductions in the cost per unit of production, either through a shift in the yield frontier or through an increase in the input use efficiency. The use of existing insect and disease resistant varieties and integrated pest management to reduce need for pesticide application, optimizing water and fertilizer use efficiency, zero tillage are some of the options. Policy changes that would encourage enhancement of input use efficiency would also contribute to the long-term sustainability of intensive food crop production and help arrest many of the problems described above.

Reference

Figueiredo N. X. and M.A. Braganza. 1992. Pest Management. Agriculture Officers' Association, Panaji, India. pp112.

Adapted from:

Pingali, P.L. and M. Shah. 1999. Rice-Wheat Cropping Systems in the Indo-Gangetic Plains: Policy Re-Directions for Sustainable Resource Use. pages 1-12. *In:* Pingali, P.L. (ed). 1999. Sustaining Rice-Wheat Production Systems. Socioeconomic and Policy Issues. Rice-Wheat Consortium Paper Series 5. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

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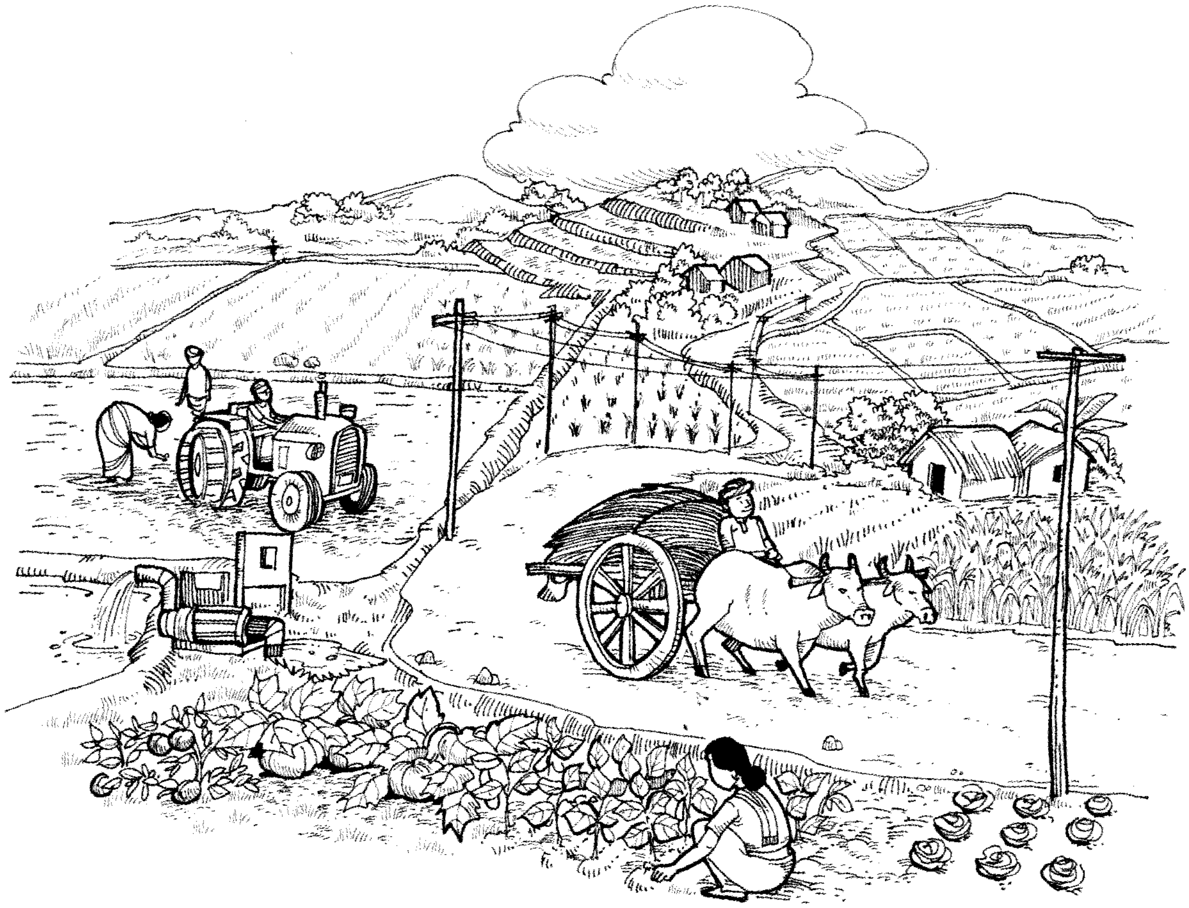
Nature and Speed of Agricultural Diversification



Globalization of agriculture has thrown up a new challenge to the agrarian sector in South Asia. The descending trend in the global prices of agricultural commodities, especially food grains, endangers the sustainability and viability of the majority of farming communities, who are dependent for their food security through tiny pieces of lands.

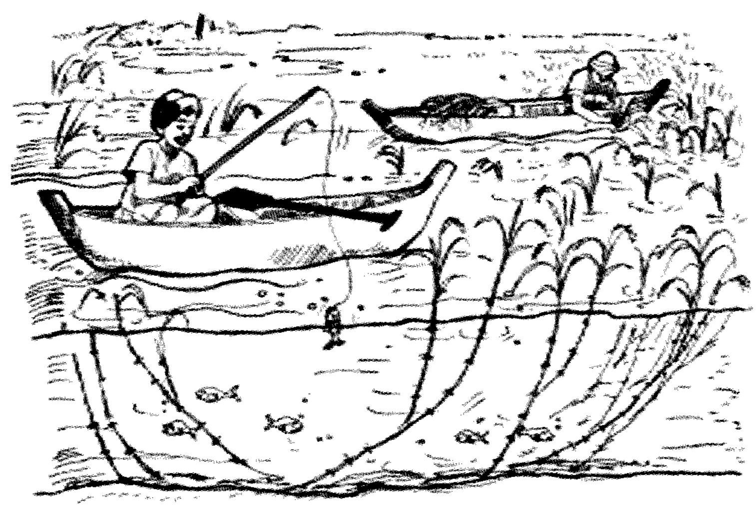
Stagnating technological advancement and declining investment in agriculture had impeded South Asia to compete at the global level on many agricultural commodities. The threat is worsened by the inherent problems of widespread poverty and malnourishment, acute rural unemployment and severe land degradation.

South Asia is the home of about half of the world's poor. About one third of the world's chronically undernourished people (255 million) live in this region. High growth in population, lack of enough employment opportunities, and declining size of landholding are leading to abject poverty and causing degradation of natural resources due to their overexploitation. How can these countries in South Asia contain the threat of globalization under such a hostile environment?

Agricultural diversification in favor of more competitive and high-value enterprises is reckoned an important strategy to overcome the emerging challenges. In many developing countries, diversification has become an integral part of structural adjustments and transformation of agricultural sector. In the traditional subsistence system, agriculture is a coping mechanism for risk aversion. In the market-led environment, it is a strategy to allocate resources optimally, augment farm income, generate employment opportunities, alleviate poverty, conserve precious soil and water resources, and intensify export.

Concepts of Diversification

At the national level, diversification is concerned with the inter-sectoral transfer of resources, production, and income in an economy (agriculture, industry, services, etc.). Within the agriculture sector, diversification is a shift from one crop to another crop, or from one enterprise to another, in terms of area, production, income, uses, and transfer of resources. It is an additional complementary or supplementary enterprise to the main enterprise, e.g., mixed crop-livestock system. Thus, the nature of diversification can be classified as:



1. a shift from farm to non-farm activities;
2. a shift from less profitable crops or enterprises; and
3. use of resources in diverse and complementary activities.

Benefits of Diversification

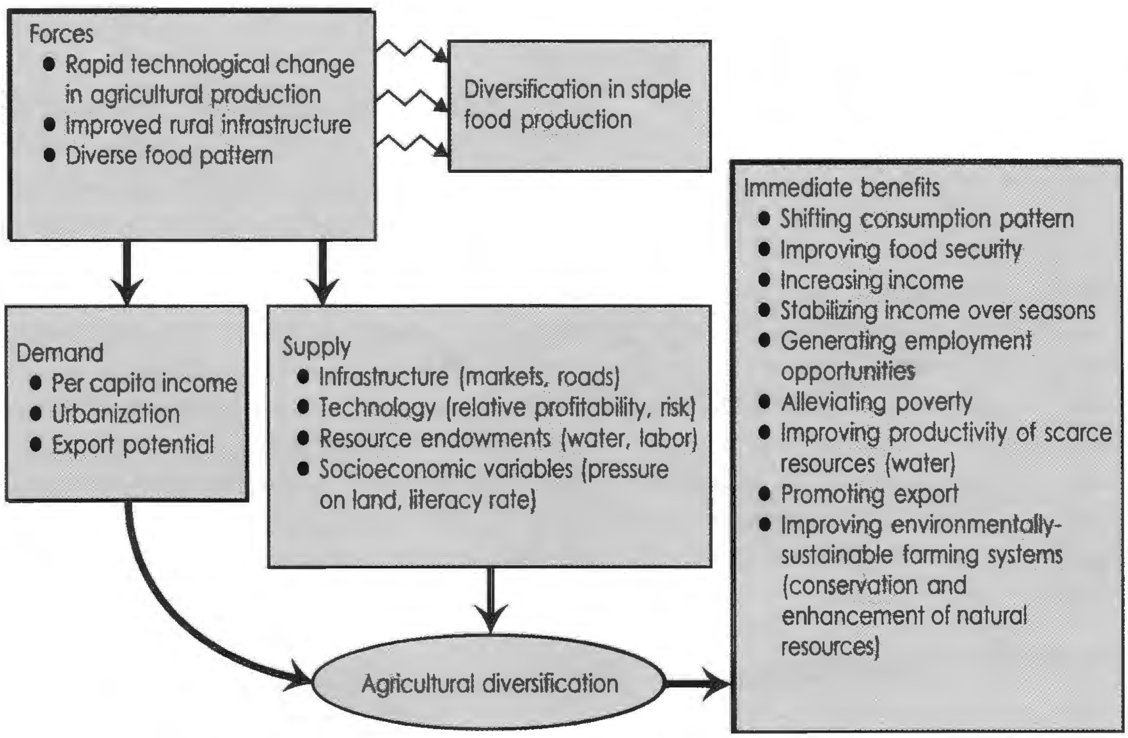
Microlevel studies on diversification showed that a shift towards high-value crops benefited the poor by directly generating employment and raising agricultural productivity. The producers who diversify their production as well as the hired laborers receive direct income benefits. Similarly, diversification in the rainfed and marginal environments is an insurance scheme that diffuses risk, arrests resource degradation, and reduces biotic and abiotic losses. Diversification of agriculture in favor of commercial crops leads to greater market orientation of farm production and progressive substitution of non-traded inputs in favor of purchased inputs.

Share of Individual Sectors (%) in Gross Value of Agricultural Output at Constant Prices								
State	Crop		Livestock		Forestry		Fisheries	
	1981-82	1997-98	1981-98	1997-98	1981-82	1997-98	1981-82	1997-98
Bihar	73.2	70.7	21.3	27.5	3.8	0.9	1.7	0.9
Haryana	69.4	71.1	30.0	28.5	0.5	0.2	0.1	0.2
Punjab	73.2	67.0	25.6	32.5	1.2	0.3	0.1	0.1
Uttar Pradesh	78.9	75.9	18.3	23.5	2.5	0.2	0.3	0.3
West Bengal	72.7	73.8	16.7	21.8	3.0	0.5	7.6	3.8
All India	76.0	75.0	18.0	23.0	4.0	1.0	2.0	1.0

South Asia is gradually diversifying with some inter-country variation in favor of high-value commodities (fruits, vegetables, livestock and fisheries). Agricultural diversification is strongly influenced by price policy, infrastructure development (especially markets and roads), urbanization and technological improvements. Rainfed areas are benefited more as a result of agricultural diversification in favor of high-value crops by substituting inferior coarse cereals. A sound and empirical understanding about nature of agricultural diversification and the constraints in accelerating its speed are needed. This would support in crafting appropriate policies for the evolution of required institutional arrangements and creation of adequate infrastructure development.

Drivers and Implications of Diversification

Several forces influence the degree, nature, and speed of agricultural diversification from staple food to high-value commodities. The benefits of diversification are more clearly captured at micro-level than at macro-level. The immediate benefits have implications for future prospects of growth in agriculture, regional equity and sustainable farming systems.



Adapted from:

Joshi, P.K., G. Ashok, P.S. Birthal and T. Laxmi. 2002. Nature and Speed of Agricultural Diversification in South Asian Countries. Paper Presented at the ICRIER-ICAR-IFPRI Conference on Economic Reforms and Food Security: The Role of Trade and Technology. 24-25 April 2002. New Delhi, India.

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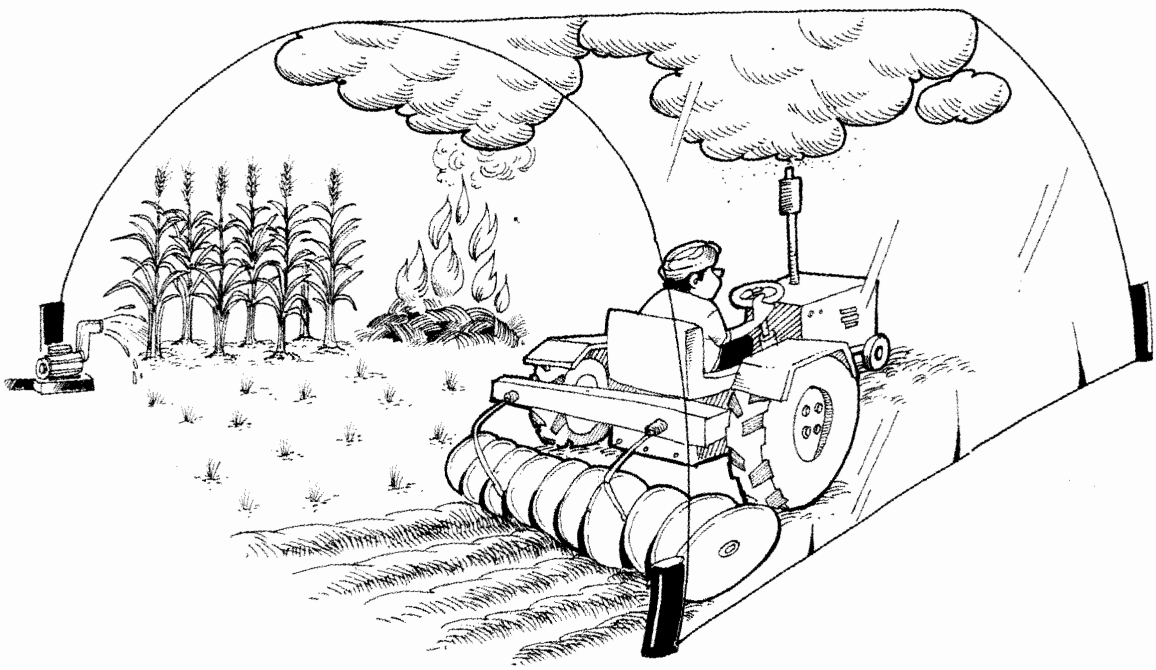
Rice-Wheat Systems and Climate Change



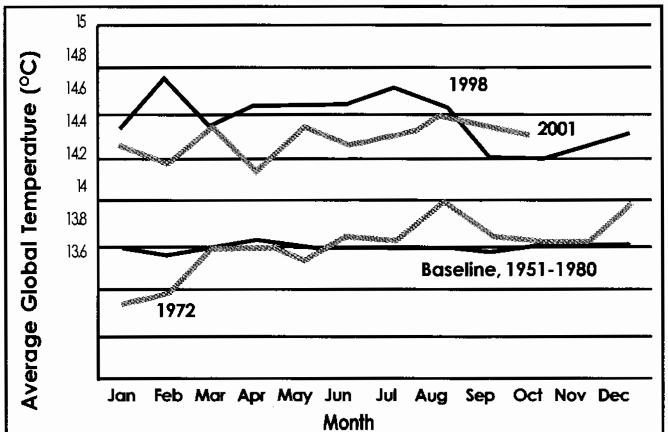
The effect of climatic changes on productivity and production in a rice-wheat system is generally accepted. What has not received sufficient attention is the effect of the rice-wheat system on local and global climate changes. A shift to, or intensification of, rice-wheat systems in the Indo-Gangetic Plains has resulted in seasonal wet and dry crop cycles, a heavy reliance on irrigation and an increased fertilizer usage accompanied by indiscriminate burning of crop residues. The emission of greenhouse gases CO_2, CH_4 and N_2O in rice-wheat systems and other environmental concerns associated with foodgrain production now beg for attention.

One Degree

An increase of temperature by 1°C in the Indo-Gangetic Plains would be equivalent to a 150 km Northward shift of isotherms (lines joining places with similar temperature) or about 150m lower altitude. There is a 5% decrease in rice yield for every °C rise above 32°C.

Inter-relationship of CO_2, Temperature and Yields

Long-term experiments in the region have shown that degradation of soil fertility has led to decline in yields of rice and stagnation in wheat production. In particular, soil organic matter decline has been of importance because it impacts on both soil fertility and soil structural stability. However, soil organic matter decline seems inevitable given the farmers' practices of burning virtually all crop residues and manure generated by livestock, fed thereon. Decline in soil structure compounds yield decline due to nutrient deficiencies. Addition of 15t/ha/annum of organic inputs (farmyard and green manure) in conjunction with NPK fertilizers consistently increased yields of wheat compared to NPK fertilizers alone in a 20-year experiment, but rice yields declined regardless. The role of tillage under warm, wet conditions in fostering rapid soil organic matter loss and the consequences for CO_2 emissions into the atmosphere also needs to be taken into account.



1972: A sample year within the baseline period
1998: The hottest year on record

Higher atmospheric CO_2 content increases grain yields. However, wheat yields are unlikely to increase by more than 10% for double pre-industrial CO_2 levels, even under optimal field conditions, because of decreased crop duration (and hence yield) as a consequence of warming. A 5% to 7% increase in wheat yields is more likely under average management conditions. The prognosis for rice is even worse. Spikelet sterility is caused when temperature exceeds 32^{0}C at flowering. There is a reduction in yield of about 5% per ^{0}C rise above 32^{0}C. This is unaffected by, and may even offset the benefits of, an elevated CO_2 level.

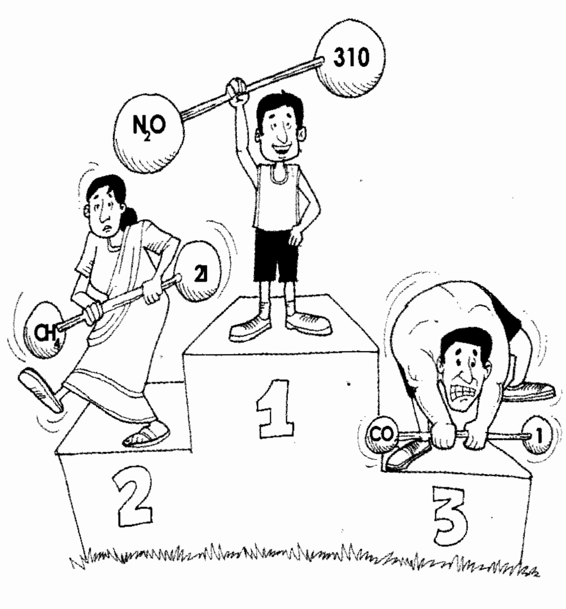
<u>Global Warming Potential</u>

Global Warming Potential (GWP) is used to compare with CO_2 the relative effectiveness of each greenhouse gas (GHG) to trap heat in the atmosphere.

GWP of common GHGs.

CO_2	Carbon dioxide	1
CH_4	Methane	21
N_2O	Nitrous oxide	310

Different gases last for different lengths of time in the atmosphere. GWP is based on a 100-year time horizon. Although present in lower concentrations, N_2O is a very potent GHG as 1kg N_2O is equivalent to 310 kg CO_2.



Sources of Greenhouse Gases

Rice-wheat systems produce greenhouse gases through both biological processes and burning of fuel by farm machinery.

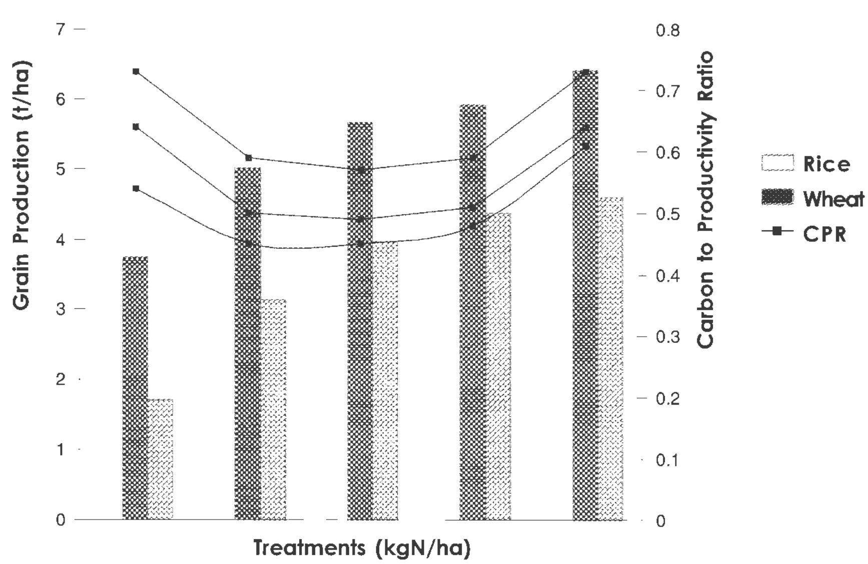
Carbon Dioxide

Tillage operations contribute CO_2 through the rapid organic matter decomposition due to exposure of larger surface area to increased oxygen supply. Experiments in Mexico have shown that tillage almost doubles the rate of decline in soil organic carbon levels in the top 20cm of soil. Every liter of diesel fuel used by tillage machinery and irrigation pumps also contribute 2.6kg CO_2 to the atmosphere. Thus, nearly 400kg CO_2 would be generated per hectare assuming an annual use of 150 litres diesel in the conventional rice-wheat system. For the 12 million ha, this would amount to 4.8 Mt CO_2 per annum or 1.3 MMTCE. This is one third the value (4 MMTCE) of CH_4 from ricefields. Diesel use remains greatly an underestimated source of GHG.

The presence of nitrogen (N) enhances microbial decomposition and release of CO_2. An important off-site source of CO_2 is the production of N fertilizers. For every kilogram of N fixed in fertilizer 1.8 kg CO_2 is the by-product. It is presumed that CO_2 generated by burning crop residues will be taken up by the following crop.

Carbon to Productivity Ratio

To assess how environmentally efficient the various productions systems are with respect to GHG emission and how much food is actually placed on the table, a Carbon to Productivity Ratio (CPR) is an ideal measure. CPR the value obtained by dividing the total annual on-site GHG emissions stated as Carbon Equivalents (CE) by the total annual food production in that area. Yield data of a long-term experiment at Pantnagar with NPK fertilizers at 50, 100 and 150% of the recommended dose when analyzed after constructing annual GHG budgets individually for CO_2, CH_4 and N_2O indicated that CPR values of 0.45 to 0.48 were possible with zero tillage and retention of crop residues at all three levels of N fertilizer use as against 0.54 for control, i.e., without fertilizer. However, with conventional tillage practices and burning of crop residue the CPR values were between 0.57 to 0.73 showing a higher level of ineffectiveness in the production system. The lower the CPR, the more efficient the system is at producing food with respect to the health of the global environment.



Carbon to Productivity Ratio at Various Levels of Nitogen and Production of Rice and Wheat Over 20 Years

Treatment N Fert/Crop Kg/ha	Production			Carbon Equivalents (CE)			Carbon to productivity ratio		
	Rice (t/ha)	Wheat (t/ha)	Fodder (t/ha)	C/RR	C/BR Kg C emitted	Z/RR	C/RR	C/BR	Z/RR
0	3.74	1.71	1.86	3496	3953	2966	0.64	0.73	0.54
60	5.02	3.13	1.93	4103	4774	3646	0.50	0.59	0.45
120	5.67	3.97	2.36	4721	5510	4362	0.49	0.57	0.45
180	5.92	4.38	2.32	5232	6086	4981	0.51	0.59	0.48
120+	6.41	4.60	2.47	7137	8032	6724	0.64	0.73	0.61

120+ - 120 kg N + 15 + FYM
C - Conventional tillage
RR - Retained residues of crop
Z - Zero tillage
CPR - Carbon to productivity ratio
BR - Burn residues

Methane

Methane is produced by fermentation, i.e., anaerobic decomposition of organic matter reducing CO_2 to CH_4. The continuously flooded rice fields produce CH_4 due to their anoxic conditions and rice plants serve as conduit for its release to atmosphere. Multilocational experiments in five countries studied CH_4 production in irrigated, deepwater and rainfed rice ecosystems. Irrigated rice fields had the highest CH_4 emission rates that also showed seasonal variations. Rainfed rice showed less than half of the emission from irrigated fields. The CH_4 emission rate can be greatly reduced by single or multitude aeration of fields instead of continuous flooding. In 12 million ha of rice-wheat in the Indo-Gangetic Plains about 0.7 Mt of CH_4 per year (or 4 MMTCE/annum) is produced by rice cultivation. This is primarily due to low organic carbon levels in this region.

The burning of crop residues contributes about 0.14 Mt of CH_4 (0.8 MMTCE/annum) assuming that half of the crop residues produced at the rate of 10t/ha (rice and wheat) in the 12 million ha are burnt. This is equivalent to 20% of the total CH_4 emitted from paddy fields in the same area.

IGP A-L-E-R-T

- The Indo-Gangetic Plains (IGP) occupy one-sixth of South Asia's geographical area, hold nearly 42% of its population and produce more than 45% of its food.
- Rice-wheat is grown on more than 12 million ha and provides livelihood for millions in the IGP.
- Observations suggest that during the 1990s the atmospheric abundance of almost all greenhouse gases (GHG) reached their highest values in recorded history. According to recent estimates by IPCC, by 2100 A.D., the average global surface temperature is projected to increase by 1.4 to 3°C above 1990 levels for low emission scenario of GHG and between 2.5 to 5.8°C for higher emissions.
- By using no-till (zero-tillage) and other soil conservation practices that preserve crop residue, farmers can help reduce GHG emission and curb global warming.
- Water and agriculture sectors are likely to be most sensitive to climate change in South Asia.
- Increasing demand for waters by competing sectors may limit the viability of irrigation as a sustainable adoption to climate change.

Source M.Lal, IIT, New Delhi

Nitrous Oxide

This gas is released even from soils to which no nitrogen containing fertilizer has been applied. Destruction of the ozone layer due to N_2O is an important consideration beyond the concern for nitrogen losses from applied fertilizers and manures. Experiments have shown that both the processes of nitrification and denitrification contribute to the release of N_2O from the soils into the atmosphere.

The N_2O production is greatly affected by soil water content. Water creates anaerobic conditions by slowing down the diffusion rate of oxygen by ten thousand times. Generally, an increase in denitrification and potential N_2O losses is observed following irrigation or rain in aerobic or partially aerobic soils. Rice paddies are not considered to be an important source of atmospheric N_2O because it is further reduced to N_2 under strong anaerobic conditions due to standing water. N_2O flux increases sharply due to draining of the fields at mid-tillering stage.

The burning of crop residue produces 40g N_2O/t. Assuming as before that half of the 10t/ha crop residue produced on 12 million ha is burnt, then 2000 tons of N_2O (about 0.2 MMTCE/annum) is released into the atmosphere. This is almost a quarter of the value derived in terms of CH_4 from the same process.

Reducing Greenhouse Gases

Positive changes in agronomic practices like tillage, manuring and irrigation can help reduce greatly the release of greenhouse gases into the atmosphere. Adoption of zero tillage and controlled irrigation can drastically reduce the evolution of CO_2 and N_2O. Reduction in burning of crop residues reduces the generation of CO_2, N_2O and CH_4 to a significant extent. Saving on diesel by reduced tillage and judicious use of water pumps can have a major role to play. Changing to zero tillage would save 98 liters diesel per hectare. With each liter of diesel generating 2.6 kg, about 3.2 Mt CO_2/annum (about 0.8 MMTCE) can be reduced by zero-tillage in the 12 million ha under rice-wheat systems in the Indo-Gangetic Plains alone. Intermittent irrigation and drainage will further reduce CH_4 emission from rice paddies by 28% to 30% as per the findings at IARI (Delhi) and at Pantnagar.

Use of calcium nitrate or urea instead of ammonium sulphate and deep placement instead of surface application of nitrogenous fertilizers can increase its efficiency and plant uptake thereby reducing N_2O emission.

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Adapted from:

Grace, P. R., M. C. Jain and L.W. Harrington. 2003. Environmental Concerns in Rice-Wheat Systems. pages 99-111. *In:* Proceedings of the International Workshop on Development of Action Program for Farm-level Impact in Rice-Wheat Systems of the Indo-Gangetic Plains. 25-27 September 2000. Rice-Wheat Consortium Paper Series 14. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

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Peter R. Grace

Carbon Sequestration in Soils of the Indo-Gangetic Plain

The Indo-Gangetic Plain (IGP) of India, with about 13% geographical coverage, produces nearly 50% of the food grains for 40% of the total population of India. However, recently, there has been a general decline in soil fertility. Soils which earlier showed rarely single nutrient deficiency symptoms are now deficient in many nutritional elements. Long-term soil fertility studies have shown reduction in soil ogranic matter content, particularly in soils that had higher levels in earlier years (Abrol and Gupta, 1998).

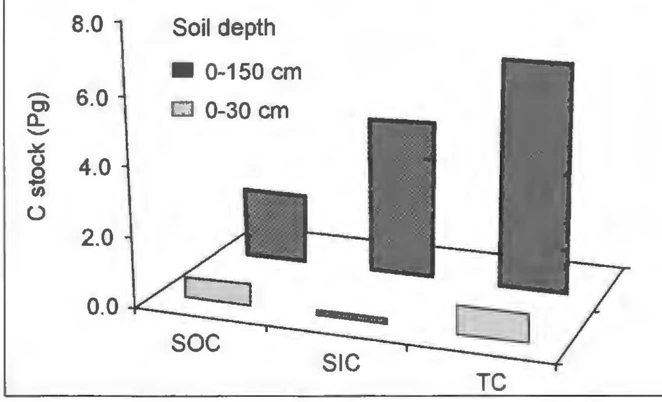
The process of natural chemical degradation in soils of the semi-arid parts of the IGP is also proceeding at a fast rate. Attemps to increase and stabilize yields in arid regions by extension of irrigation, therefore, may fail if adequate care is not taken to prevent the menace of formation of calcium carbonate ($CaCO_3$). The biology of soils has been gradually eroding resulting in reduced efficiency of applied inputs as a consequence of current aridic environments in parts of the IGP. Hence, the soils of the IGP of the Indian subcontinent require immediate attention for better carbon management.

Organic and Inorganic Carbon Stock

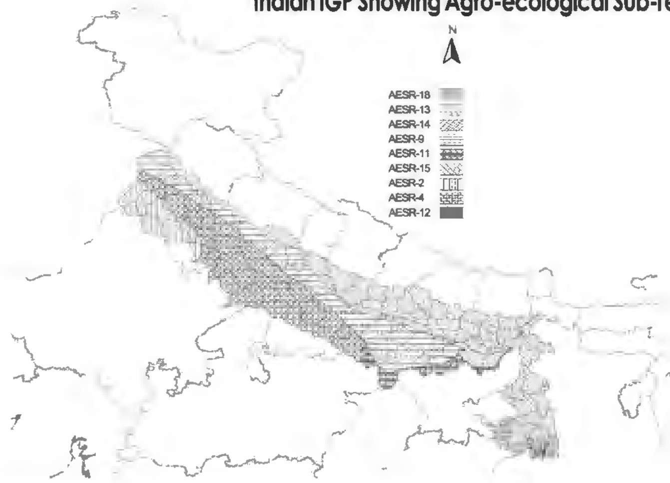
High calcareous IGP soils in aridic and semi-aridic ecosystem contain low SOC.

The total carbon stock includes soil organic carbon (SOC) and soil inorganic carbon (SIC). In India, the agro-ecological regions (AERs) 4 and 13 (hot, semi-arid and hot subhumid, moist) have the highest carbon stock followed by AERs 2, 9 and 15 (hot arid, hot subhumid, dry and hot subhumid, moist to humid) (Bhattacharyya *et al.*, 2001). The contribution of SOC stock in the overall total carbon stock decreases from 83% at 30cm soil depth to 30% at 150cm depth while the SIC stock increases. The areas under arid and semi-arid climate cover about 38% of the IGP. This climate induces decomposition of SOC but favors the accumulation of SIC, indicating an inverse relation between these two forms of carbon.

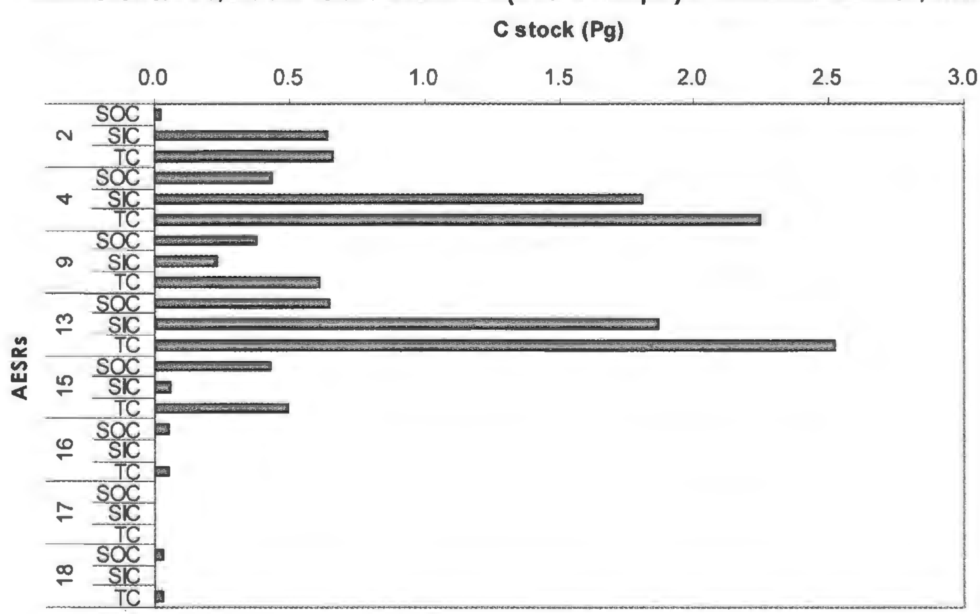
SOC, SIC and Total Carbon Stock in IGP, India



Indian IGP Showing Agro-ecological Sub-regions



Distribution of SOC, SIC and Total Carbon in Soil (0-150 cm depth) in Different AESRs of IGP, India



Carbon Removal and Restoration

High accumulation of SOC is related to vegetative cover supported by high rainfall. This is observed in the eastern part of the IGP under humid to perhumid AER. However, due to intensive agricultural practices, these areas have become impoverished in SOC over time. The cooler humid, and humid to perhumid climate is the most conducive situation for soils to be enriched in SOC as in Mollisols of the sub-Himalayan region, and in Central and Western India. This suggests that there is a greater scope of organic carbon sequestration of soils under semi-arid and humid tracts of the IGP.

Continuous application of farmyard manure and green manure in rice-wheat cropping system in sodic soils of the IGP has improved the organic carbon status substantially. The sequestration of organic carbon in these soils is also possible not only through agricultural practices but also through agroforestry and silviculture. The sustainability ratings of some soil series of the IGP for the rice-wheat cropping system indicate many soil constraints including low SOC.

Suitability of Different Soils for Rice and Wheat in the IGP, India

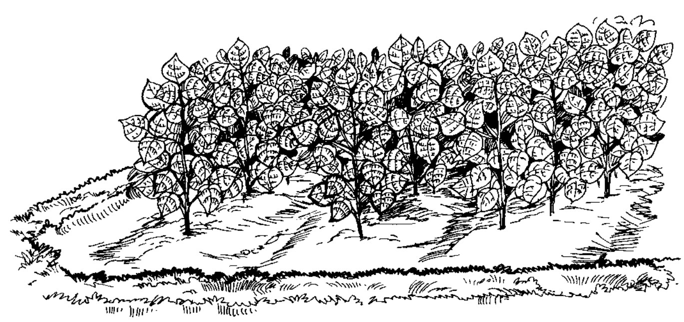
AESR	Soil series	Rice	Wheat	AESR	Soil series	Rice	Wheat
2.1	Masitawali	S3sw	S2s	9.2	Basiaram	S2S1	S1
	Nihalkhera	S3sw	S2s		Itwa	S2S1	S1
2.3	Jassi Pauwali	S2sw	S3sw		Simri	S2S1	S2w
	Jodhpur Ramana	S3sw	S2sw		Akbarpur	N1n	N1n
4.1	Fatehpur	S3s	S3s	13.1	Bahraich	S2S	S2w
	Phaguwala	S2s	S3	13.2	Haldi	S2S1	S1
	Zarifa Viran	N1n	N1n	15.1	Sasnaga	S2S1	S2w
	Ghjabdan	N1n	N1n		Konarpara	S2S1	S2w
4.3	Bijapur	S2s	S1		Hangram	S1	S2w
	Hirapur	N1n	N1n		Amarpur	S1	S2w
	Sakit	N1n	N1n		Modhupur	S1	S2w
9.1	Dhoda	S2sw	S1	15.3	Barak	S2S1	S1s
	Jagitpur	S3sn	S3n		Seoraguri	S1	S2w
	Bhanra	S3sw	S3sw	16.1	Singivila	S2S1	S2s
	Berpura	S2S1	S1	18.5	Sagar	S1	S2w

S1 = Suitable
S2 = Moderately suitable
S3 = Marginally suitable
N1 = Presently unsuitable but can be improved
s = Soil-related constraints (texture, structure, $CaCO_3$ content, depth and low organic carbon)
w = Wetness-related constraints (flooding and drainage)
n = Constraints related to salinity and alkalinity

Source: Velayutham *et al.* (1997)

Organic and Inorganic Carbon Equation

The SIC in the form of $CaCO_3$ is virtually immobile due to its insolubility in alkaline soil in arid and semi-arid environments. Therefore, this SIC stock is a source of available calcium for plants. By improving vegetative cover, these soils could be ameliorated with two-fold gains. Firstly, the vegetation itself will sequester soils with organic carbon and secondly, dissolution of $CaCO_3$ through root exudates, will improve soil drainage with better soil structure.



Perspective

The present scenario of temperature and shrinking of annual rainfall in the major geographical area of the IGP will continue to remain as a potential threat for soils of the region. The knowledge of SOC and SIC stock can, however, help in focusing areas of immediate rehabilitation for improving SOC. But the carbon stock equation vis-à-vis the cause-effect relationship of the various factors controlling both SOC and SIC stock in the IGP should be considered. Based on this, restoration of SOC balance and its follow up by enlarging the soil carbon pool by appropriate management techniques should form the strategic perspective for soils of the IGP.

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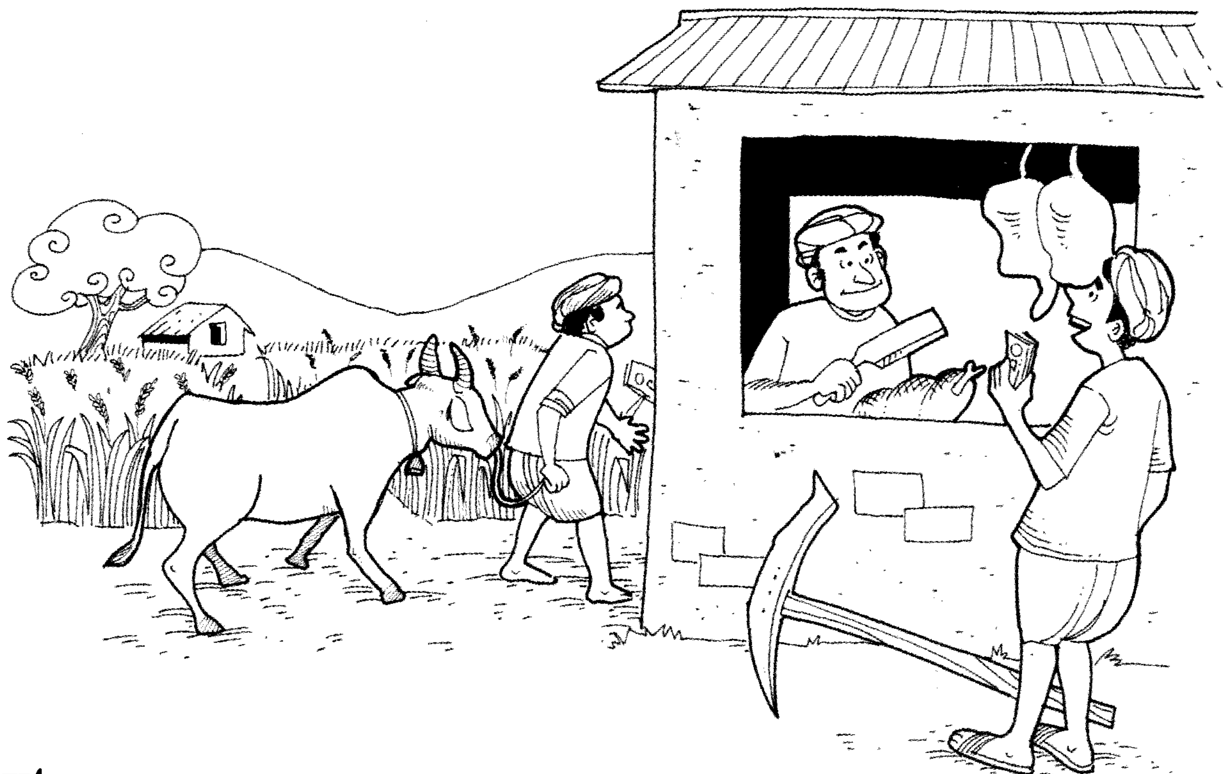
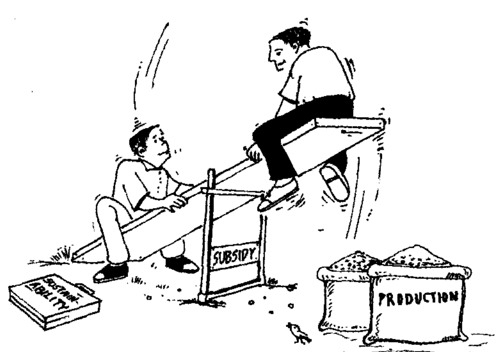
Contributed by:
T. Bhattacharyya and **D. K. Pal**

Major Trends in the Rice-Wheat System in Pakistan's Punjab



The introduction of Green Revolution technologies in Pakistan's rice-wheat systems during the mid-1960s produced impressive results in reversing the food crisis as well as stimulating the economic growth in agriculture, particularly in the Punjab Province. Land under cultivation increased by a mere 0.7% annually from 1966 and the increased production was primarily triggered by changes in technologies like fertilizers, mechanization, seed of high-yielding varieties, and superior livestock breeds. Changes in cultivation technology also had its impact on the livestock, both quantitatively and qualitatively. The sustainability of the various practices, however, needs to be considered.



Two-way Changes

Intensification strategies and high doses of external inputs in the agricultural sector heralded a bright new dawn through the Green Revolution. Food shortages decreased while agricultural growth received a boost in the mid-1960s and 1970s. Could this be sustained? The very same factors that contributed to the success, *vis a vis* intensification and external inputs, show indications that they have led to degradation of the resource base and now there is growing evidence of a slowdown in productivity growth.

Changes in the Crop Sub-sector

Pakistan's Punjab Province, with a farming population of over 60 million, has assured irrigation for over 80% of its cropped area through a network of canals and tubewells. It is known as Pakistan's bread basket as it is the center of production of wheat and rice, which form the staple diet of its populace.

Technology

Technological change was triggered by the introduction of new varieties of wheat in 1966. By 1983, almost all the wheat-growing area was covered with these modern varieties. The technological innovations in the high-valued, aromatic Basmati rice, mainly for the export purpose, initiated with the release of Basmati 385 in 1985, which was rapidly adopted (Sharif *et al.,* 1992). New high-yielding cotton varieties gained acceptance only in the post-Green Revolution period (1985-1994). Fertilizer use jumped more than sixty fold in less than 30 years from 1.5 kg of nutrient per hectare in 1966 to 94 kg per hectare in 1994.

Irrigation

Irrigation water from tubewells is the lifeblood of the rice-wheat system in the Punjab. Timely availability of irrigation water in adequate quantities has been possible through investment in privately-owned tubewells. Per hectare quantities of water from canals available for crop irrigation has decreased both in absolute terms and in relation to groundwater use.

Changes in Contribution of Irrigation Water from Tubewells and Canals in Pakistan's Punjab

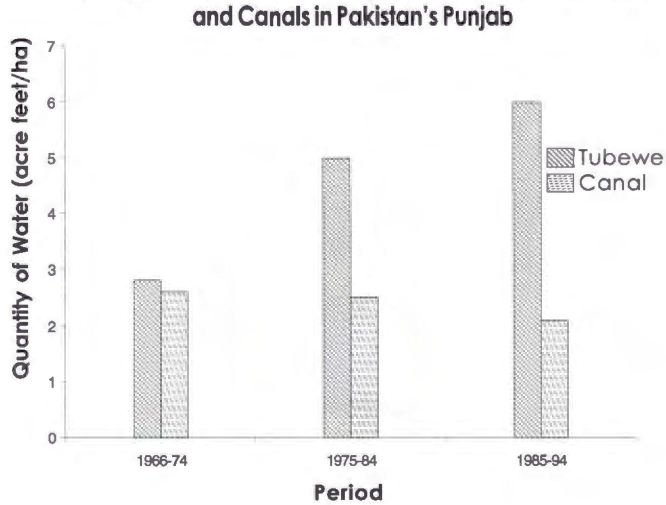


Table 1. Fertilizer and Water Use Trends									
Crop System	Fertilizer Nutrient kg/ha			Water (Acre feet/ha) Tubewell			Canal		
	1	2	3	1	2	3	1	2	3
Wheat-Mungbean	6.1	26.0	49.1	0.6	1.4	2.0	3.5	3.2	2.9
Wheat-Mixed	14.1	46.0	76.0	1.1	1.9	2.5	4.9	4.6	4.2
Wheat-Rice	12.3	44.8	64.7	2.8	5.0	6.0	2.6	2.5	2.1
Wheat-Cotton	18.5	62.3	120.3	1.5	2.4	2.6	5.9	5.4	4.8
Punjab Average	14.1	48.3	86.1	1.4	2.5	3.0	4.7	4.3	3.9

1 = Green Revolution Period (GRP) 1966–1974
2 = Input Intensity Period (IIP)1975-1984
3 = Post Green Revolution Period (PGR) 1985-1994

Labor

Labor use and labor wages saw major changes due to the Green Revolution. Intensification increased the demand for labor from 71 labor days per hectare in 1966 to 108 labor days in 1977, representing an increase of 40% in just 12 years. The increased demand, coupled with alternative employment opportunities in the affluent Middle East, pushed the wages high enough for the farmers to consider other options.

Mechanical Power

Mechanization of agricultural operations reversed the trend of labor use. From a peak of 108 labor days in 1977, the requirement dropped to just 63 labor days per hectare in 1994 i.e., almost 10% below the 1966 level. Mechanization also decreased the use of bullocks from 82 days per hectare in 1966 to just six days in 1994. During this period, the use of mechanical power (tractor, harvester, thresher) increased from less than one hour per hectare to 17 hours.

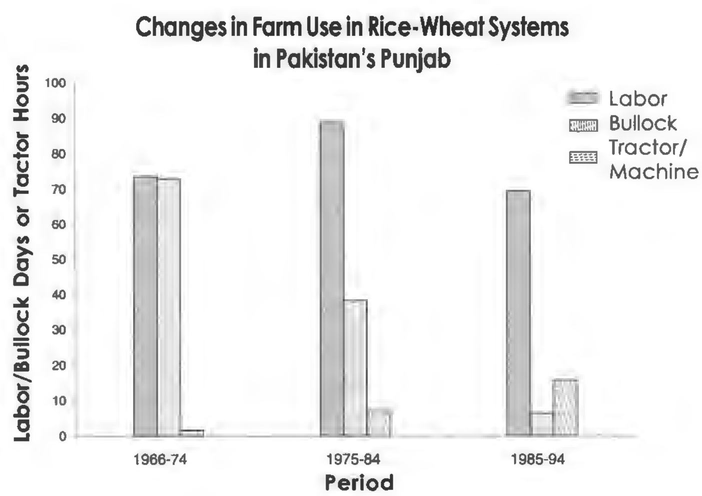


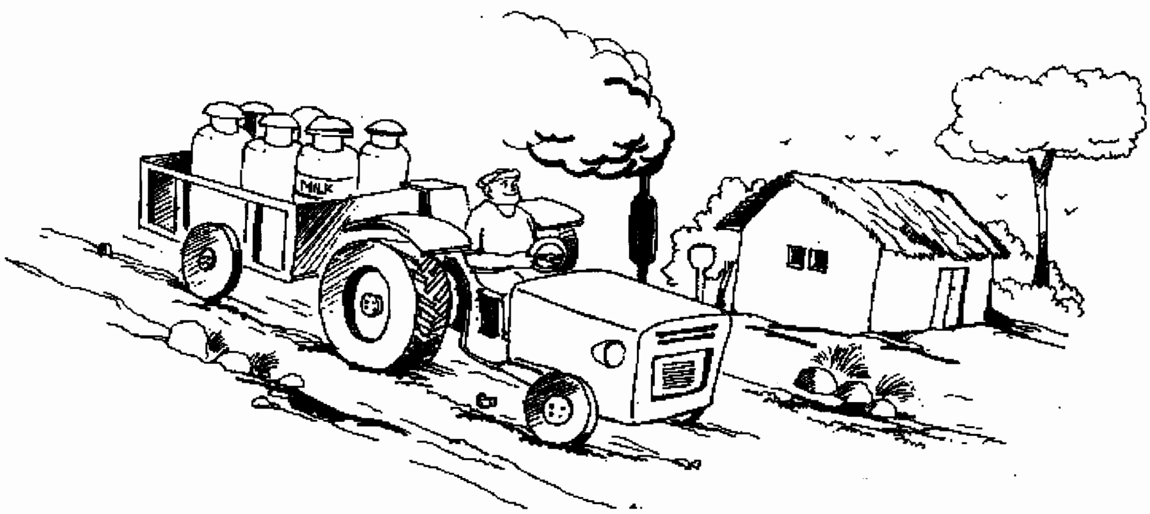
Table 2. Farm Power Sources (per hectare)

Crop System	Labor (days)			Bullock (days)			Machine (hours)		
	1	2	3	1	2	3	1	2	3
Wheat-Mungbean	82.4	86.4	62.6	83.8	45.8	8.0	0.8	2.6	9.1
Wheat-Mixed	89.5	108.4	84.6	74.4	45.6	10.8	1.4	6.0	14.7
Wheat-Rice	73.6	88.7	69.4	72.9	38.1	6.5	1.6	7.1	15.7
Wheat-Cotton	87.2	100.7	65.8	85.4	49.6	7.7	1.7	6.4	17.3
Punjab Average	85.0	98.7	71.1	79.6	45.8	8.5	1.5	5.7	14.8

1 = 1966-1974
2 = 1975-1984
3 = 1985-1994

Intensification

The introduction of short-duration modern varieties of major crops, supported by increased water availability, triggered double crop cultivation on the same land. This, coupled with increased use of fertilizers, contributed to the highest yield gain during the Green Revolution period. The yields of all crops in the province increased at an average rate of 1.8% per annum, led by wheat and cotton. The production increased at a rate of 3.8% per annum during the Green Revolution period (1966-1974) and then slowed down to 2.8%. The average rate of increase in production during 1966-1994 was 3.3% for all crops. After the release of new, early-maturing mungbean and high-yielding cotton varieties in the post-Green Revolution period (1985-1994), the growth in wheat-cotton and wheat-mungbean systems was double that of wheat-rice system.



Soil Deterioration

Soil organic matter content which was already low in the 1970s got worse and showed a decline at the rate of 2.4% per annum. Available phosphorus has decreased in all the four systems. The total soluble salts increased significantly during this period in all of the four cropping systems and soil reaction or pH increased in two of these systems indicating an increase in salinity and alkalinity of the soil.

Water Quality

Electro-conductivity of tubewell water shows drastic increases at a rate of 1.3% per annum in all the production systems. Residual carbonate (RSC) doubled during the study period reflecting the common observation that the tubewells are increasingly yielding low quality ground water. Steady decline in the contribution of canal water to crop irrigation is a disturbing trend.

Effects on Livestock

Mechanization of farm operations dramatically reduced the need for bullocks from 82 days per hectare in 1966 to just six days per hectare in 1994. This led to the increase in meat production due to the slaughter of bullocks and male calves. Bullock population was increasingly substituted by milch cows and buffaloes leading to a spurt in milk production. With increased availability of fodder, the number of animal units increased at a rate of 1.5% per annum.

Conclusions

Green Revolution has ushered in a better life for the millions of people living in Pakistan's Punjab. It has not only increased production of food grain and cotton but also triggered increases in livestock, meat and milk. The Green Revolution, however, also resulted in high irrigation water and fertilizers being used at higher levels having deleterious effects on soil and groundwater quality and thereby raising disturbing questions about the future.

There are several reasons to believe that the resource degradation is not internalized to producer decision making and that policy intervention is necessary. Distorted policies have led private and social costs to diverge, e.g., fixed annual energy charges have led to overuse of low quality tubewell water, a major contributor to soil salinity. Public-sector research has been biased towards developing technologies based on packages of modern inputs neglecting sustainable practices like integrated crop management. Removal of price distortions and a focus on diversification and sustainability are opportunities that must seriously be considered.

Adapted from:

Ali, M. and M. Byerlee. 1999. Technological Change and Productivity in Pakistan Punjab: Economic Evidence. pages 78-95. *In:* Pingali, P.L.(ed). 1999. Sustainaing Rice-Wheat Production Systems: Socioeconomic and Policy Issues. Rice-Wheat Consortium Paper Series 5. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

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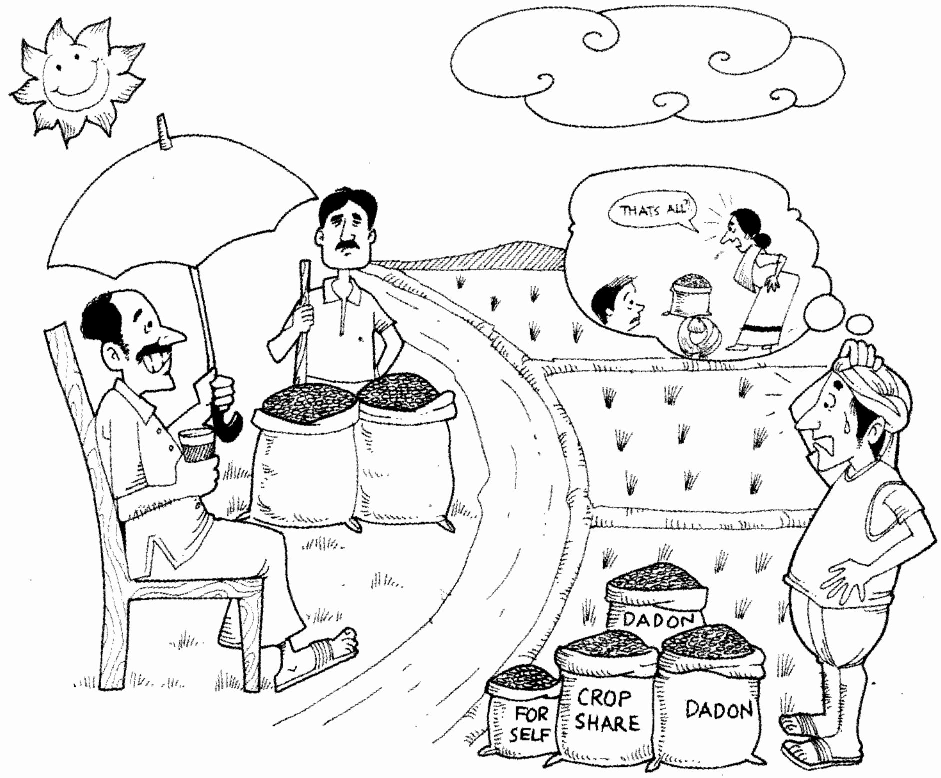
Socioeconomic Constraints in Rice-Wheat in Chuandanga, Bangladesh



When the national policies do not properly address the issue of sustaining the production of staple foodgrains i.e., rice and wheat, it gives rise to socioeconomic problems even at the sector and farm level. Modernization, and a shift from subsistence agriculture to a commercial production system, involves higher investments and greater risks, both in terms of physical crop loss and output price risk. A household survey was conducted in the rice-wheat system in Chuadanga, Bangladesh, where wheat production mainly came through area expansion at the expense of minor dry season crops such as oilseeds and pulses.

Based on field observations and discussions, the farmers' perception of the ten main constraints to sustainability of the rice-wheat system was assessed. Two ranking criteria were used to prioritize the problems:

- percentage of farmers affected by the given problem; and
- the frequency of the problem's occurrence.

The product of the two criteria was obtained to arrive at a cumulative value for each of the ten constraints. Higher value of cumulative score indicated higher priority perception.

Headstart
A successful production program requires, apart from modern variety (MV) seeds and improved production technologies, a satisfactory delivery system of inputs and positive but effective pricing and marketing policies for the output (Hossain, 1991).

Socioeconomic Constraints to Rice-Wheat Systems Sustainability in Chuadanga, Bangladesh				
Constraints	% farmers affected	Frequency x % farmers affected	Cumulative Value	Rank
Low-output price	84.6	119.3	203.9	1
High-input cost	80.8	103.9	184.7	2
Lack of draft power	80.8	96.2	177.0	3
Non-availability of inputs	73.1	77.0	150.1	4
Shortage of labor	65.4	65.4	130.8	5
Lack of extension service	46.2	80.9	127.1	6
Non-availability of credit	38.5	65.8	104.3	7
Non-availability of fuel	46.2	50.1	96.3 8	
Land tenancy	38.5	36.2	74.7 9	
Irrigation water	19.2	23.1	42.3 10	

Source: Primary level information collected by the authors (Islam, *et al*., 1999)

High-Input and Low-Output Prices

The farmers argue that the twin constraints of low output (grain) prices coupled with high prices of inputs like fertilizers are the main hindrance to increasing the area under wheat cultivation. An effective procurement policy, including fixing of a reasonable procurement price and designation of procurement agencies, is of utmost importance.

Rural Credit

The primary source of rural credit is the village money lender or *Mohajan*. The loan repayment system or *dadon* involves an agreement to sell grain to the money lender at a lower price at harvest time. Loans provided by non-government organizations (NGOs) are unsuitable to the farmers because of their recovery system of weekly instalments after loan disbursement and a high (22%-30%) interest rate. Rural banking services are currently not available to these farmers.

Key Concerns

- Inequitible distribution of land and dependence on share-cropping.
- Lack of rural credit leading to prevalence of *dadon* system.
- Absence of support price and procurement policy for rice and wheat.
- Unstable marketing system.
- Non-availability of seeds and fertilizer in time.
- Inadequate storage facilities for seed.

Sharecropping System

More than half of the rural farm families are landless and dependent on sharecropping for their livelihood. Due to the intense competition for cultivable land among landless sharecroppers, the share of inputs to be provided by the land owners is reduced or completely eliminated. Often, the landless sharecroppers cannot shoulder the burden of high input costs of *boro* rice or wheat cultivation and face the risk of low grain prices or crop loss due to natural calamities like floods and cyclones which are not uncommon in Bangladesh. The shift to less capital-intensive crops like maize, oilseeds and pulses is inevitable.

Input Distribution

The shift from subsistence to commercial agriculture necessitates inputs like modern variety seeds, chemical fertilizers, pesticides, etc. which, unlike cowdung and other organic matter, are not locally produced. The privatization of fertilizer distribution has resulted in malpractices with a view to higher profits. High-value phosphoric acid based fertilizers are most susceptible to misbranding. Single Super Phosphate (SSP) is labelled and sold as Triple Superphosphate (TSP), leading to a higher input price and lower productivity. Non-availability of both seeds and fertilizers is a common complaint.

Adapted from:

Islam, M. R., M. Hossain and S.I. Bhuiyan. 1999. Socioeconomic and Policy Issues Constraining the Sustainable Rice-Wheat System in Bangladesh. pages 29-42. *In:* Pingali P.L. (ed). 1999. Sustaining Rice-Wheat Production Systems: Socioeconomic and Policy Issues. Rice-Wheat Consortium Paper Series 5. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

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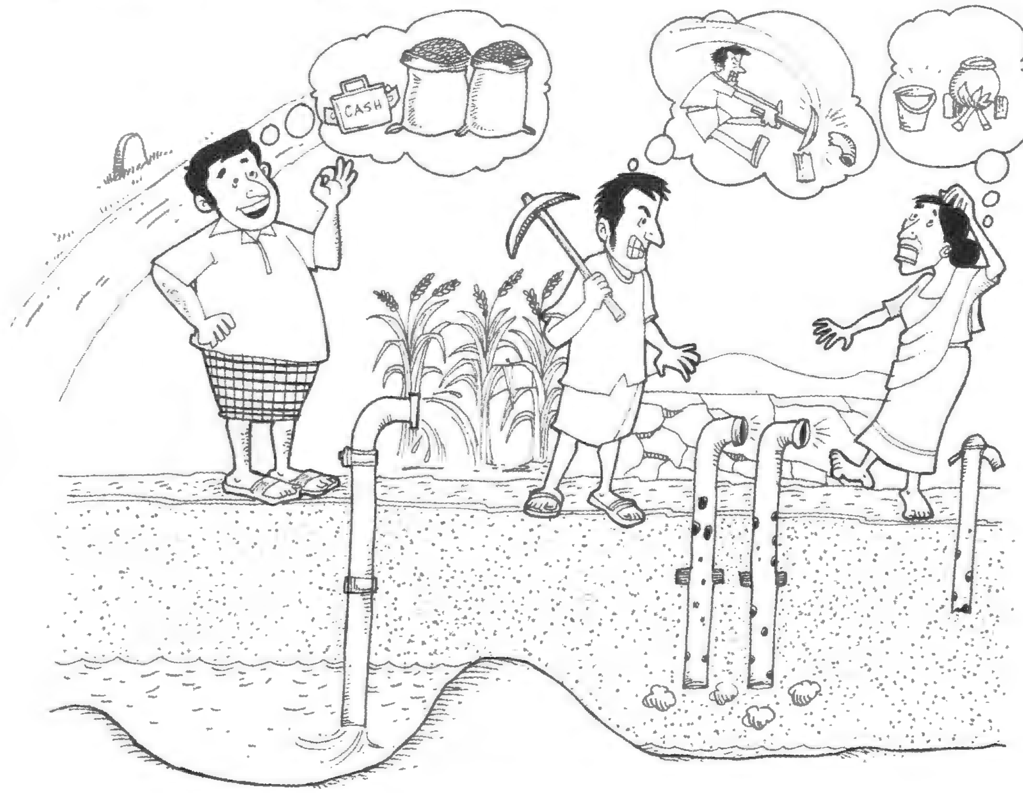
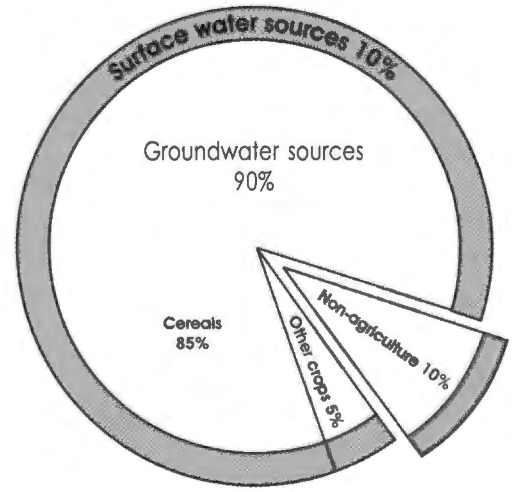
S.I. Bhuiyan

Water Resource Management Policy in Bangladesh



About 40% of all agricultural lands have access to irrigation water, with 90% of this water being derived from groundwater sources mostly through tubewells in the private small-scale sector. The policy of privatization for this critical input and scrapping of taxes on equipment import has encouraged the installation of pumps in what is commonly referred to as the "tubewell revolution". Consequently, the limits of safe withdrawal of groundwater have been crossed in many areas. The true extent of long-term economically, environmentally and socially sustainable groundwater withdrawal is yet to be determined (Bhuiyan, 1995).

Sources and Utilization of Water Resources in Bangladesh



Sources
Groundwater: 90%
Surface Water: 10%

Utilization
Crops: 90%
Non-agriculture: 10%

Sustainable Development of Irrigation

Even considering that there are areas where unsustainable exploitation of groundwater has taken place, it is inevitable that the area under irrigation has to be increased from the present level of 40% for increasing cereal production in the foreseeable future.

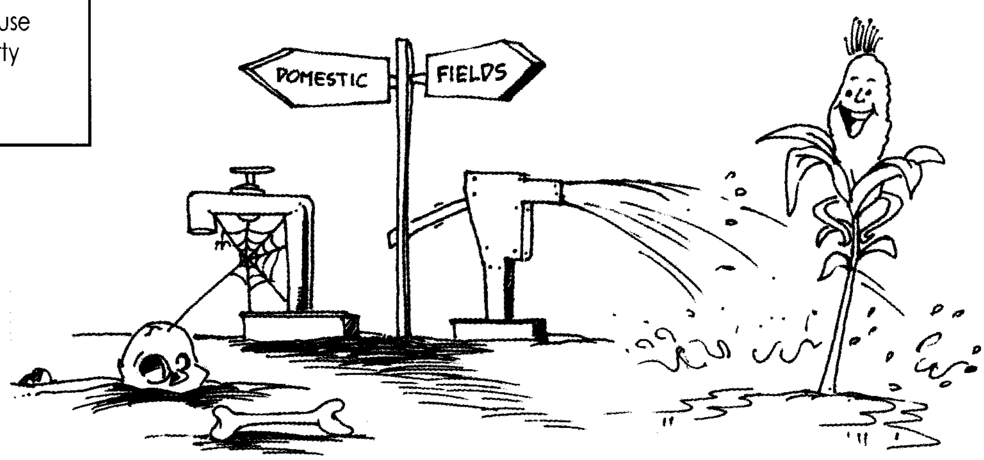
Common Property Resource
Estimates of potentially irrigable areas that could be supported by groundwater are generally based on the concept of "hydrologically safe" withdrawals from aquifers. The aim of this estimation was to prevent irreversible lowering of the groundwater table.

Experience has shown that this estimation is not enough. Issues of environment, water quality, social equality, etc. must be adequately considered in planning groundwater development and its use as a common property resource. (Bhuiyan, 1995).

It is, however, clear that for sustainable increases in irrigation facilities, groundwater resources must be managed more scientifically and greater use of surface water resources must be encouraged through appropriate policies. Continuation of the current policy of allowing indiscriminate proliferation of tubewells cannot be sustained.

Social Implications of Water Policy

The proliferation of deep tubewells for irrigation of the remunerative *boro* rice has raised two major social concerns. Unbridled withdrawal of water for irrigation has created a drinking water crisis for the villagers dependent on shallow hand pumps causing a serious negative impact on the poor in rural society (Saddeque, 1996). There are also increasing concerns about the quality of groundwater and its impact on health of the people in Bangladesh.



Impact of Policy
A change in macroeconomic policy in Bangladesh to withdraw subsidies from irrigation sector, like in energy prices for pumps, and to privatize irrigation equipment led to the imposition of higher irrigation fees on small farmer users adversely affecting the profitability and sustainability of rice-wheat system.

Water Quality and Health

Groundwater that is used by the people for drinking and irrigation is recently reported to contain high concentrations of toxic arsenic in 70% of the 64 districts, mostly in the Gangetic flood plains. Many people have developed serious skin diseases from drinking the contaminated water and from extended contact with it in the irrigated fields. It is believed that arsenic content has increased to dangerous levels in these areas due to excessive lowering of the water table in the dry season for irrigation of *boro* rice.

Cropping Policy

Appropriate policy and package of incentives to promote the cultivation of wheat or directly seeded rice crop instead of transplanted or *boro* rice can lead to a significant saving in irrigation water during the dry season. Rice production in the dry season consumes much more water than does wheat. Combining direct seeding and choice of early-maturing rice variety can give the dual benefits of reduced water requirement and availability of land for timely planting of the wheat crop for higher total system productivity.

Policy Interventions

Sustainable development and management of water resources needs attention to issues at the farm level, irrigation system level and macro-policy level. The social and environmental implications of water use policy must be considered alongside the irrigation needs for boosting rice-wheat systems while framing such policy. Water management issues are increasingly becoming important as water availability for irrigation is getting scarce day by day. This has already led to disputes on sharing of river water.

Adapted from:

Islam, M.R., M. Hossain and S.I. Bhuiyan. 1999. Socioeconomic and Policy Issues Constraining the Sustainable Rice-Wheat System in Bangladesh. pages 29-42. *In:* Pingali P.L. (ed). 1999. Sustaining Rice-Wheat Production Systems: Socioeconomic and Policy Issues. Rice-Wheat Consortium Paper Series 5. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

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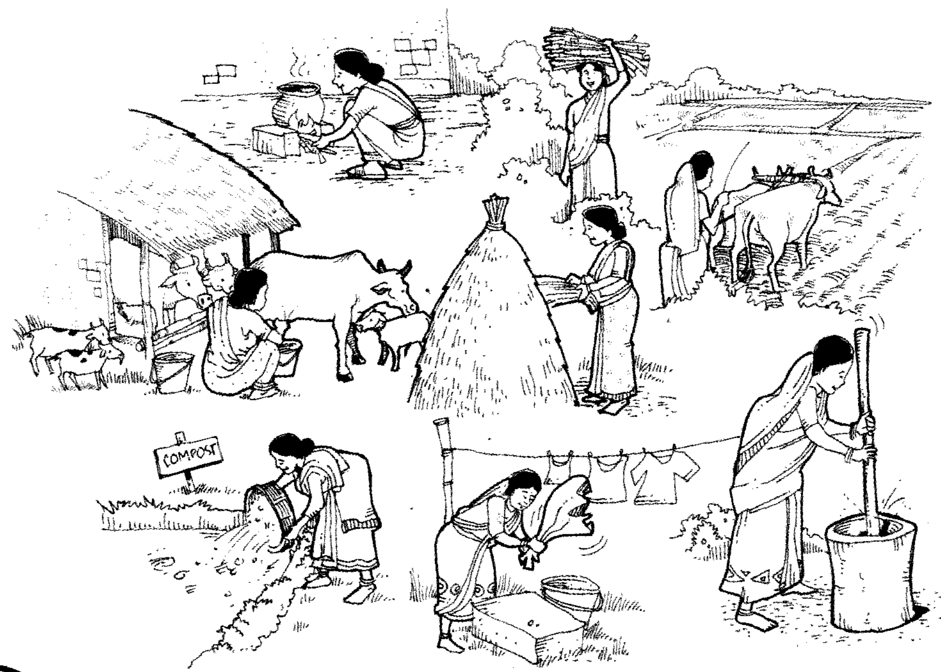
S. I. Bhuiyan

Gender Roles in Rice-Wheat Systems: A Case Study



During the Green Revolution era, the South Asian nations worked with the objective of maximizing food crop production to feed their hungry millions. Self-sufficiency, and even surplus production, in food grains has been achieved by some of these countries. However, the role of women in these food production systems is still a-begging for attention and possible recognition. One study of gender roles was carried out in the heartland of rice-wheat systems in Faizabad area of eastern Uttar Pradesh, India. The study was revealing.

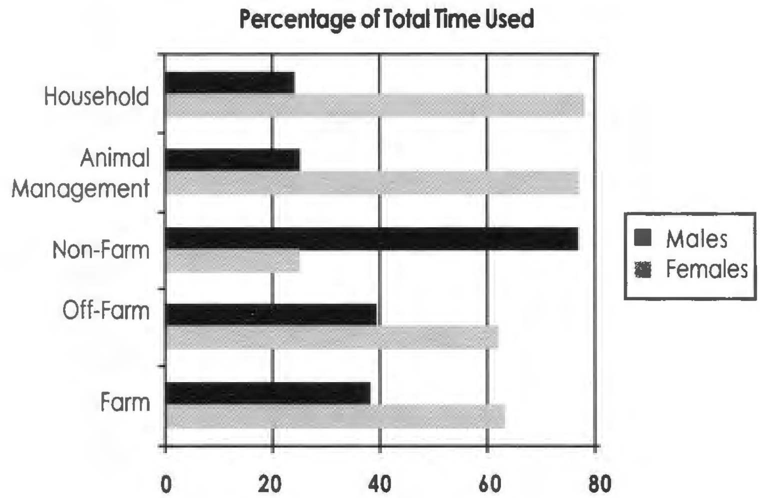
Target Population

The survey was carried out for 288 households spread over two villages, Chandpur and Mungeshpur, near Faizabad City. Rice and wheat were the predominant crops and accounted for 50%-60% of the total cropped land. Rice and wheat were also the staple food of the people in these two villages. Straw of both these crops was fed to the livestock, an important source of livelihood to the people. Landholding size was less than one hectare per household. Out of the 288 households surveyed, as many as 243 households (72%) owned less than 0.25 ha.

It is not surprising that, despite the importance of rice and wheat in terms of cropped area, the system's contribution to household incomes was very low. It was a mere 11% in Chandpur, the village nearer to the market town where households have greater access to other income-generating activities and 22% in the remote village of the Mungeshpur, where agriculture is the predominant source of livelihood. Non-farm income (52%) and livestock (27%) are the major sources of household income, particularly in Chandpur which is nearer Faizabad City. The rest of the incomes come from other crops, and sale of farm by-products.

Gender-wise Distribution of Work

Within these small cultivating households, female family members provide most of the labor in crop and livestock activities and are highly dependent on by-products of rice and wheat for livestock feeds. As menfolk seek employment and income-earning opportunities in the non-farm sector, often temporary migration, the management of the farm is done by women for a large proportion of households. The *de facto* female headed households were 30% higher in Chandpur. Gender analysis showed that the labor requirements of rice and wheat production are met mostly by women from the lower social status. While women contibute major portion of labor in the household, over crop production, animal raising and off-farm work, three-fourths of the labor in non-farm activities is contributed by men. Adult female members spend half a day on livestock-related activities such as collection of fodder, feeding the animals, collection of farmyard manure, and preparing cowdung cakes and sticks for fuel, cleaning the sheds, and grazing the animals. Post-harvest activities in rice and wheat such as dehusking, seed selection and seed storage, and food preparation (parboiling rice, making puffed rice, making chapatis) carried out within the homestead are done exclusively by female family members.



As rice and wheat straw is a unique source of animal fodder, women consider quantity and quality of straws important criteria for selection of modern varieties. These findings have important implications for rice-wheat systems research in terms of developing varieties with quality and quantity of biomass for animal fodder, designing cropping patterns wherein the peak of rice-wheat crop management does not conflict with the timing of non-farm employment, introducing improved varieties suitable in the system, and increasing farmer (including women) participation in improving seed selection, storage practices and cultural management of rice-wheat cropping system.

Adapted from:

Paris, T., A. Singh, M. Hossain and J. Luis. 2000. Using Gender Analysis in Characterizing and Understanding Farm Household Systems in Rainfed Lowland Rice Environments. page 488. *In:* Tuong, T.P., K.S. Kam, L. Wade, S. Panday, B.A.M. Bouman, B. Hardy (eds). 2000. Characterizing and Understanding Rainfed Environments. Proceedings of the International Workshop on Characterizing and Understanding Rainfed Environments. 5-9 December 1999. Bali, Indonesia. International Rice Research Institute, Los Banos, Philippines.

Ladha J.K., K.S. Fischer, M. Hossain, P.R. Hobbs and B. Brady (eds). 2000. Improving the Productivity and Sustainability of Rice-Wheat Systems of the Indo-Gangetic Plains: A Synthesis of NARS-IRRI Partnership Research. IRRI Discussion Paper Series 40. International Rice Research Institute, Los Banos, Philippines. pp31.

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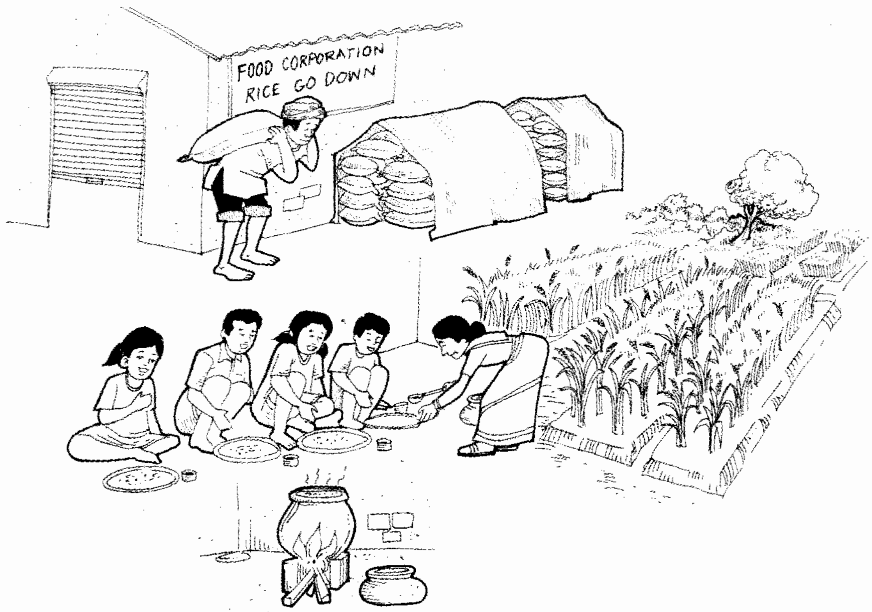
Thelma Paris

The Rice-based Livelihood Support System in South Asia



A livelihood support system that is so large and so pro-poor as the rice system has a major potential to impact, favorably or adversely, on the world's food security and on its politico-economic stability. Seventeen Asian countries annually harvest at least 600,000 hectares of rice and 11 of these countries have both food deficit and low per capita income. A dozen of these Asian countries have severe prevalence, and depth, of hunger. The annual requirement of rice is 600Mt in Asia, whereas the rest of the world produces only 60Mt rice per year. If during the period 2003-2030, should there be a succession of years in which rice supply is inadequate, the task of substituting it by alternative foods will be immense, if not impossible.

Asia's Ricelands

Harvest area	:	133 million hectares
Bovine livestock	:	200 million head
Rice workers	:	200-300 million
Rice consumers	:	3 billion persons
Foodgrain deficit in	:	11 countries
undernourished persons		
a) adults & children	:	400 million
b) pre-school children	:	124 million
c) total	:	524 million

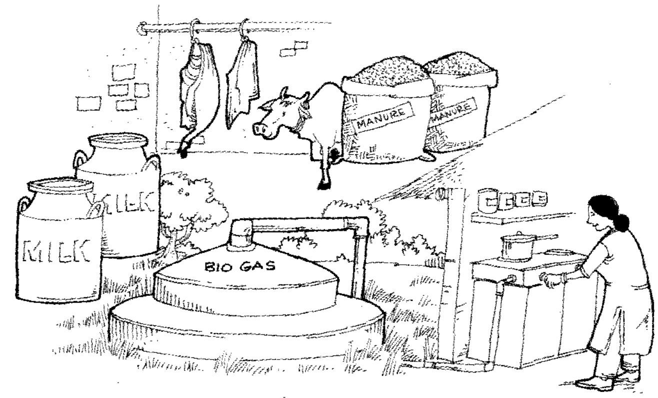
Irrigation and Crop Sequences

Rice systems are characterized by the water regime: irrigated, rainfed lowland, rainfed upland, and flood-prone lowland. Irrigated land constitutes 56% of the total rice field area and produces 75% of the rice yields. It has higher benefit for food security because the production levels are more stable year to year than in non-irrigated production systems. Various crop sequences are possible when there is a provision for irrigating the field. Among crop sequences in Asia, rice-rice occupies about 28 million ha of rice land followed by rice-wheat in 25 million ha. Rice-rice-legume and rice-wheat-rootcrop are the possible sequences where year-round irrigation is available. In multi-year sequences, long duration crops like sugarcane (with one ratoon) can be grown. Rice-oilseed-sugarcane-sugarcane-wheat is one such option. Rice-oilseed, rice-pulse, rice-vegetable and rice-fallow are sequences practiced even in rainfed lowlands using residual moisture after harvest of the rice crop.

Generic Farming Systems

Rice-rice and rice-wheat based farming systems are prominent generic farming systems. There is sufficient commonality of conditions within each generic system so that system-wide strategies for livelihood-enhancing interventions can be formulated and appraisal can be made of candidate strategies to choose the one that is most likely to lessen rural hunger and poverty.

Food and Livestock



Ricefields do not just provide food and employment to about 200 million people but also support about 200 million head of livestock on the rice straw and husk. Throughout the rice-based systems, ruminants constitute sources of income, savings, meat, milk, hides, manure and draft power. In some rice-based systems, there is a valuable contribution of protein, vitamins and income from fish grown along with the crop or in sequence. The annual yield of rice grain varies from 40 kg per person in Iran and Pakistan to 390 kg per person in rice-exporting countries. Crops grown in sequence with rice are making an ever increasing contribution to human food and livestock feed. Notably, small holdings contribute greatly to food security, both by satisfying the own household food requirement and by supplying the surplus food to the market. Analysis for India shows dramatic increases in contribution to the total national production since 1971 by farms smaller than 2.0 hectares. Other rice-producing countries may similarly be benefitting from small holder support to their food security. Rice imports into rice-growing countries respond to individual year's circumstances and even consistent rice exporters like Thailand, India and Vietnam may import rice occasionally.

Trends and Projections

The global developing country demand for rice is projected to be 665 and 765 million ton per annum in 2015 and 2030 as against 540 million ton in 1996. The average rice yield will have to increase from current 3.5 t/ha to 4.6 t/ha by 2030. This implies a growth rate of 1.2% during 1996-2015 and 0.6% between 2015 and 2030. Actual growth achieved between 1975 and 1995 was 2.3%. The deceleration in the growth rate of demand for rice is likely to continue. At current trends, the four most populous rice-producing countries (China, India, Indonesia and Pakistan) and their rice systems, shall facilitate four-fifths of the projected year 2015 global decrease in under-nourishment. However, rice-family livelihoods do not depend on food supply alone but also on interactions of social, economic and natural resource endowments. For several countries in the contiguous rice belt, rice has cultural and political dimensions. The price of rice is often an issue during democratic elections. Multi-stateholder partnerships of a wide range are thus needed to supply the support that can lessen the rice lands' food insecurity and poverty.

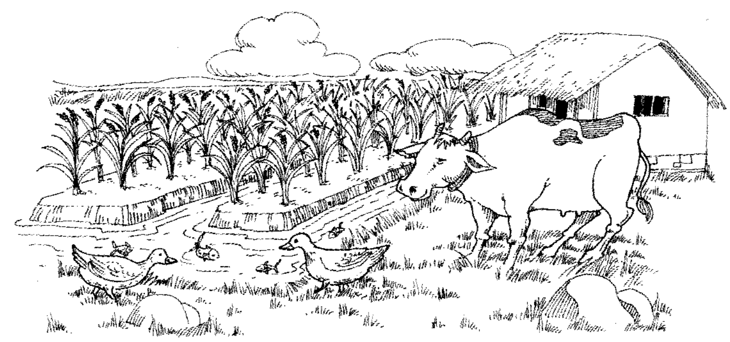
The increase in rice production now is not due to increase in area under cultivation. The per capita area under rice has actually declined from 0.12 ha/person to 0.07 ha between 1961 and 1998. The increase is due to increased productivity made possible by increases in:

- irrigation facilities;
- manure (from livestock) and fertilizer application;
- human resources, both knowledge and skills;
- investment in technology; and
- quality of seeds and new rice varieties.

Rice varieties are increasingly of shorter crop duration. The yield potential should no longer be computed for a season but rather be based on per day in the field. The new plant types and hybrids have a yield potential of 12 t/ha as compared to 10 t/ha for cultivars grown in 1998-2000. The yield potential per day per hectare for irrigated rice in tropical ecozones has risen from 67 kg/ha in 1970 to 77 kg/ha in 1990. It is projected to reach 92 kg/ha by 2010.

Threats

The increased livestock production in rice-based systems will generate greater quantities of dung and other excreta. While these can be used as manures, the emission of nitrous oxide is expected to increase by 50% while methane and ammonia production will double between the year 2000 and 2030. This will aggravate global warming more than emissions directly from the rice crop. Any rise in the sea level due to warming will increase salinity and decrease yields in coastal areas. There will be increased risk from cyclones and typhoons while rainfall is likely to decline in mid-latitudes. The increased temperature may increase fungal and viral diseases and insect pests. The annual growth in pesticide use may get accelerated from the present rate of 4-5% per annum and cause harm to non-target organisms.



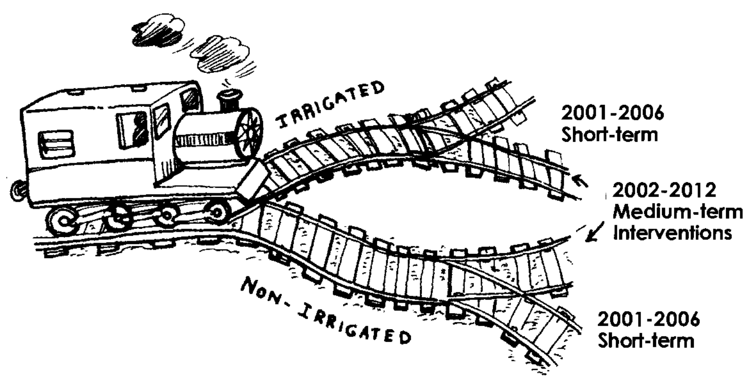
Strategies and Opportunities

Strategies based on previous "best practice" and success case experiences have the best chance to succeed. They must recognize that generation of rural employment is vital because poverty in Asia is predominantly rural. The poor are dependent on their labor. Their priority is not the increase in productivity but, rather, in lessening the risk.

It must be recognized that investment in female literacy and women development is crucial in achieving sustainable development, health, food security and poverty reduction. This investment can be made within rural employment, natural resources management or agricultural production. Governments should be assisted to implement pro-smallholder, pro-women policies, through investments in micro-finance, rural institutions and rural endowments. Interventions must ensure that there are policies, including resource management and trade management. Civil societies and governments must be encouraged to accord priority to non-irrigated ricelands to obtain substantial returns in enhanced livelihoods, production, national wealth and sustainable resource management and of lessened poverty per unit investment. In most ecozones, small farms employ more workers per hectare and achieve higher productivity than larger farms. Their proportionate contribution to food security is increasing and must be further encouraged.

Post-harvest value adding activities at household level can expand employment opportunities and generate additional income in rice-based communities. Baby foods, soups, noodles, convenience foods, flour, bran and brown rice have increasing demand. Poultry, duck farming, dairy and livestock farming can augment rural income and create employment, specially for women. Training of adult rural women in financial management and accounting can yield wonderful results. They should be given equitable access to community and family assets and income-generating resources.

Prospective Interventions



Any intervention should be based on participatory planning, action and appraisal and with maximum adoption of indigenous knowledge and experience. The interventions must address the vision and goals of providing to the younger generation a realistic expectation of life more agreeable than that of their parents. They should address the interactive triplet of food security, poverty alleviation and environmental sustainability. Operationally, interventions should be implemented on the twin twin-track approach. The first twin pair would have one track for the non-irrigated. Each track would have a twin pair: one track for the short-term (2001-06) interventions and the other for the medium-term (2002-12) interventions. Each country should be allowed to choose from a menu of prospective interventions by the donor agency targeting prospective beneficiaries and can be done by multi-agency coalitions.

Locally-active non-government organizations (NGOs) and community-based organizations (CBOs) can ensure that the interventions utilize the community-specific comparative advantages and strengths.

There are many constraints and challenges to lessening rural hunger and poverty, within rice-based communities or otherwise. However, appropriate investments made now may well obviate the need for a more costly crisis management later.

Adapted from:

Woodhead, T. and R. B. Singh. 2002. The Rice-Based Livelihood Support Systems. FAO-RAP 2002/12. FAO, Bangkok.

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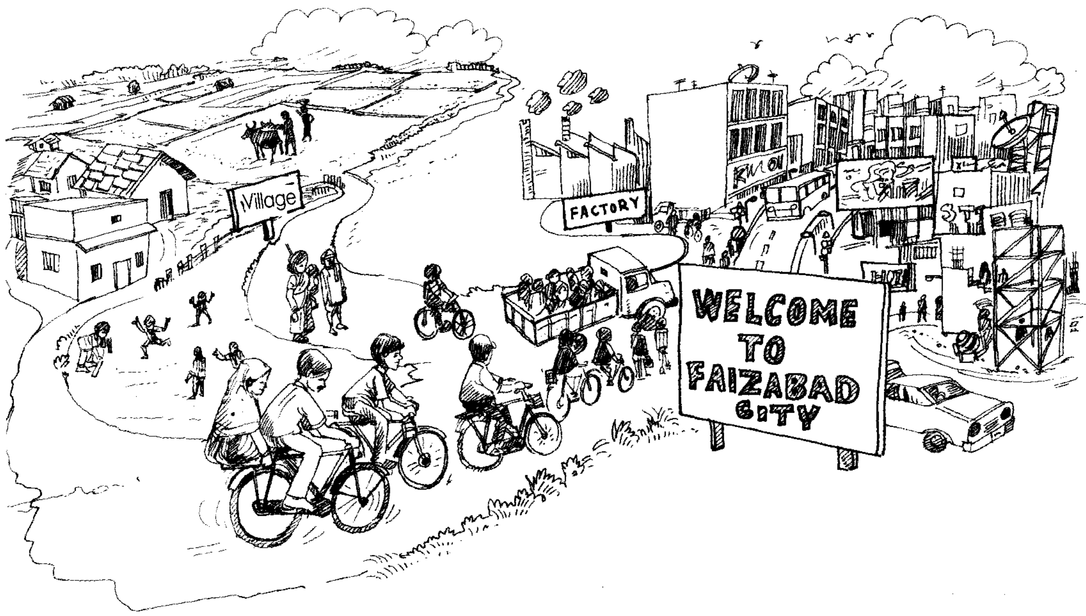
R. B. Singh

Activities Contributing to Livelihoods in Eastern Rice-Wheat Tracts



Socioeconomic factors like size of landholding, distance from the market and employment opportunities in off-farm and non-farm activities greatly influence the relative importance of a crop system in sustaining livelihood. A study of farming systems and their contribution to livelihoods in a survey covering 288 households in two villages, Chandpur and Mungeshpur, of eastern Uttar Pradesh, the heartland of rice-wheat systems, was revealing.

- Of the 288 households, 243 (84%) owned fields.
- The majority (72%) of land owners possessed less than 0.25 ha of cultivable land.
- Inspite of accounting for 50%-60% of the cropped land, rice-wheat systems contributed only 11% and 22% to the household income in the two villages.
- Men, specially in Chandpur village, seek employment and income-earning opportunities in non-farm sector, often through temporary migration to Faizabad and other towns.
- A high proportion (74%-89%) of the small landholders (<0.5 ha) are engaged in non-farm earning activities.
- Labor requirement for raising livestock as well as rice and wheat production is mostly met by women of the lower social strata.
- Women dedicate thrice the amount of time spent by their male counterparts for livestock management.
- Men (75%) spend more time than women for non-farm activities.
- Subsistence livestock raising is done by 65%-87% of the small landholders.
- Non-farm income (52%) and livestock (27%) are major sources of household income.

Fig: 1(a) Percentage Land Distribution by Cropping Pattern, in Chandpur, Faizabad District, 1995

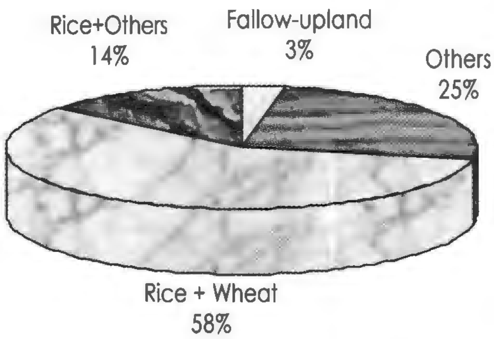
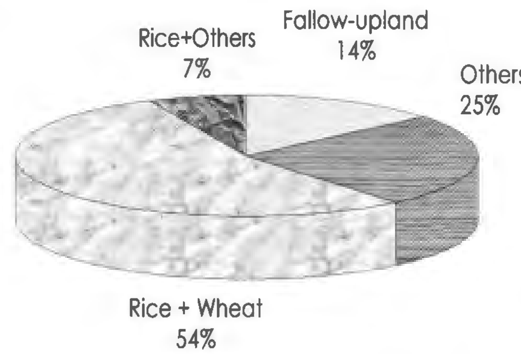


Fig: 1(b) Percentage Land Distribution by Cropping Pattern, in Mungeshpur, Faizabad District, 1995



Rice-Wheat Farming Households with Non-farm Income

Farm size (hectares)	No. of Households	% of total Households	Households with non-farm income		% of total number of households with land
			Number	%	
Less than 0.25	174	72	155	89	75
0.26 and 0.5	54	22	40	74	19
0.51 to 1.0	15	6	13	87	6
Total	243	100	208	-	100

Social Implications

As men temporarily migrate in search of income-earning opportunities in the non-farm sector, the number of *de facto* female-headed households increased in the village closest to the market town. This has also led to more than 60% of the farm activity being carried out by female labor. Livestock contributes more (27%) to livelihood than the rice-wheat system (11% to 22%). As rice straw is a major source of animal fodder, the quantity and quality of straw are important criteria when selecting modern varieties of crops.

Food For Thought

Rice-wheat systems research must also focus on developing varieties with high quality and quantity of biomass for animal fodder. The cropping pattern should be designed to avoid conflict with the timing of non-farm employment.

Adapted from:

Paris, T., A. Singh and M. Hossain. 1996. Social Consequences of Stressed Environments. pages 207-220. *In:* Singh, V.P. (ed). Physiology of Stress Tolerance in Rice. Proceedings of the International Conference on Stress Physiology of Rice. 24 Feb - 5 March 1997. Lucknow, U.P. India.

Ladha J.K., K.S. Fisher, M. Hossain, P.R. Hobbs and B. Hardy (eds). 2000. Improving Productivity and Sustainability of Rice-Wheat Systems of the NARS-IRRI Partnership Research. IRRI Discussion Paper Series 40. International Rice Research Institute, Los Banos, Philippines.

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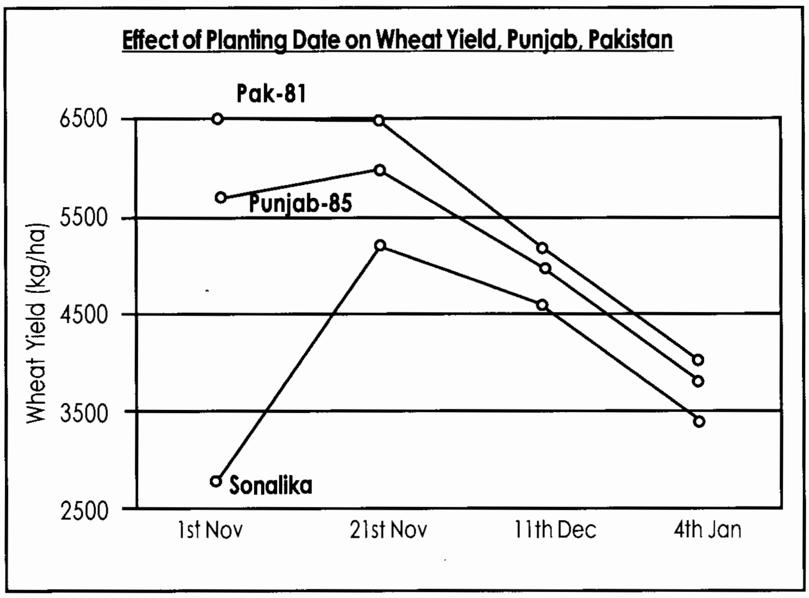
Thelma Paris

The Problem of Late Planting in Wheat

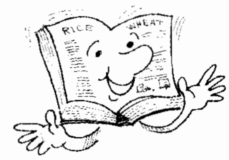
Late planting is a major problem in most rice-wheat areas of South Asia. Late planting not only reduces yield but also reduces the efficiency of inputs applied to the crop. To improve the productivity of the rice-wheat system, the wheat crop must be planted at the right time.

A linear decline in yield of 1-1.5% per day is observed when wheat is planted after the end of November irrespective of short-or medium-duration varieties. Increased nitrogen applications cannot compensate for the decline in yield from late planting.

Long turn-around time can be caused by excessive tillage, soil moisture problems (too wet or too dry), lack of animal or mechanical power for plowing, and the priority farmers place on threshing and handling the rice crop before preparing land for wheat.



Stagnation in the Productivity of Wheat



For the past several years, productivity of wheat in India has been oscillating around 2700 kg per hectare despite greater use of new varieties. Stagnating wheat yield is a major national concern. India needs to produce an additional 40-45 million tons of wheat in the next two decades to sustain food security for its growing population. Additional food essentially has to come by maintaining yields in Haryana, Punjab and western Uttar Pradesh and increasing yields in the eastern areas.

Yield stagnation has occurred at productivity levels (2.7 Mg/ha) which are much lower than the genetic level (6.5 Mg/ha) or the achievable potential (5.8 Mg/ha) of the wheat crop. Stagnation in the productivity of wheat has occurred despite increased use of inputs, assured irrigation and a seed replacement rate of 15%. Enhanced production achieved through increased use of agricultural inputs and expansion in crop acreage is difficult to sustain.

In the Indo-Gangetic Plains, *basmati* rice fields occupying sizeable acreage are vacated for wheat sowing towards the end of November. In nearly 80% of the rice area in Punjab and 60% of the rice area in Haryana, sowing of wheat is completed by mid-November. In the rest of the area, wheat sowing is completed after mid-November which reduces wheat yield. Planting of wheat after mid-November reduces productivity of wheat at the rate of 1-1.5% per day's delay after the 20th November.

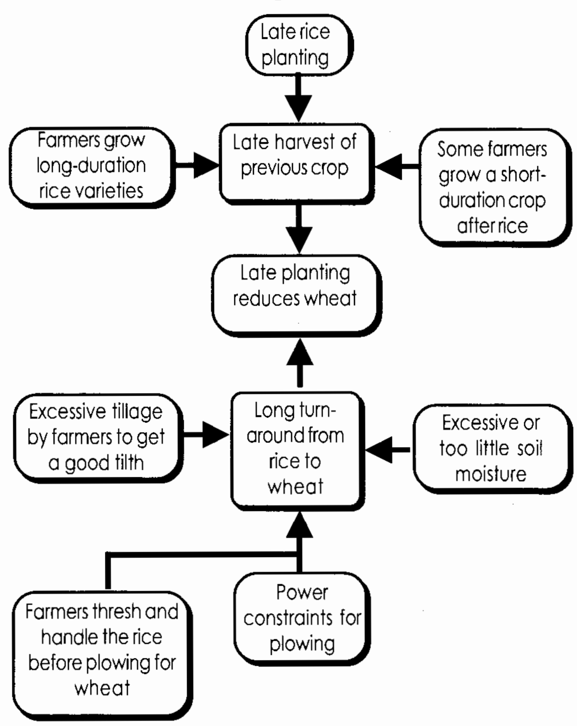
Growth in rice and wheat production has slowed down with a general decline in total factor productivity. Gross returns from the rice-wheat system have increased but at increasing costs. According to an estimate, annual losses in regional wheat productivity due to weeds, declining soil fertility, poor groundwater quality, inadequate plant population, and late planting of wheat have been 7.8, 6.4, 3.3, 2.9 and 2.6%, respectively, in Haryana.

Adapted from: Mehla, R.S., J. K. Verma, R. K. Gupta and P. R. Hobbs. 2000. Stagnation in the Productivity of Wheat in the Indo-Gangetic Plains: Zero-till Seed-cum-Fertilizer Drill as an Integrated Solution. Rice-Wheat Consortium Paper Series 8. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

Reasons for Late Planting

- Late harvest of the preceding rice crop.
- A short-duration third crop planted after rice.
- Preference of farmers in some parts of the Indo-Gangetic Plains to grow *basmati* rice, a long-duration crop, despite its lower yields, because of its high quality rice, high market value, good quality straw for livestock, and lower fertilizer requirements.
- Difficulty of replacing *basmati* varieties readily with a shorter-duration rice variety.
- Long turn-around time between the rice harvest and wheat planting.

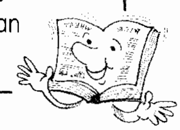
The Most Common Causes of Late Planting of Wheat Following Rice in South Asia

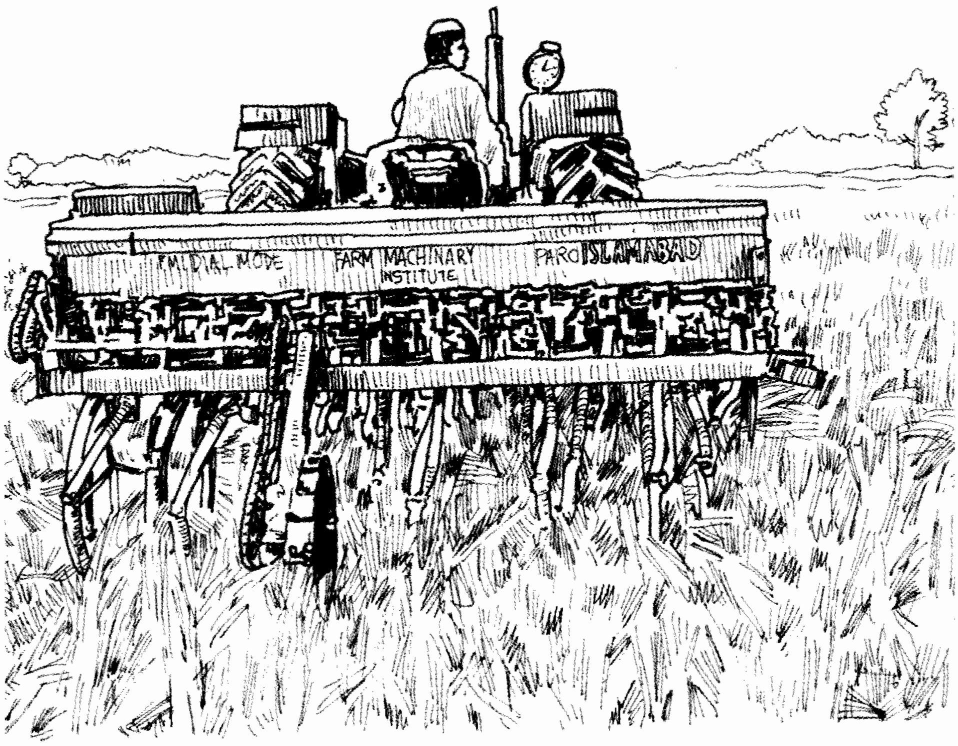


Farmers' Present Tillage Practices

- Puddling (plowing soils when they are saturated) before transplanting rice seedlings.
- Tilling soils through use of animals or tractors.
- Preparing the soil with either a nine-tine cultivator or a disk harrow.
- Deep plowing with a moldboard or disk plow which is rare.
- Several passes of plowing followed by planking even after mechanical (tractor-based) preparation of land.
- Tractors, mostly four-wheel tractors, are the major power source in the higher potential areas. Even smallholders take advantage of this power source by renting tractors from larger landholders in the village. Eventually, tractors will probably replace animal power as the cost of maintaining a pair of bullocks for a whole year becomes prohibitive.

> Puddling benefits rice by reducing water percolation and controlling weeds. However, puddling also results in degraded soil physical properties (particularly in more finely-textured soils) and subsequently creates difficulties in providing a good soil tilth for wheat. This conflicting soil management situation occurs whenever rice is followed by an upland crop.





Zero-Till Seed Drill

The zero-till seed drill reduces tillage to only one pass against the normal practice of 8-11 passes. This allows more timely sowing, which raises yields and lowers production costs by saving soil, fuel, tractor costs, water and fertilizer.

Zero-till seed drill is used in Punjab of Pakistan on 78,500 hectares involving 10,300 farmers and 1,600 drills. In India, it is used on 97,200 hectares in Haryana involving 15,000 farmers and 3,000 drills in 2001-2002 wheat season. The farmers' incomes in these areas rose by US$90 per hectare due to less production costs, higher yield and less water and herbicide use.

Data on Tillage and Crop Establishment for Diagnostic Surveys of Selected Rice-wheat Cropping Systems, South Asia

Location	Area planted late (%)	Turn-around time (days)	Average number of passes with plow
Punjab, Pakistan	40	2-10	2-10 (6)
Pantnagar, India	35	15-20	5-12 (8)
Faizabad, India	25	20-45	5-12 (6)
Haryana, India	25	15-35	4-12 (8)
Bhairahawa, Nepal	40	13-35	4-8 (6)

Note: Late planting is defined as wheat planted after the first week of December.

What Needs to be Done?

Reduced and zero-tillage options, and complementary practices, need to be tailored and adapted to specific soils and different farmers' circumstances. A stronger farmer participatory approach is needed to do this. Local machinery manufacturers should be encouraged to collaborate so that prototypes can be tested and modifications made straight away.

Adapted from:

Hobbs, P. R., G. S. Giri and P. Grace. 1997. Reduced and Zero-Tillage Options for the Establishment of Wheat After Rice in South Asia. Rice-Wheat Consortium Paper Series 2. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

Mehla, R.S., J.K. Verma, R.K. Gupta and P.R. Hobbs. 2000. Stagnation in the Productivity of Wheat in the Indo-Gangetic Plains: Zero-till Seed cum Fertilizer Drill as Integrated Option. Rice-Wheat Consortium Paper Series 8. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

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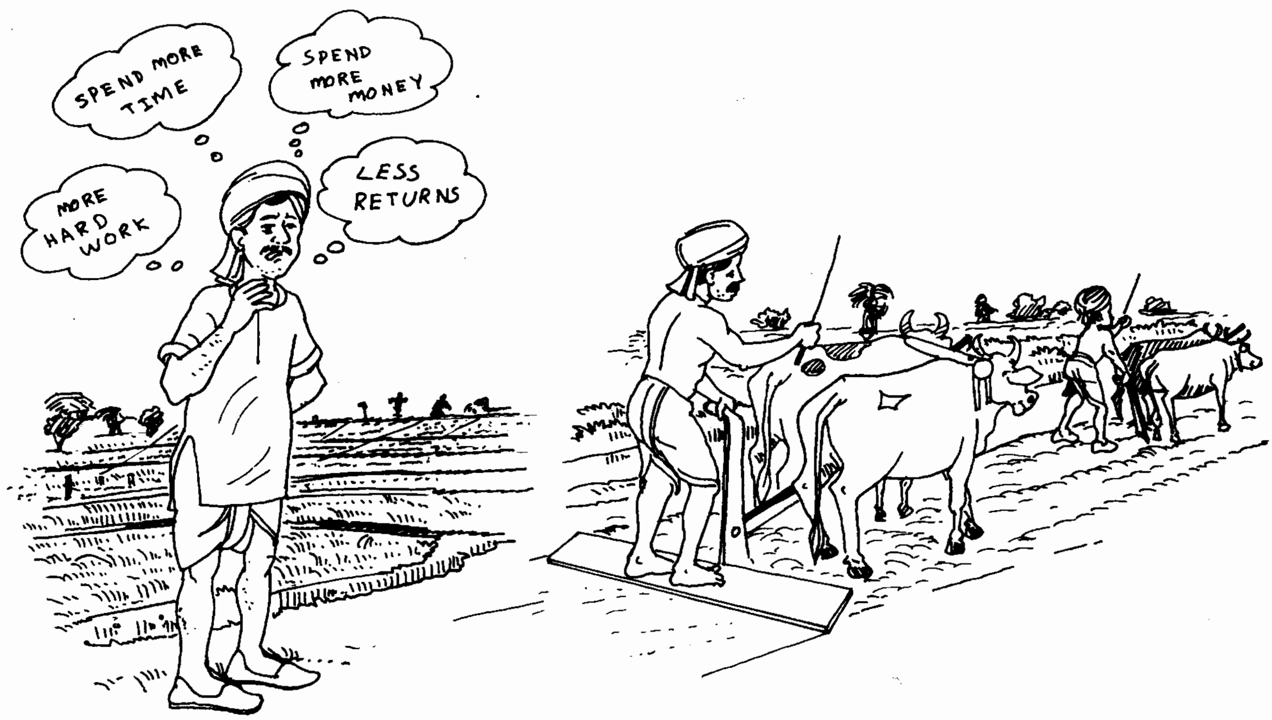
Is Conventional Tillage Essential for Wheat?



Does conventional method of wheat cultivation promise superior yields? Research has shown this may not be true. Preparing a fine seedbed before sowing may be a waste of time and money! Repeated plowing and planking hardly affects crop stand and yield.

One of the most important factors for increasing yield and efficiency of inputs in wheat is timely planting. Data has shown that wheat yields decline by 1 to 1.5% per day after a critical optimal planting date. For the North West IGP, yields are best when wheat is planted from November 9 to 16. In the Eastern IGP, this critical date is sometime in the last week of November. The other issue is a good plant stand.

Both these issues can be taken care of by using reduced tillage and zero-tillage technologies.

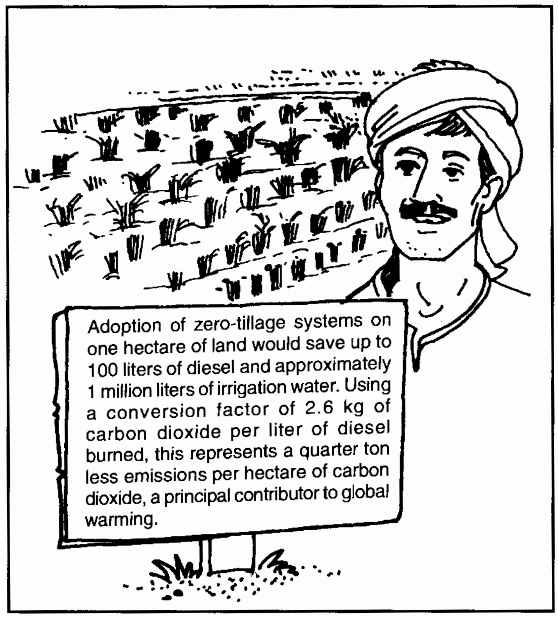
Why Planting of Wheat Gets Delayed?

One of the major reasons for late planting of wheat is the time of the harvest of previous crop, mostly rice, especially in those areas where traditional or photosensitive quality rice varieties are grown. The soils remain wet for a long time after rice. In some areas, farmers may not have access to alternative varieties that allow earlier rice harvest.

Another reason for late planting of wheat is the time and energy consumed in preparing a so called "perfect" seedbed for the sowing of wheat. It is commonly believed that more tillage operations promise superior yields. Many operations are performed to prepare a good seedbed like repeated plowings, pulverizing the top soil and sometimes breaking the colds and plow pan to promote deeper rooting. Some farmers even plow the fields up to ten times and repeatedly plank the field. Such operations only increase cost and reduce profit margin. In the process, the farmers lose precious time causing delay in sowing. This is a major inefficiency in the system.

Zero-Tillage and Reduced Tillage Systems

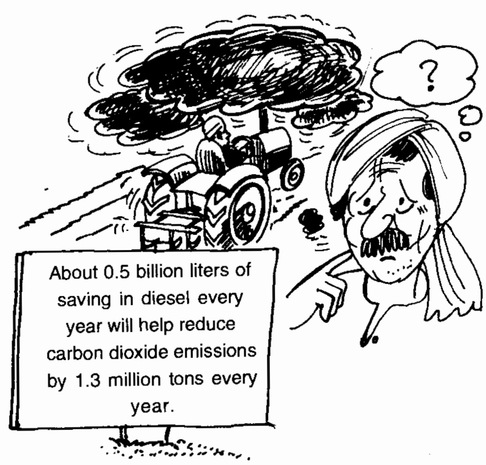
Zero-tillage and reduced tillage systems allow early and timely planting of wheat crop and reduce cost of production through less use of fossil fuel. Substantial increases in nutrient and water use efficiency have been recorded by farmers. Higher yield levels have been achieved with lesser inputs. The reduced tillage systems help in reducing water pollution, halt or decrease groundwater depletion and reduce fuel use.

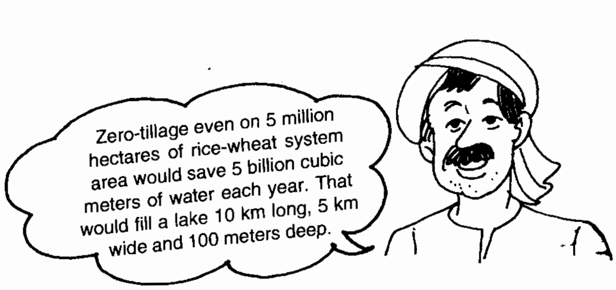


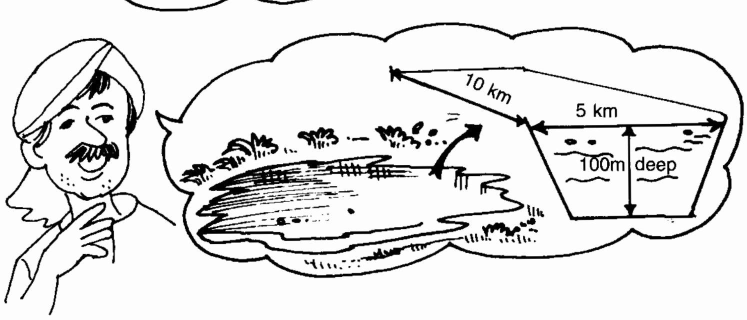

Save Water

Save Diesel

Participatory research studies in Haryana, India have shown that zero-till systems give better yields, save at least a week's time, and can be used for both early and late wheat planting.



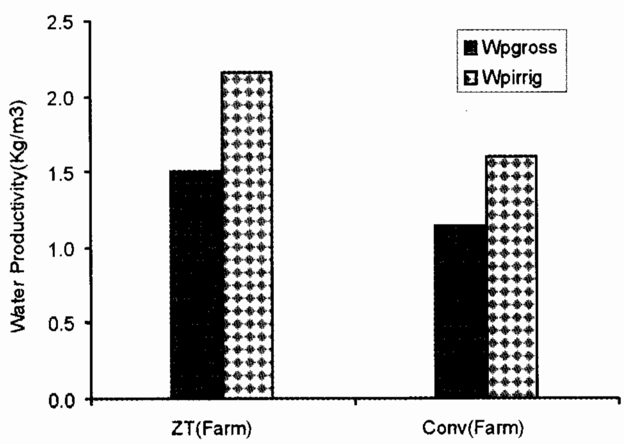




Other Advantages of Zero-Tillage Systems

- Savings in water due to less need for pre-irrigation and faster and less water (20% at least) for the first irrigation. No yellowing is reported after first irrigation.
- Efficient fertilizer use due to drill placement. In conventional method, the fertilizer is broadcasted.
- Savings in fuel by as much as 100 liters per hectare.
- Savings in time as the fields can be planted quicker in a single pass. The farmers need less number of tractors/or tractor time to get the work done.
- There is less wear on the tractor and the implements.
- There are fewer weeds, especially *Phalaris* minor, because the soil is not disturbed in the zero-tillage systems.
- The system keeps the plant residue on the surface and provides an option for not burning the same and thus reduce air pollution.
- The residue left standing provides a friendly habitat for beneficial insects and spiders that are predators to common rice and wheat pests.
- Significant increases in profit as costs of production are reduced.
- Zero-tillage technology is scale-neutral as farms of varying sizes can utilize it through contract hiring.

Water Productivity of Zero-tilled and Conventioned Farmers in Haryana

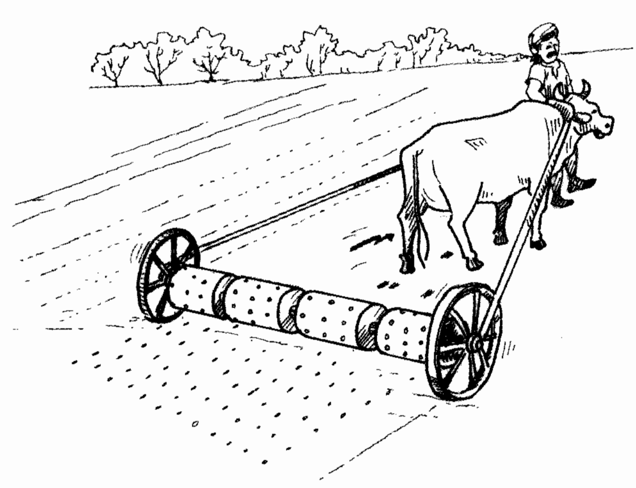


Farmers' Feedback Regarding Zero-tillage

- Row to row spacing of 20 cm is more.
- Cost for field preparation is less (Rs. 550/ha) as compared to normal sown (Rs. 2000/ha)
- Saving of irrigation water (approx. 25%)
- Not suited for light soil due to poor germination

Surface Seeding

This is the simplest form of zero-tillage systems. This method is suitable for excessively moist conditions of finer-textured, poorly drained soil commonly found in the low-lying areas of eastern Indo-Gangetic Plains (IGP) in Nepal, India and Bangladesh. These soils generally cannot be tilled for normal planting.



In this method, the wheat seed is broadcast on to the wet soil surface either before or after rice harvest and the broadcasting is done without disturbing the soil. The seeds germinate and the roots follow the saturation fringe as the water recedes.

It is very appropriate system for resource-poor farmers as no equipment is needed. It can be practiced on any field of any size. The system can be improved by soaking seed. Mulch is used to deter weeds, keep the surface moist, delay nitrogen application until later, and to make sure the soil is moist at seeding and during the initial stages of root elongation.

Reduce-tillage systems have the potential of increasing cropping intensity as farmers can avoid rice fallows in many areas of eastern Uttar Pradesh, Bihar, Nepal and Bangladesh. It is also a very popular system in the Yangtze River Valley of China.

Zero-Till Drill-Pantnagar Drill

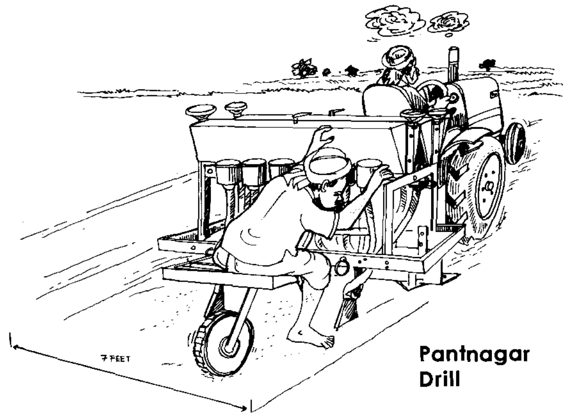
This is a special type of inverted-T attachment which makes narrow grooves in the soil for the placement of the seed and fertilizer in one pass. This attachment is fixed with a normal seed drill. This system of planting was introduced into the IGP region through import of a drill from New Zealand (Aitchison drill was imported to Pakistan in 1983 and India in 1988). The coulter option has since been copied and placed on locally-manufactured drills. In India, this is called the Pantnagar drill as it was first developed at the G.B. Pant University of Agriculture and Technology, Uttaranchal.

Establishment of Wheat Following Rice, Bhairahawa Agricultural Farm, Nepal, 1993-94

Method	Wheat yield (kg/ha)	1000 Grain weight (gm)	Cost to plow (Rs/ha)	Net benefit (Rs/ha)	Extra days needed to plant[a]
Surface seeding	2,775[a]	46.11[a]	0	11,485a	0
Chinese seed drill	2,831[a]	45.43[b]	600	12,090a	8
Farmers' practice	2,314[b]	40.87[c]	2300	8065b	15

Note: Figures followed by the same letter are not significantly different at 5% probability using DMRT.
a Number of extra days needed for land preparation before seeding compared to the surface seeding.

This drill needs the right soil moisture for planting as the roots have to penetrate the soil without the aid of tillage. Higher moisture content keeps the soil strength low and allows good root penetration. It can also plant seeds into drier soil but in this case first irrigation must be given earlier.



Pantnagar Drill

Pantnagar drill was used in some of the demonstrations in Haryana State. Wheat yields in the area sown with the drill where *Phalaris* minor weed had developed resistance to herbicides, rose to 4.35 tons per ha in 1999-2000 as compared to 3.45 tons per ha in 1994-95 and 1995-96 when the drill was not used. On the contrary, the yield in the non-herbicide resistant area has gone up from 3.7 tons to only 3.9 tons per ha. Even if the gain of 2 quintals is attributed to favorable weather condition, the resistance management has accounted for major gains in wheat productivity.

This technology has brought about a revolution in rice-wheat cultivation in Pakistan and northwest India. In two years, Pantnagar drill has been widely adopted by farmers. In 1997, 120 ha were covered by this drill; in 1998, 1200 ha were covered and in 1999, the area covered increased to 12000 ha. Depending upon availability of the drill, its use has increased to 300,000 ha in 2002 in the Indian subcontinent.

Zero-Tillage Allows Fewer Weeds!

This technology can be used for both timely and late planting. In case of early planting, the wheat crop germinates and covers the soil before the germination of *Phalaris minor*, a weed that has developed resistance to the common herbicide Isoproturon in the northwest India. This weed germinates only when temperatures drop below a critical level after mid-November. Also, as the soil disturbance is very little compared to the conventional tillage, fewer weeds germinate, and weed seed stock remains burrowed in plow layer.

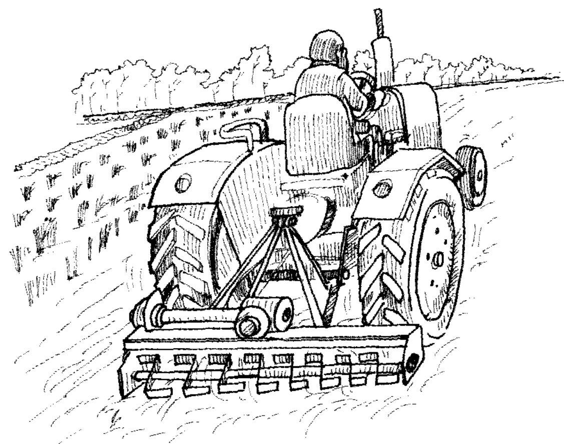
Studies on long-term trials using zero-tillage at Uchana and Teek in Haryana have shown that the population of *Philaris minor* decreased over the three-year period. In all these plots, alternate herbicides including clodinafop, fenoxaprop or sulfosulfuron were used during the three years. The reduction in population is because of the combined effect of new herbicides and zero-tillage. The yield of wheat in both permanent trials also increased over the three-year period. The yield in the zero-tillage plots at Teek were 6.87 ton per ha.

Effect of Zero-tillage on Yield and *Phalaris minor* Population at Teek Village, Haryana

Year	Grain yield kg/ha	*Phalaris* minor plants/m^2
1997-1998	5350	1165
1998-1999	5500	28
1999-2000	6240	6

Reduced Tillage

This technology is based on combining tillage done by a rotovator with seeding. Planting in this system is done in a single pass. There are several systems available for both two-wheel and four-wheel tractors. In some systems, the entire swath of soil is rotovated while in others, some of the rotovator blades are removed and only a strip is cultivated and planted. The Punjab Agricultural University has developed a "strip-till drill on a four-wheel tractor" which can effectively undertake this operation in the sandy soils of northwest India. A two-wheel tractor implement imported from China has been found to be effective in the eastern IGP.



Rotovator

This system has an advantage in the eastern region where rice weeds tend to carryover to the next wheat crop and interfere with surface seeding. Farmers also use this system by first broadcasting the seed and then using the rotovator to incorporate the seed into the soil. This system works better than the Chinese implement on heavy soils specially when it is difficult to do surface seeding due to weeds. It also provides the benefit of timely planting, fertilizer incorporation and reduced costs. Main problem is the availability of the machinery, especially in India. When available, this machine not only reduces the cost of planting, but the power source is also used for running reaper, irrigation pump, thresher, winnowing fan and trailer for transport.

Bed Planting of Wheat

This includes raising wheat crop on beds made 70cm apart. Although there is no saving on the cost of land preparation or time, the same beds can be used for cultivation of the next crop after minor repair. Most of the research done by the Rice-Wheat Consortium (RWC) on this system only enables convenient weeding and fertilizer application. It has the advantage of using lower seed rate which is important when hybrid seed is being used or seed multiplication is being done.

The main advantage is to save water by 30% to 35%. Fertilizer application also becomes easier as the top of the beds are still hard because water has not reached to that level. Even last irrigation does not lead to crop lodging.

Adapted from:

Gupta, R.K., R.K. Naresh, P.R. Hobbs, Z. Jiaguo and J.K. Ladha. 2003. Sustainability of Post-Green Revolution Agriculture: The Rice-Wheat Cropping Systems of the Indo-Gangetic Plains and China. *In:* Ladha, J.K. (ed). Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts. ASA Special Publication. American Society of Agronomy/Crop Science Society of America/Soil Science Society of America. Madison, Wisconsin, USA. (In print).

Hobbs, P.R. and R.K. Gupta. 2000. Sustainable Resource Management in Intensively Irrigated Rice-Wheat Cropping Systems of the Indo-Gangetic Plains of South Asia: Strategies and Options. *In:* Singh, A.K. (ed). Proceedings of the International Conference on Managing Natural Resources for Sustainable Agricultural Production in the 21st Century. 14-18 February 2000. Indian Society of Soil Science. New Delhi, India.

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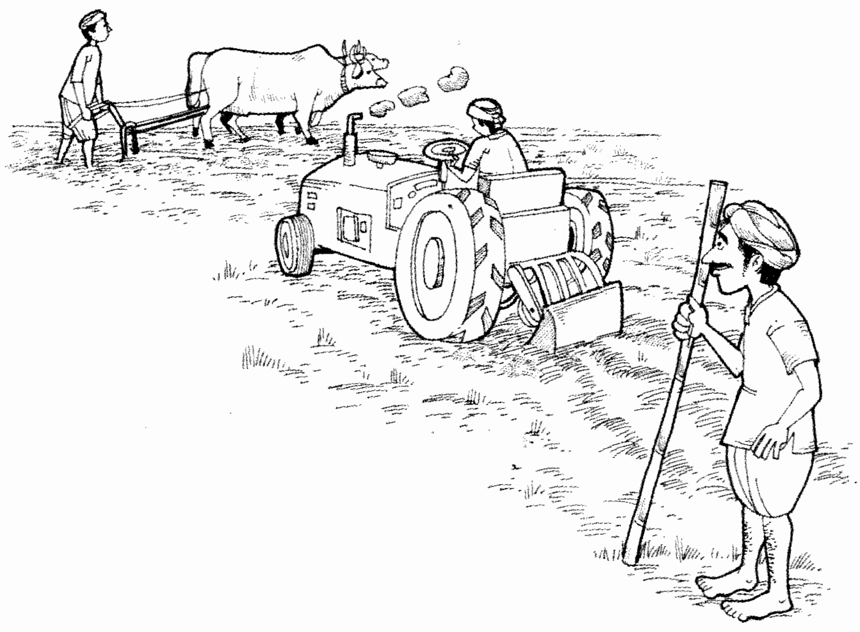
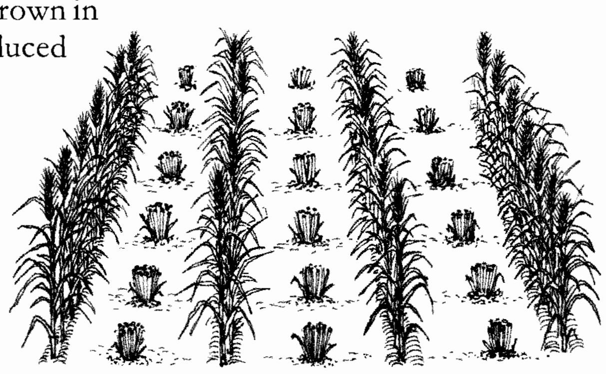
Location-specific Crop Establishment Options



Natural resources management problems are complex and location-specific. Following an ecoregional approach, the Rice-Wheat Consortium addressed these problems through farmer participatory research programs in the Indo-Gangetic Plains (IGP). Crop establishment techniques vary in different transects of the IGP. Therefore, crop and soil management practices (e.g., tillage, nutrients and water) have to be fine-tuned according to the crop establishment requirements in a particular transect. Rice in the IGP has been grown traditionally by raising nursery in a separate field and transplanting seedlings in the puddled main field or by direct seeding, either dry seeding or seeding in a puddled field. Researchers have worked with farmers in growing rice and wheat crops in sequence following various tillage and crop establishment options. These options have been generated for timely crop establishment, low production costs, increased productivity and improved soil quality. The improved options allow farmers to experiment with more diverse systems as sufficient time, labor and land are available. Thus, farmers obtain higher yields and income than the traditional practice.

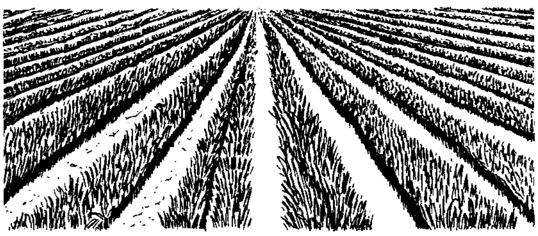
Non-puddled Planting and Zero-Till

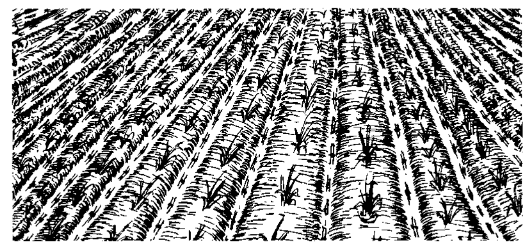
Non-puddled transplanted or direct seeded rice is grown in combination with wheat planted with zero-till or reduced till. These combination options are potentially important for many areas across the IGP. Zero-till reduces cost to plow, increases yields, reduces weed population, and saves irrigation water by 20%. Reduced till is useful in eastern IGP where rice weeds carryover to the next wheat crop and interfere with surface seeding. It also reduces costs of power source and planting.



Raised Bed Planting

Permanent raised bed planting system is a more sustainable system which has potential for adoption by farmers in large areas. It offers scope for diversification and intensification of the cropping systems in the IGP even during the monsoon season. In this system, seed rates and crop lodging are low. It saves irrigation by 35 to 40%. Yields are good and large panicles with bold grain are produced. Intercropping of maize or sugarcane with wheat is beneficial using this system.





Rice-Wheat Crop establishment options in IGP Transacts

Rice \ Wheat	Conventional Tillage	O-Till	SS	Red. Till Tractor 2W	Red. Till Tractor 4W	Bed planting
P-TR Conventional	**General**	**TU***M*	*ML*	*ML*	**TU**	
P-DSR	TU	TU*M*	**ML**	*ML*	**TU**	
NP-TR	**TUM**	*TUM*	*TUML*	*ML*	TU	***TUM***L*
NP-DSR	**TUML**	**TUM**	TU**ML**	**ML**	**TU**	*TU***ML***

Techniques:
- PTR = Puddled transplanted rice
- PDSR = Puddled direct seeded rice
- NPTR = Non-puddled transplanted rice
- NPDSR = Non-puddled direct seeded rice

*Bed Planting promotes diversification

Regions:
- T = Trans-Gangetic Plain
- U = Upper Gangetic Plain
- M = Middle Gangetic Plain
- L = Lower Gangetic Plain

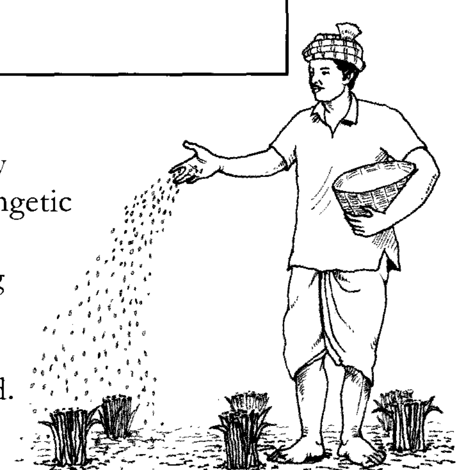
Important for large areas in specific IGP Transact

IMPORTANT FOR MANY AREAS

May be important in some areas:

Surface Seeding

Surface seeding of wheat and other crops is potentially important in many areas of the Middle and Lower Gangetic Plains. This practice is intended to reduce rice fallows. Surface seeding is applicable in wetlands where drilling operation is not possible due to excess moisture. In surface seeding, there is no cost to plow as the land is not tilled. Sowing is timely and weed growth is detered. Surface seeding increases yields and net income.

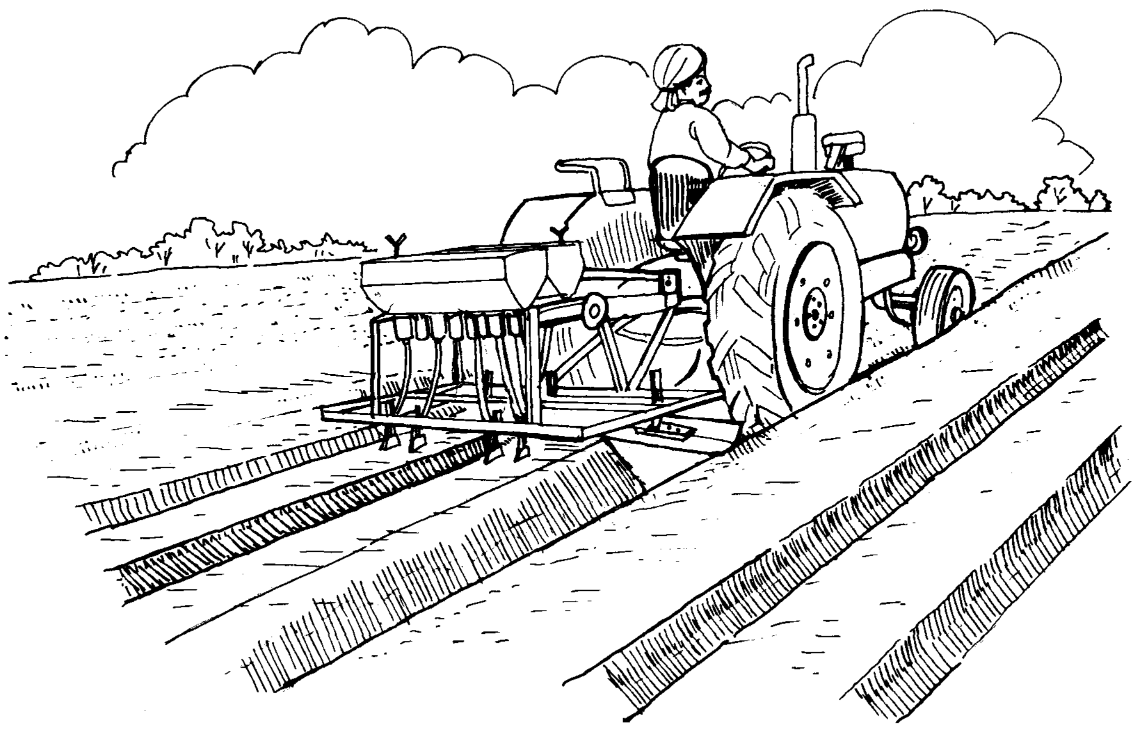


Adapted from:

Gupta, R.K., P.R. Hobbs, J.K. Ladha and S.V.R.K. Prabhakar. 2002. Resource Conserving Technologies: Transforming the Rice-Wheat Systems of the Indo-Gangetic Plains. Rice-Wheat Consortium - A Success Story. Asia Pacific Association of Agricultural Research Institutions. Bangkok, Thailand.

Corresponding author:
Peter R. Hobbs

Bed Planting in Rice-Wheat System



In bed planting systems, wheat or other crops are planted on the raised beds in ridge-furrow system. This system is often considered more appropriate for growing high value crops that are more sensitive to temporary waterlogging stress. Farmers often raise crops such as cotton, maize-soybean and wheat on the raised beds. However, the practice of growing rice, the major water-using crop in rice-wheat systems, on narrow raised beds was introduced only very recently in the Indo-Gangetic Plains (IGP) to reduce water use, conserve rainwater and improve system productivity. Recent work shows that system of raised bed planting of crops may be particularly advantageous in areas where groundwater levels are falling and herbicide-resistant weeds are becoming a problem. This tillage and crop establishment option also facilitates crop diversification and intercropping of wheat, chickpea and Indian-mustard with sugarcane, maize with potato, mint with wheat, rice with soybean, and pigeon pea with sorghum or green gram. Although bed planted wheat in rotation with soybeans covered more than 75% area under wheat by 1994 in Mexico, the South Asian rice-wheat farmers are still experimenting with this system of crop planting in the IGP to address issues of receding watertables, crop losses due to temporary waterlogging in monsoon season and declining factor productivity and for crop diversification. Results of farmer participatory trials indicate that significant water savings can be effected by planting rice (major consumer of irrigation water in rice-wheat systems) on raised bed besides improvement in crop yields.

Effect of Tillage Options on Plant Attributes and Yield of Rice and Saving in Irrigation Water

Tillage options	#Experimental area (ha)	Spike length (cm)	Grains/ panicle	Saving in irrigation water, %	Grain yield (Mg/ha)
Transplanted rice on beds	12(20)	23.4	173	41.5	56.2
Direct seeded rice on flats	12(10)	21.9	163	17.8	56.9
Conventional tillage	14 (35)	21.5	163	-	52.9

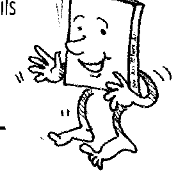
* Percent saving in water (in terms of irrigation time) when compared to farmers' practice
\# Number of farmers' participation in trials in parenthesis

Potential of Raised Beds

Change over from growing crops in flat to ridge-furrow system of planting crops on raised bed alters the crop geometry and land configuration, offers more effective control over irrigation and drainage as well as their impacts on transport and transformations of nutrients, and rainwater management during the monsoon season. In furrow irrigated raised bed (FIRB) system, water moves horizontally from the furrows into the beds (subbing) and is pulled upwards in the bed towards the soil surface by capillarity, evaporation and transpiration, and downwards largely by gravity. In determining the dimensions of the beds, factors such as spacing between tractor tyres, soil types, rainfall and groundwater conditions, salinity and irrigation water quality and requirements of crops grown in rotation are of prime importance. For developing a permanent system of bed planting, factors like irrigation and fertilizer management, crop residue management, inter-tillage and weed management must be considered together. For major soil types (sandy loam to loam soils) and crops (inter-row crop spacing requirement) grown in the IGP, ridge-furrow system, of 67cm width (top width of bed-37cm; and of furrow-30cm) is often considered appropriate . On the raised beds, two rows of rice, wheat, maize or chickpea are generally grown. Yields with 2 and 3 rows of wheat per bed are comparable, but lodging is greater with 3 rows per bed. It is advantageous to plant on beds a single row of pigeon pea or intercropped wheat/mustard with furrow planted sugarcane. For effective weed control, choice of crop cultivars that cover the surface early in the season is of great importance. Crop cultivars are known to vary significantly in their performance on FIRB. Efforts are in progress to identify appropriate cultivars in rice, wheat and other crops which are better suited for raised bed planting system.

Precautions for FIRB Planting in Unfavorable and Marginal Environments

Alkali soils having high exchangeable sodium are slowly permeable. These soils need o be amended with gysum, iron-pyrite and or other acid formers and leached before making raised bed. Gypsum should be mixed in surface 10cm layer of alkali soils and reaction products leached for several days.



Advantages

There are several advantages associated with bed planting systems, which are as follows:

- Management of irrigation water is improved, is simpler, and more efficient. On an average it uses, 30% less water than flat bed methods and improves crop yields by more than 20%.
- FIRB planting saves 30% to 50% wheat seed compared to flat bed planting.
- Better upland crop production is possible in the wet monsoon because of better drainage.
- Fertilizer efficiency can be increased because of better placement including top dress applications.
- Wheat seed rates are lower. Plant stands are better.
- Better tillering, increased panicle/ear length and bolder grain.
- Farmers can apply N and irrigation water at grain filling stage in wheat to improve protein content without lodging. Reduced lodging can have a significant, positive effect on yield as many farmers do not irrigate after heading precisely to avoid lodging. As a result, water can become a limiting factor during grain filling, resulting in lower yields.
- Bed planting facilitates irrigation before sowing and thus provides an opportunity for weed control prior to planting. If pre-sowing irrigation is likely to delay planting, bed planted crops can be irrigated immediately after seeding.
- Weeds between the beds can be controlled mechanically, early in the crop cycle.
- Herbicide dependence is reduced, and hand weeding and rouging between rows are easier. The major weed species affecting wheat, *Phalaris minor*, is less prolific on dry tops of raised beds than on the wetter soil found in conventional flat bed planting. Raised beds make it easier to apply herbicides because the beds allow the person spraying to follow the line. They also make possible mechanical weeding, and easier rouging or hand weeding.

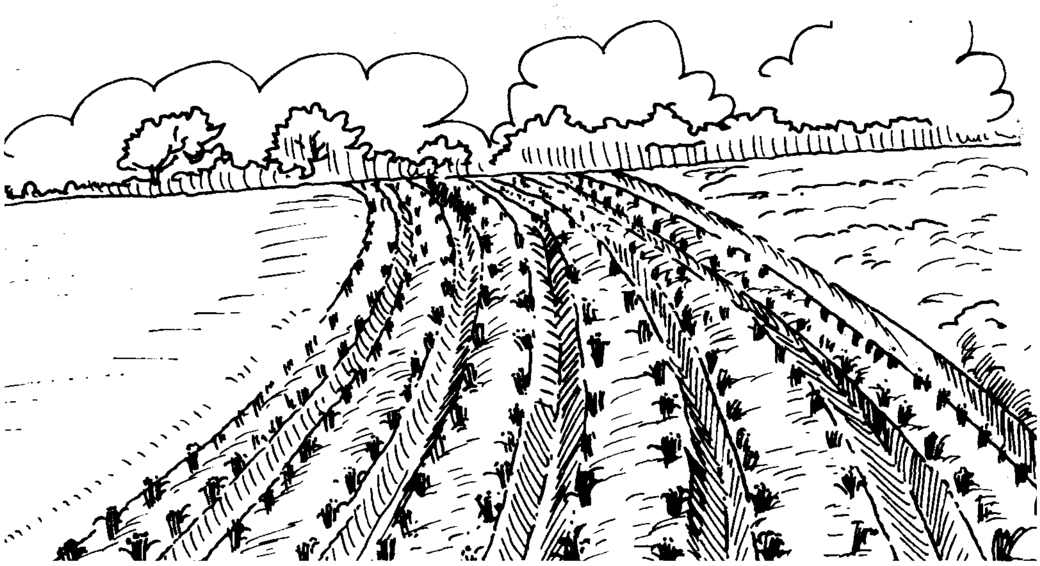
Benefits of Bed Planting Observed in India

Crops	Yield on beds (t/ha)	Yield on flat (t/ha)	Water savings (% over flat)	Yield increase (% over flat)
Maize	3.27	2.38	35.5	37.4
Urd bean	1.83	1.37	26.9	33.6
Mungbean	1.62	1.33	27.9	21.8
Green peas	11.91	10.40	32.4	14.5
Wheat	5.12	4.81	26.3	6.4
Rice	5.62	5.29	42.0	6.2
Okra	34.4	29.1	33.3	18.2
Carrot	36.3	28.6	31.8	26.9
Radish	34.7	26.7	29.4	30.0
Cabbage	33.0	27.8	26.8	18.7
Pigeonpea	2.2	1.5	30.0	46.7
Gram	1.85	1.58	27.3	17.1
Cauliflower	25.9	18.9	36.4	37.0
Average	—	—	**31.2**	**24.2**

- On raised beds, border effects allows the canopy to intercepts more solar radiation, it strengthens the straws, and the soil around the base of the plant is drier to prevent crop from lodging.
- In hand harvested rice fields, wheat crop can be planted in just one pass. The bed planter reshapes the beds and furrows, plants the crop and places fertilizer at appropriate depth into the soils along seed or between seed rows in the center of the bed at 5-10cm depth. In combine harvested rice fields, crop straws can be incorporated into the beds using a shovel type furrow openers fixed on the front bar of the bed planter frame. In the absence of appropriate machinery, farmers partially burn the rice straws before seeding of wheat.
- Yield potential is enhanced through improved nutrient-water interactions and less lodging.
- Yield of rice transplanted on FIRB is comparable with traditional rice culture with as much as 25%-50% saving in irrigation water.
- Compaction of soil is limited only to the furrows used as tramlines (tractor tracks).

Conservation Tillage with Raised Beds

Research into permanent bed systems started at CIMMYT, Mexico, is showing encouraging results. An additional advantage of bed planting becomes apparent when beds are "permanent", that is, when they are maintained over the medium term and not broken down for every crop. Making of permanent beds can help overcome constraints of resource depletion and pollution of existing systems. This has the potential of reducing cost of rice-wheat cultivation by 20%-25% over conventional methods. In this system, wheat is harvested and straw is left or burnt. The beds are reshaped by passing a shovel down the furrows. The next crop (soybean, maize, sunflower, cotton, etc.) can then be planted into the stubble in the same bed. The advantages of this system are reduced costs, erosion control, reduced soil compaction and, perhaps, better soil physical structure over time.



Zero-tillage, stubble management and reduction of herbicide use are some of the possibilities that would maintain soil structure and organic matter content while reducing air and water pollution. With permanent FIRB, crop diversification and the ability to rapidly change crop choice, for example from rice to soybean or vegetables, is possible in response to market opportunities.

After harvest, most farmers burn the crop residues and destroy the raised beds by tillage before forming new beds afresh for planting the next crop. They also apply 75% of the nitrogen fertilizers during tillage operations before planting. A long-term experiment, established in 1992 in northwestern Mexico, compared this practice with "permanent" raised beds that were formed for the first crop and only superficially reshaped before planting subsequent crops. Fourteen crops, including seven spring wheat (planted in winter) two soybean and five summer maize crops had been raised on the plots by 1998-99.

Residue Retention

Residue retention in the field had a significant beneficial effect on wheat and maize yields even under rainfed conditions of Alliplano (16-24ºN 1500-3000 MasL): Mexico with both Zero-till as well as with conventional tilage practices on flat beds.

Table 1. Comparison of Tillage/Seeding System and Residue Management on Wheat and Maize Yield

Tillage/seeding system	Residue management	Wheat yield (kg/ha at 12% H_2o)	Maize Yield (kg/ha at 12% H_2o)
Zero-till direct seeding	Full retention	5099	4361
Zero-till direct seeding	Full removal for fodder	3581	3574
Conventional tillage	Full retention	4435	3955
Conventional tillage	Full removal for todder	4098	3702
Mean		4303	3898
SED (35 df)		415	403

Sayre, K.D., M. Mezzalama and M. Martinez. 2001. Tillage, Crop Rotation and Crop-Residue Management: Effect on Maize and Wheat Production for Rainfed Conditions in Altiplano of Central Mexico. CIMMYT, Mexico.

Over the first five years, small but significant wheat yield differences were observed between the treatments. Major differences appeared in the wheat crop from the sixth year. Significant yield differences were also seen with various nitrogen management practices due to interaction between tillage/residue and nitrogen management. The differences in yields between permanent beds and conventional tillage were dramatic in treatments where no fertilizer was applied. More stable, and higher, wheat yields were obtained when permanent beds (FIRB) were used, all crop residues were retained and nitrogen application was delayed until the first node stage of the wheat crop. This yield advantage seems to be associated with gradual improvement in soil physical, chemical and biological parameters where tillage is reduced and crop residues retained. These results indicate that the retention of crop residues may be critical to ensuring long-term sustainability of bed planting.

Adapted from:

Connor, D.J., J. Timsina and E. Humphreys. 2002. Prospects for Permanent Beds for Rice–Wheat Systems. *In:* Ladha, J.K. *et al.*, (eds). Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts. Special Publication, ASA. Madison, Wisconsin, USA.

Gupta, R.K., P.R. Hobbs, M. Salim, R.K. Malik, M.R. Varma, T.P. Pokharel, T.C. Thakur and J. Tripathi. 2000. Research and Extension Issues for Farm Level Impact on Productivity of Rice-Wheat Systems in the Indo-Gangetic Plains of India and Pakistan. Rice-Wheat Consortium Traveling Seminar Report Series 1. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India. pp26.

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Sayre, K.D., M. Mezzalama and M. Martinez. 2001. Tillage, Crop Rotation and Crop Residue Management Effects on Maize and Wheat Production for Rainfed Conditions in Altiplano of Central Mexico. CIMMYT, Mexico (Poster).

Sayre, K.D. 2001. Bed Planting Systems: An Overview. CIMMYT. Mexico (Poster).

Corresponding authors:
D.J. Connor, Raj K. Gupta, Peter R. Hobbs and **K.D. Sayre**

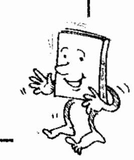
Reduced and Zero-Tillage Options

Reduced or zero-tillage systems are often found to generate higher yields, reduce production costs, and reduce erosion and other forms of land degradation, with corresponding benefits for the natural resource base. They improve environmental quality owing to less green house gas emissions and air pollution made possible by the reduced use of diesel fuel and stoppage of burning of residues (when planting could be done into surface mulch). It also ensures 25% saving in water. Many developed countries use these systems along with a whole system of mechanization to ensure good crop establishment, proper placement of fertilizer, and handling of crop residues. This is accompanied by a set of crop protection practices for handling weed, disease and pest problems.

In South Asia, reduced and zero-tillage practices for wheat after rice have been developed, though progress in the elaboration of complementary crop management practices is not as advanced as in developed countries. Nevertheless, farmers have already started to use some of these technologies. Zero-tillage for wheat after rice generally results in yields that are better than or equal to yields obtained using conventional practices.

Reduced and Zero-Tillage Options

- Surface seeding
- Reduced tillage with two- and four-wheel tractors
- Zero-tillage with four-wheel tractor
- Bed planting systems, particularly permanent beds



Surface Seeding

Surface seeding is the simplest method of zero-tillage system involving the placement of seed onto the soil surface without any land preparation. Farmers in parts of eastern India, Bangladesh and Nepal commonly use this practice to establish legumes and oilseeds and occasionally for wheat. Wheat seed is either broadcast before the rice crop is harvested (relay planted) or afterward.

The key to success with this system is having the correct level of soil moisture. Too little moisture will result in poor germination, and too much moisture will cause seed to rot. A saturated soil is best. The seed germinates into the moist soil and the roots follow the saturation fringe as it drains down the soil profile. High soil moisture reduces soil strength and thus eliminates the need for tillage, but at the same time the moisture level must not be too high, as oxygen is needed for healthy root growth.

> Zero and reduced tillage can increase fertilizer efficiency because they enable wheat to be planted on time, but they can also be the cause of inefficiency when nitrogen has to be applied on the soil surface, and where nitrogen losses are high.

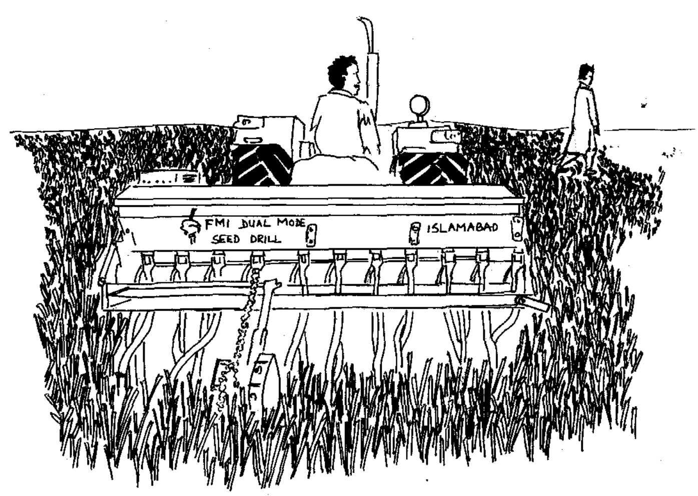
An early, light irrigation may be required. Some farmers who relay wheat into the standing rice crop place the cut rice bundles on the ground after harvest. This practice allows the rice to dry and also act as a mulch, keeping the soil surface moist and ensuring good wheat rooting. Young seedlings are also protected from birds. However, relay planting can be done only if the soil moisture is enough for planting at this stage.

Surface seeding gives significantly higher yield than that in the farmers' practice, and because the cost of land preparation is zero, surface seeding also generates higher net benefits.

There are benefits associated with delayed application of nitrogen in surface seeding which include higher efficiency of applied nitrogen, higher yield and better grain protein content.

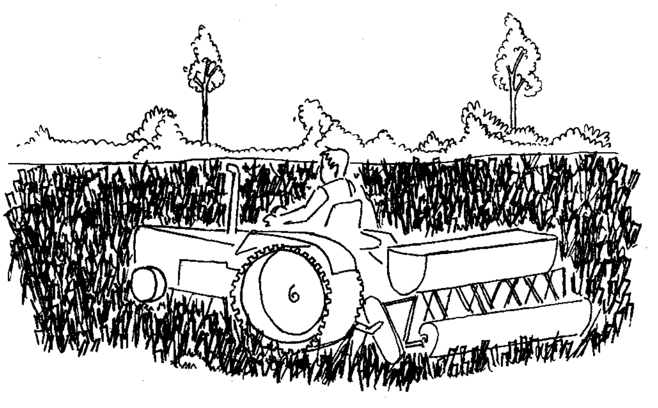
Reduced Tillage with Two-and Four-Wheel Tractors

Chinese scientists have developed a seeder for use with a 12 horse power, two-wheel diesel tractor that prepares the soil and plants the seed in one operation – even planting into standing rice stubble on heavy soils. This system consists of a shallow rotovator followed by a six-row seeding system and a roller for compaction of the soil.



As with surface-seeding practices, soil moisture was found to be critical in this reduced tillage system. The rotovator fluffs up the soil, which then dries out faster than when conventional land preparation technologies are used. The seeding coulter does not place the seed very deeply, so soil moisture must be high during seeding to ensure germination and root extension before the soil dries appreciably. This problem could be overcome by modifying the seed coulter to place the seed a little deeper.

One benefit of the two-wheel tractor is that it comes with many options for other farm operations; it includes a reaper, a rotary tiller, and a moldboard plow and it can also drive a mechanical thresher, winnowing fan, or pump. However, most farmers are attracted to the tractor because it can be hitched up to a trailer and used for transportation.

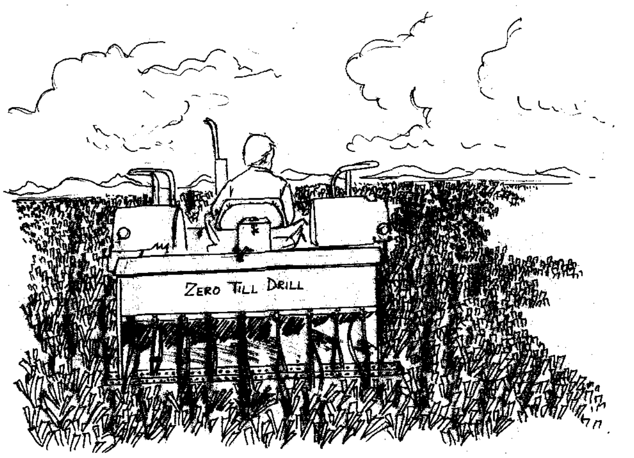


The main drawback of this technology at the moment is that the tractor and the various implements are not available in sufficient numbers.

In India, a four-wheel version of the two-wheel tractor is available. Engineers at Punjab Agricultural University, Ludhiana, India, have developed a "strip-till drill," which uses the same rotary land preparation and seeder combination described earlier but differs by tilling the soil in a strip into which the seed is planted, rather than tilling the whole area. The results have been encouraging.

Zero-Tillage with Four-Wheel Tractors

Zero-tillage may be defined as the placement of seed into the soil by a seed drill without prior land preparation. This technology was first tested in the higher yielding, more mechanized areas of northwestern India and Pakistan, where most land is now prepared with four-wheel tractors but recent work in eastern areas of India, Nepal and Bangladesh shows that it also has great potential in those areas especially if a two-wheel tractor or animal drawn implement can be developed. It can also be used for planting other crops like lentil, chickpea and even rice.



In the late 1980s, 34 zero-tillage trials were conducted on farmers' fields over three years in the rice-growing belt of the Pakistan Punjab. The implement used in these trials was a tractor-pulled seed and fertilizer drill with inverted-T openers. With this equipment, farmers could place the seed directly into the standing rice stubble without any land preparation.

As with the reduced tillage systems discussed previously, earlier planting is the main reason for the additional yields obtained under zero-tillage. In trials in Pakistan, zero-tilled plots were planted as close as possible to 20 November, the optimum date for planting wheat; the longer the farmer delays planting, the lower the yield.

Data from a Trial on Establishment of Wheat Following Rice
Bhairahawa Agricultural Farm, Nepal 1993-94

Method	Wheat yield (kg/ha)	1000-grain weight	Cost to plow (Rs/ha)	Net benefit (Rs/ha)	Extra days needed to plant[a]
Surface seeding	2,775a	46.11a	0	11,485a	0
Chinese seed drill	2,831a	45.43 b	600	12,090a	8
Farmers' practice	2,314b	40.87c	2300	8,065b	15

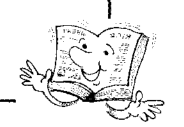
Note : Figures followed by the same letter are not significantly different at 5%probability using DMRT.
[a] Number of extra days needed for land preparation before seeding compared to the surface seeding

At Pantnagar University, India, engineers have modified the seed drill used to plant *rabi* (winter) wheat by replacing the old seed coulters with the new inverted-T openers that had been tested in Pakistan. This seeder is now being produced locally in India at a fraction of the cost of a similar, imported New Zealand drill.

Combine harvesting of wheat is becoming popular among farmers in northwestern India and Pakistan. A potential difficulty with this technology is that the inverted-T opener may not work well where combines are used, as the opener acts as a rake for the loose straw. In this case, various options need to be considered:

- Stubble can be burnt, as is presently done in most conventional systems. However, this creates environmental problems of air pollution and also results in a loss of organic matter.

> Weed problems typically are more severe under conventional tillage than under zero-tillage. Longer-term research is needed to anticipate how changes in tillage practices may affect weed populations.



- A suitable trash drill, using some form of disk opener, can be developed. It could either take the form of disk cutters running ahead of the inverted-T openers or a new system of disk planters could be developed and tested. This implement would raise the weight and cost of the seeder, but it might still be within reach of some farmers, particularly those using combination for harvesting. Through the use of custom hiring, a common practice for resource-poor farmers without tractors for plowing, even these farmers can benefit from the new technology.

- The combination should be modified to chop the straw into small pieces before it leaves the machine and also distribute it evenly on the soil. These small pieces of straw would not interfere with the inverted-T openers and would leave a stubble mulch on the soil surface.

Adapted from:

Hobbs, P. R., G. S. Giri and P. Grace. 1997. Reduced and Zero-Tillage Options for the Establishment of Wheat after Rice in South Asia. Rice-Wheat Consortium Paper Series 2. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

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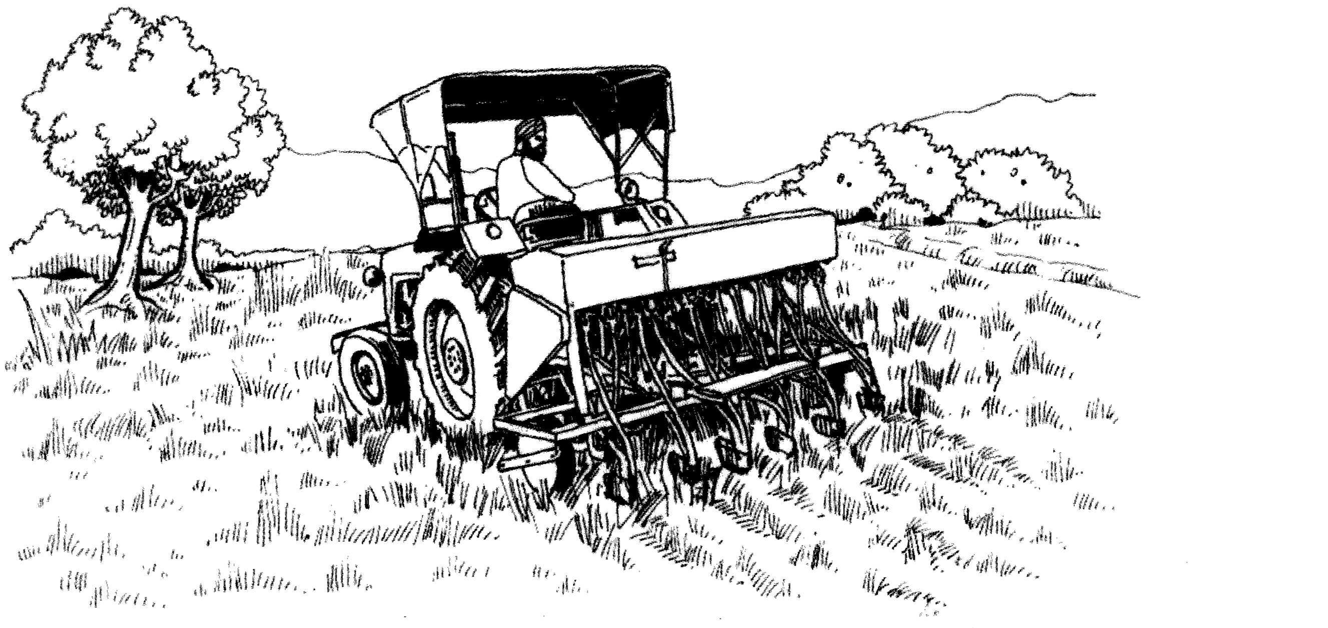
Problems Addressed by Reduced and Zero-tillage and Bed Planting



Late planting is a major problem in many rice-wheat areas of South Asia, except in Punjab, India. To improve the productivity of rice-wheat system, the wheat crop must be planted at the optimal time. Typically, wheat in South Asia produces optimal yield when planted in the end of November followed by a linear decline of 1% to 1.5% per day after that date. Although there is variation among varieties, all show a decline regardless of whether they are short- or medium-duration lines. Late planting not only reduces yield but also reduces the efficiency of the inputs applied to the wheat crop.

Reduced and zero-tillage can save time taken for land preparation. Thus, the turn-around time between rice harvest and wheat planting is reduced and delay in wheat planting is avoided. Similarly, in permanent bed planting system, farmers sow wheat on raised beds already prepared and used for transplanting rice and vice-versa. Also, short-duration rice varieties that can be harvested in October can be used with the improved tillage options; wheat can then be planted in November.

Reasons for Late Planting of Wheat

- Large amount of time farmers invest to prepare a good seedbed for wheat, sometimes plowing six to eight times to achieve this (zero-till and permanent beds help resolve the issue). The long turn-around time is due to excessive tillage, unavailability of tractors or power to plow, too wet or too dry soils, etc.
- Late harvest of the preceding rice crop.
- Late harvest of the preceding short-duration crop (third crop) planted after rice.
- Use of basmati rice that matures late and results in late rice harvest. Farmers prefer to grow basmati rice despite its lower yields because of its high market value, good straw quality (livestock feed), and low fertilizer requirements. Hence, basmati varieties cannot be readily replaced by short-duration rice varieties.

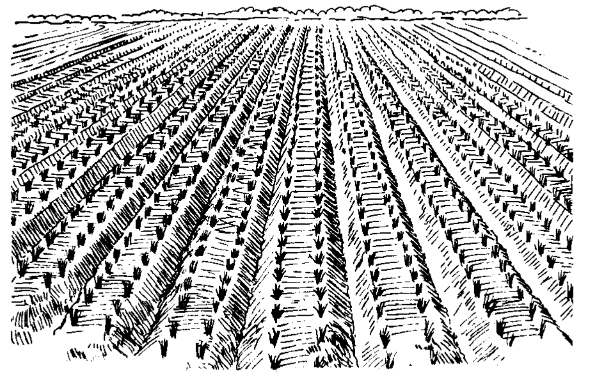
Plant Stand

Generally, farmers in the Indo-Gangetic Plain (IGP) plant wheat by broadcasting the seed into plowed land and incorporating the seed by another plowing. Broadcast seed results in seed placement at different depths and into different soil moisture levels resulting in poor and variable germination. Reduced-till and zero-till machines facilitate drilling and proper incorporation of wheat seed into the soil and thus improve germination and plant stand.

Water and Nutrient Efficiency

Water and nutrients are two major factors that limit yields in the IGP. Increase in cost of fertilizers affects the cost of production and profit margins. The improved tillage options increase the water and nutrient use efficiency by allowing timely planting and producing high yields. These options increase the efficiency of inputs as given below:

- Zero-tillage can be done in wet soils, soon after rice harvest, and so can save the first irrigation.
- Zero-tillage does not loosen the soil and so the first irrigation flows faster over the land than on land prepared by plowing. Some farmers estimate that it takes four to five hours to irrigate an acre when land is prepared and only one to two hours when no tillage is done. This saves water and also results in less leaching of nutrients.



- In bed planting, water is channeled through the furrows and saves about 30% of water.
- In bed planting, fertilizer can be managed for higher efficiency by placing the topdress fertilizer in the soil rather than broadcasting on the surface as in the traditional system.

Cost of Production

The major benefit of the improved tillage options is the reduction in the cost of production. Land preparation is one of the major expenses to grow a crop and any reduction in the number of operations obviously results in saving money. Farmers in the IGP estimate that they pay about US$50 to US$60 per ha for land preparation. They also use considerable amounts of fuel. There is a lot of wear and tear on tractor engines and accessories. By using reduced tillage systems, enormous savings can be obtained by farmers. Additional benefit in income is obtained due to high yields.

Adapted from:

Hobbs, P.R. 2001. Tillage and Crop Establishment in South Asian Rice-Wheat Systems: Present Practices and Future Options. pages 1-22. *In:* Kataki, P.K. (ed). The Rice-Wheat Cropping System of South Asia: Efficient Production Management. Food Products Press, New York, USA.

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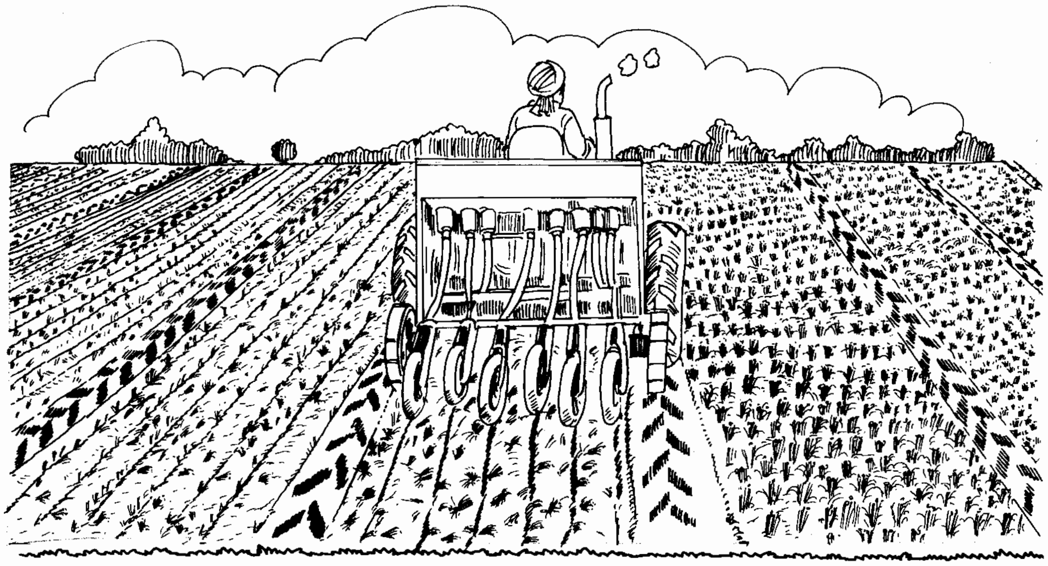
Peter R. Hobbs

Improving Zero-tillage by Controlled Traffic



Conventional crop production practices of the 1960s were asociated with substantial soil and water erosion. To overcome the problem of runoff and soil erosion, resource conservation technologies were developed. These have replaced the frequent tillage and fallow practices that characterized conventional tillage.

Role of Zero-tillage in Conservation Farming

Conservation tillage refers to various practices that provide better protection for the soil. These practices include stubble mulching (maintenance of residue cover with mechanical weed control), minimum tillage (using a mixture of herbicide and mechanical weed control) and zero-tillage (soil disturbance occurs only at planting). Conservation tillage has been widely adopted over the past 20 years in Australia and also in other countries.

Zero or minimal tillage systems are optimal in terms of productivity and sustainability for most grain cropping. Despite overwhelming evidence in favor of this practice, excessive crop residue levels and soil compaction prevent farmers from maintaining zero-tillage production for more than one or two crops. Continuous zero-tillage farming is still rare, except where soils are highly resistant to compaction, and crop residues are minimal due to low yield, grazing, or burning.

Practice with Care

Zero-tillage is the key to improvement of crop productivity and sustainability. But it will be futile unless crops are planted without plowing, burning crop residues, or soil compaction.

What is Controlled Traffic?

Additional effort is required to disturb soil that has been compacted manually or mechanically during tillage. Traditional agricultural systems such as those described by Chi Renli and Zuo Shuzhen (1988) can sometimes avoid this energy penalty by maintaining separate zones for traffic and crop growth, but this is not easily achieved over the full cycle of operations involved in current crop production systems. The negative effects of traffic on infiltration, tilth, and penetration resistance of clay soils in Australia were first quantified by Arndt and Rose (1966), who advocated the use of improved traffic systems to minimize the problems.

Wheeled traffic is unavoidable in current crop production systems. Soil subjected to normal wheel traffic treatment is referred to as "wheeled" and that managed in controlled traffic as "non-wheeled". Optimum conditions for crop production, i.e., soft, friable, and permeable soil are quite unsuitable for efficient traffic and traction, and vice versa.

Wheel traffic increases soil strength and the draft requirement of subsequent tillage, while tillage reduces soil strength and the efficiency of subsequent traction (Tullberg, 2000). It also leads to degradation of soil physical properties (Yuxia Li *et al.*, 2001). Where field traffic follows a different pathway for each of a series of operations, the processes of tillage and traffic are contradictory. These contradictions are avoided in controlled traffic farming (Taylor, 1983), where all field traffic is confined to permanent lanes, and all crops are grown in permanent beds.

Wheeling Problem and Solution

Tractor and implement wheels drive over a large proportion of the field area every time a crop is produced. This proportion is more than 50%, even in zero-tillage. With one or two tillage operations, the total area wheeled, per crop, is greater than the area of the field. Implements (even zero-tillage planters) disguise the effect of wheels on the soil surface. Most of the damage is subsurface, so one has to dig to see it, but because the whole field area has been wheeled, a difference is seen only if there is a nearby non-wheeled area.

Research in the heavy clay soils of northern Australia has shown that most damage in the 10-30 cm depth zone occurs the first time a wheel passes over the soil. The damaging effects last for 2-4 years even in these self-mulching soils, which recover their structure during wetting and drying. The major effects of this damage are:

- Runoff from wheeled areas increases dramatically, increasing erosion and loss of nutrients.
- Infiltration of rainfall into wheeled soil is reduced by 5%-20% (overall); internal drainage is also reduced. Waterlogging is a greater problem.
- Plants can extract ~50% less water from wheeled soil.
- Wheeling kills more earthworms and other beneficial soil organisms than most tillage operations.
- Planting or tillage of wheeled soil requires much greater tractor power.

Lower tyre pressure might help to reduce soil damage, but lower pressures usually require wider tyres, which affect a greater area. The best solution is controlled traffic farming, where all heavy wheels are restricted to permanent laneways, and all crops grown on permanent beds. This is most easily done where the permanent laneways are in the furrows. In controlled traffic fields, 25% or more of field area is lost to permanent laneways, but farmer experience has usually been an overall yield increase of >10%, combined with a significant reduction in costs.

REMEMBER: Plants grow best in soft soil, and wheels work best on hard surfaces.

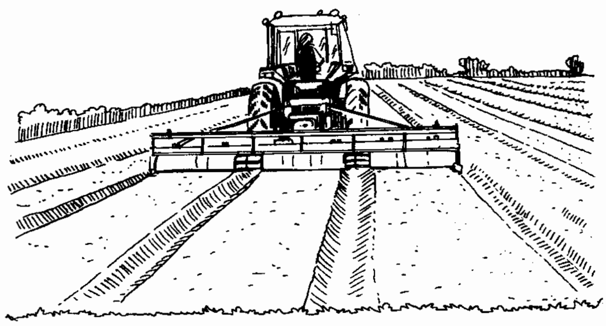
Need for Controlled Traffic

While there are biophysical and insect/disease conditions which can restrict zero-tillage, the major single constraint is the simple issue of planting. Effective zero-tillage planters available in Australia and North America are all complex, large and heavy, and their high cost and power requirement has been a major impediment to the adoption of improved systems even in capital-intensive agriculture. They are quite unsuitable for use in developing country systems, where tractor power and lifting capacity are limited (Murray and Tullberg, 2002, Zero-tillage planting: Project proposal, unpublished).

The cost and complexity of the machinery is a direct consequence of the need to plant through residue into a soil surface that is hard and sometimes uneven. There are many residue soil interactions, but soil surface issues can be overcome by permanent bed or controlled traffic cropping systems. Crop residues left in the field can be reduced by avoiding interrow planting, baling, or cutting; these activities are influenced by residue type, quantity, and condition. Some multinational farm machinery companies have ceased research on zero-tillage equipment in response to limited adoption. Controlled traffic avoids the contradictions inherent in most mechanized farming systems to provide substantial, demonstrable, and consistent improvement in the economics and sustainability of cropping.

Beneficial Effects of Controlled Traffic

Permanent Bed System



Permanent bed system allows soil conditions in the beds to be optimized for crop production, and the lanes optimized for traction. The advantages of controlled traffic include an indirect energy economy which occurs because there is less need for deep tillage. The direct effect occurs because non-compacted soil requires less tillage energy than compacted soil, and traction is more efficient when tyres are working on compacted permanent tracks (Tullberg, 2001).

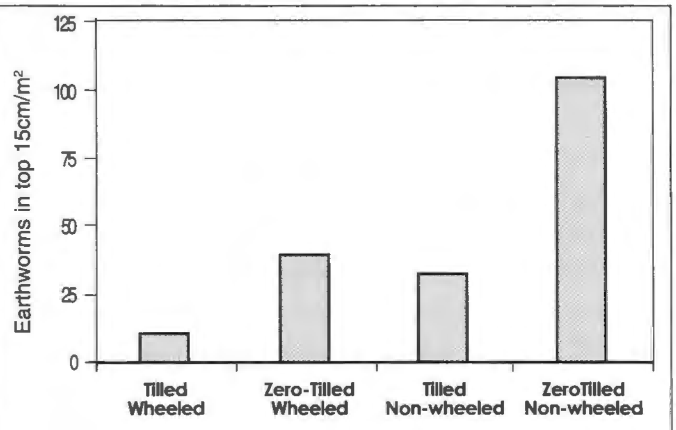
Thus, permanent bed systems provide all the advantages of controlled traffic in terms of reduced energy input and improved soil condition (structure, hydrology, soil life, and crop yield). Bed or controlled traffic systems avoid the problems of leveling and planting tractor wheel tracks, but the permanent wheel tracks also provide a place for the temporary storage of excess residues, and an alternative to residue burning. Permanent bed systems also provide major advantages in direct costing and timeliness in rice production, where the cost of reforming beds for every crop is high and the operation may not be possible if the rains have started.

Soil Response to Traffic

In controlled traffic systems, all field traffic is restricted to permanent, defined traffic lanes. Traffic lanes are normally untilled and not planted to optimize traction and trafficability. Soil in the intervening beds is managed to optimize crop performance, uncompromized by traffic.

Controlled traffic farming avoids the situation where a large proportion of tractor power is dissipated in soil degradation. It is a system in which the management of different soil zones is optimized to provide maximum benefit in terms of:

(1) energy requirements to allow a reduction in fuel use, tractor size, and production cost;
(2) soil structure and health to provide reduced runoff and enhance crop/soil performance; and
(3) spatial precision in the soil/plant/machine relationship to improve crop management.



Wheeling and Tillage Effects on Soil Health: Worms Don't Enjoy Traffic or Tillage!

Farmers Control Field Traffic

Controlled traffic is a prerequisite for zero tillage. Hundreds of Australian farmers using controlled traffic now find they can zero till for many years without the need for expensive deep tillage to undo soil compaction problems. They are saving money, getting better yields, and helping the environment.

Direct Benefit to Farmers

Controlled traffic demands and promotes the use of greater precision in field operations. In northern Australia, farmers practicing controlled traffic have experienced 10% to 20% reduction in time and material input to cropping operations. When permanent wheel tracks are accurately installed, the elimination of double coverage and/or gaps also has a positive effect on yield.

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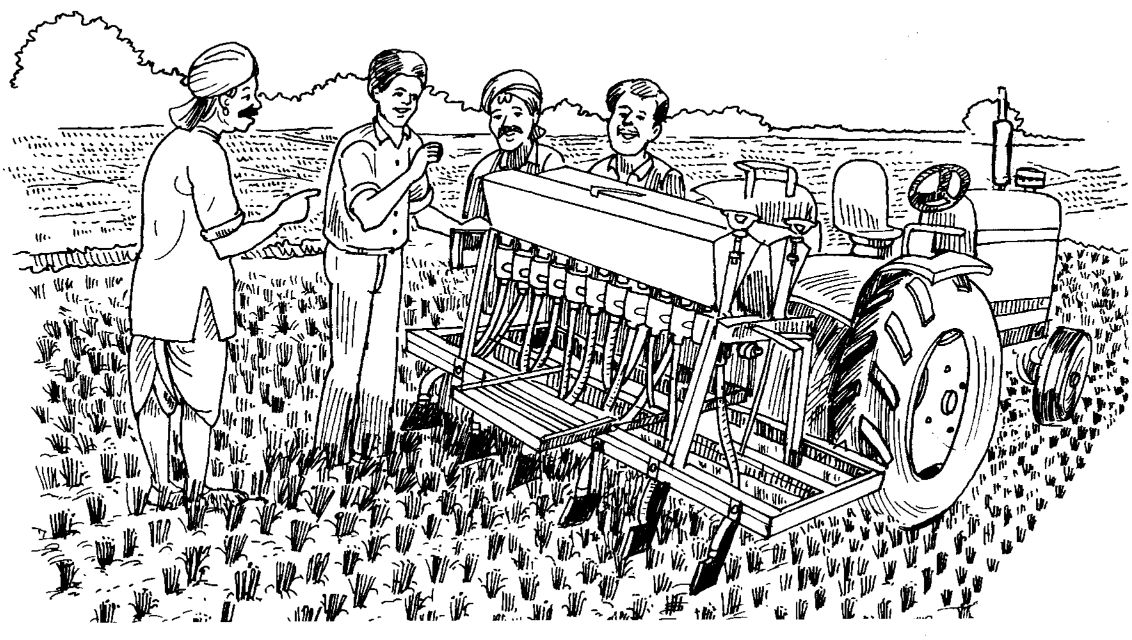
Contributed by:
Jeff N. Tullberg

Zero-tillage Technology:
Troubleshooting Tips



Zero-tillage is a resource-conserving technology that is presently gaining popularity amongst farmers in the Indo-Gangetic Plains (IGP) of India, Pakistan, Nepal and Bangladesh for establishing wheat after rice harvest. The widespread adoption of the technology is hampered because of insufficient training and dissemination of information on the proper use of the machinery and technique. Availability of drills also limits coverage. Training and suitable materials are needed to ensure all operators follow the correct procedures for successful zero-tillage.

✓ Do zero-tillage the right way.

The main problems faced by farmers using zero-tillage are:

- clogging of the drill by loose stubbles after combine harvesting rice;
- increase in rodent activity in some fields; and
- infestation by carryover weeds (e.g., *Cynodon dactylon*) from rice to wheat, particularly on high, well-drained soils in warm areas.

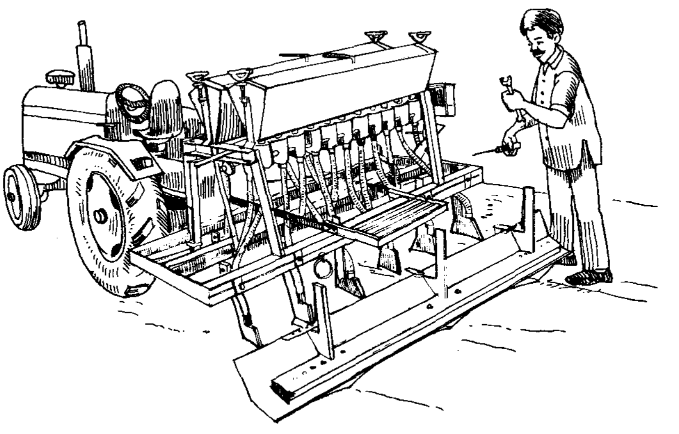
The first problem needs to be resolved by engineers and manufacturers by developing a suitable drill that allows planting into the loose crop residue. The anchored residue is not a problem. The second problem requires some rodent control measures to be taken by farmers and also perhaps community action. Use of reduced tillage and herbicides or better weed control in rice can solve the problem of weed infestation in wheat. Farmers should follow these principles of good zero-tillage practices.

✗ Do not spend money on extra plowing.

Checking the Machinery

The zero-tillage drill should be properly serviced and maintained. It should be checked before use to ensure that all the nuts and bolts are tightened and that all the parts are in good condition. For example, if the openers are worn out, they should be replaced. The fertilizer and seed boxes should also be in good condition to allow free flow of seed and fertilizer. Chains should be adjusted and oiled. After use at the end of each day, the drill should be checked, the seed and fertilizer boxes cleaned, and the moving parts oiled. After the planting season, the drill should be properly stored.

✗ Do not leave the fertilizer in the box overnight as it will clog the opening.



Calibration of the Drill

After ascertaining that the drill is in good working condition, it should be calibrated. Calibration values are sometimes placed on the drill by the manufacturer. However, it is very important to ensure that the drill is supplying the correct amount of seed or fertilizer at the time of use. A plastic or paper bag is placed over the spout to collect the seed or fertilizer dropped by the drill over a specific length or area. The material is collected and weighed. The width and length of the area covered are measured and area calculated. The amount of seed or fertilizer applied per unit area is then calculated and compared with the recommended value. Adjustments are made, if needed, and the machine re-calibrated until the operator is satisfied that the value is within the required range.

✓ Calibration should be done properly at the beginning of the planting season for both seed and fertilizer.

✗ Do not use the machine unless the drill is calibrated.

Seed Germination and Sowing Rate

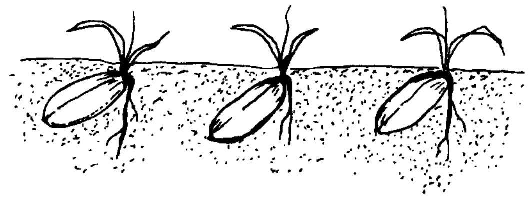
While calibrating the drill, seed germination percentage should be considered. If seed germinates 50%, then twice as much seed needs to be sown. To check germination, place 100 seeds onto a wet newspaper, roll it up, and then carefully close the ends. Keep the roll moist and at moderate temperature for three to five days. Open the roll and count the number of seeds that have germinated and then calculate germination percentage.

✓ Use good quality seed for high germination percentage.

The seed rate for sowing is based on seed germination. Accordingly, the drill is adjusted and the recommended seed rate is used. In zero-till, the seed is placed uniformly at the correct soil depth. The recommended seed rate for wheat is 100 to 120 kg per ha. If seed rate is increased, wheat plants will be spindly and therefore, will lodge resulting in low yield. However, wheat can compensate for low seed rate by tillering and adjusting head size and grains per head.

> X Do not use poor quality seed and high seed rate for sowing because germination and plant growth will be poor.

Some varieties respond better than others to zero-tillage. Wheat varieties that have vigorous early growth and tillering are good for zero-tillage. The best variety available in the region or the variety that has performed well with conventional planting should be used.



Adjustment of the Drill

The three point hitch adjustments where the drill fixes to the tractor should be adjusted. The drill should be level from side to side and have just enough forward and backward adjustment to enter the soil at the proper angle.

> X Do not adjust the drill too steep as planting will be too deep. Do not adjust the drill too shallow as the seed will drop on the surface.

Fertilizer Mixing and Use

Once the drill is calibrated for fertilizer, the chemical should be placed in the fertilizer box. Di-ammonium phosphate (DAP) should be applied at sowing and urea at the first irrigation and second irrigation by topdressing.

> X Do not mix DAP aDd urea and leave the mixture in the fertilizer box for prolonged period because the two products react and form a cake. Thus, there is no free flow of fertilizer to the ground. Do not apply urea at sowing because it burns young wheat roots and reduces seedling emergence.

Soil Factors

Zero-tilled fields should be more wet than conventionally plowed fields at planting. This additional moisture reduces soil strength and allows the emerging roots to penetrate the soil. If the soil is too dry, the soil strength is high and roots may not be able to penetrate the soil. If it is too wet, the roots may experience aeration stress and rot. The correct soil moisture depends on soil texture and is best determined by the farmer. On heavy clay or silty clay soils, it is difficult to operate the zero-till machine due to excess water and poor drainage in the field. In sandy soils, the soils dry out quickly and soil strength increases fast. The field should be irrigated soon after planting with zero-till drill to facilitate root penetration into the sandy soil.

> X Do not use zero-till when the soil is too wet or too dry.

Irrigation

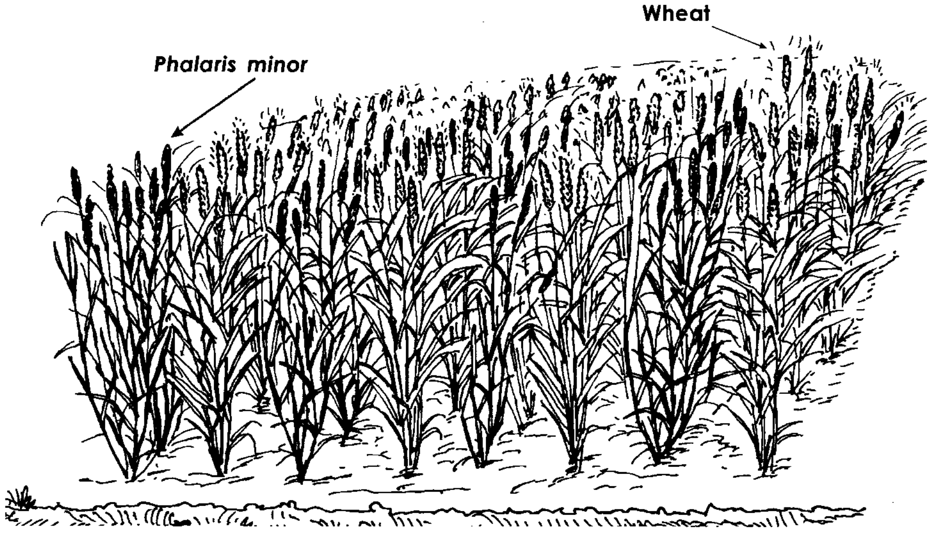
For zero-tilled wheat, rooting depends on high soil moisture that softens the soil and allows easy root penetration. The timing of the first irrigation depends on the soil moisture at planting and soil texture. Light textured and sandy soils should be irrigated earlier in zero-tilled fields than plowed fields to ensure good rooting and subsequent tillering.

✗ Do not irrigate heavy textured soils earlier than recommended unless soil moisture is low.

Weed Control

Zero-tillage disturbs the soil less than plowing. Therefore, few weed seeds reach the surface soil and germinate. The weed population, especially *Phalaris minor*, is low in zero-tilled wheat fields compared to plowed fields. But if the weed population is above the economic threshold, herbicides should be applied at the proper rate and time with proper equipment (e.g., T-jet nozzle). Glyphosate can be sprayed a few days before or soon after planting to control Bermuda grass.

✓ Use herbicides only after proper training.

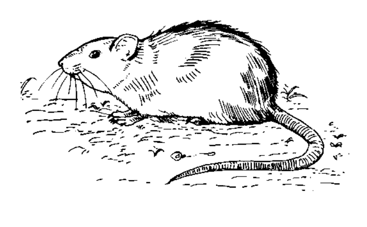


Insect and Rodent Problems

Rice stem borer is often cited as one of the major issues that limits the use of zero-tillage for wheat after rice. But data shows that this is not a problem. In fact, if the anchored residues as well as the loose residues are left in the field and not burnt, beneficial insects proliferate. These act as predators and thus reduce the population of the stem borer.

✗ Do not use pesticides indiscriminately as the population of beneficial insects will be reduced.

Rodent menace is more in zero-tilled fields than plowed fields as their habitat is less disturbed. Appropriate control measures should be followed.



Contributed by:
Peter R. Hobbs

Surface Seeding as a Crop Establishment Option in Problem Areas

In some areas in the eastern part of the Indo-Gangetic Plain, the soils are fine-textured and poorly-drained, impeding normal tillage. These soils take long to come to workable soil moisture conditions before they can be plowed. This delays sowing of wheat after rice harvest. Thus, the traditional tillage practices result in rice-fallows or in uneconomic wheat yields. Farmers have adopted surface seeding for good crop establishment. It is a new option that offers farmers many benefits including less cost and drudgery, timely planting and higher yields.

Surface seeding is a farmer practice for wheat establishment in parts of eastern India, Nepal and Bangladesh. It is particularly relevant to farmers with small landholdings and who have limited or no farm power sources. It is popular with the farmers in Nepal, Bihar (India), and China for its potential of increasing the cropping intensity in many areas where soils remain waterlogged for long or fields are vacated late for winter crops. In the Yangtze River Valley of China, wheat seeds are sown after a pre-seedling herbicide application and then covered with rice straw mulch. Farmers are practicing surface seeding successfully not only in wheat but also other upland crops. High yields have been obtained in wheat, pea and lentil. This technology is commonly used throughout the Indo-Gangetic Plain for establishing winter pulses and oilseeds after rice.

Surface Seeding: The Practice

Seeds of wheat are broadcast or seeded in rows using drum seeders on the surface without disturbing the soil. The seed is sown before or after rice harvest depending on soil moisture. Surface seeding of wheat onto unplowed, wet soil before rice harvest has worked well in heavy, poorly drained soils.

Relay Planting

Wheat can be relay planted into the standing rice crop if the soil moisture is suitable (saturated) for surface seeding of wheat before rice harvest. When the crop is ready for harvest, the cut rice bundles are placed evenly on the surface. This allows the rice to dry while the straw acts as mulch. However, relay planting is feasible only if the soil moisture is correct. Mulching can also give similar benefits. A layer of loose rice straw is spread on the ground after surface seeding the wheat.

Advantages of Mulching

- deters weed growth
- protects the seed and young seedlings from birds
- maintains good soil moisture for germination
- keeps the surface soil moist for long
- ensures good root growth

In surface seeded wheat, fertilizer cannot be incorporated into the soil. Hence, it is better to apply phosphorus and potassium fertilizer with the seed at planting and delay the nitrogen fertilizer until the first topdressing, usually best applied after the rice crop is removed and wheat is established. This practice improves the efficiency of applied fertilizers.

Practice in Coarse Soils

Surface seeding in coarse soils is successful if the soil moisture can be manipulated. Soaking the seed can help as there would be enough surface moisture to germinate the seed. Light irrigation at root penetration stage reduces soil strength and thus facilitates root growth.

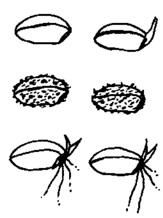
Key to Success

Ensure correct soil moisture for surface seeding.

Why?

Too little moisture results in poor germination. And too much moisture causes seed rot. So you must ensure correct soil moisture.

Check the soil moisture by placing a foot print in the soil. If the soil is saturated, water will appear in the imprint. A saturated soil is the best as it facilitates seed germination and root elongation. The roots penetrate into the moist soil, following the saturation fringe. High soil moisture reduces soil strength. However, if the soil moisture level is too high, it reduces the oxygen supply. Oxygen is needed for healthy root growth.



But how?

Production of Wheat Following Rice in Nepal, 1993/94

Parameter	Surface seeding	Chinese drill	Farmer's practice
Grain yield (t /ha)	2.78	2.83	2.31
1000-grain mass (g)	46.11	45.43	40.87
Cost to plow (Rs/ha)	0	600	2300
Net benefit (Rs/ha)	11485	12090	8065
Extra days needed for land preparation before seeding	0	8	15

Benefits to Farmers

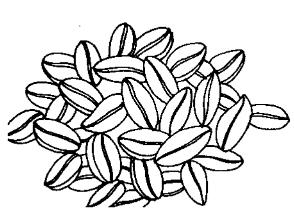
Surface seeding is the simplest of all crop establishment options wherein the seed is placed on the soil surface without any land preparation or tillage. Timely surface seeding of wheat significantly improves yields at relatively less cost. As the cost of land preparation is zero, surface seeding generates high net benefit.

Wonders in Nepal!

Heavy rains in November 1996 reduced wheat yields which were lower than in 1995. Although surface seeded wheat was damaged, yield was higher than yields from plowed fields. In 1997/98, continuous rain hampered wheat planting. Farmers who used surface seeding planted their crop on time and harvested 3 to 4 tons of grain per ha. But farmers who used the traditional plowing methods could not plant the crop.

Bonus for the Farmer

The 1000-grain mass of wheat is high in surface seeded fields as the crop is planted 15 days earlier than the normal practice. Farmers in the Terai region of Nepal receive a premium for bold grain.



Adapted from:

Hobbs, P.R. 2001. Tillage and Crop Establishment in South Asian Rice-Wheat Systems: Present Practices and Future Options. pages 1-22. *In:* Kataki, P.K. (ed). The Rice-Wheat Cropping Systems of South Asia: Efficient Production Management. Food Products Press, New York, USA.

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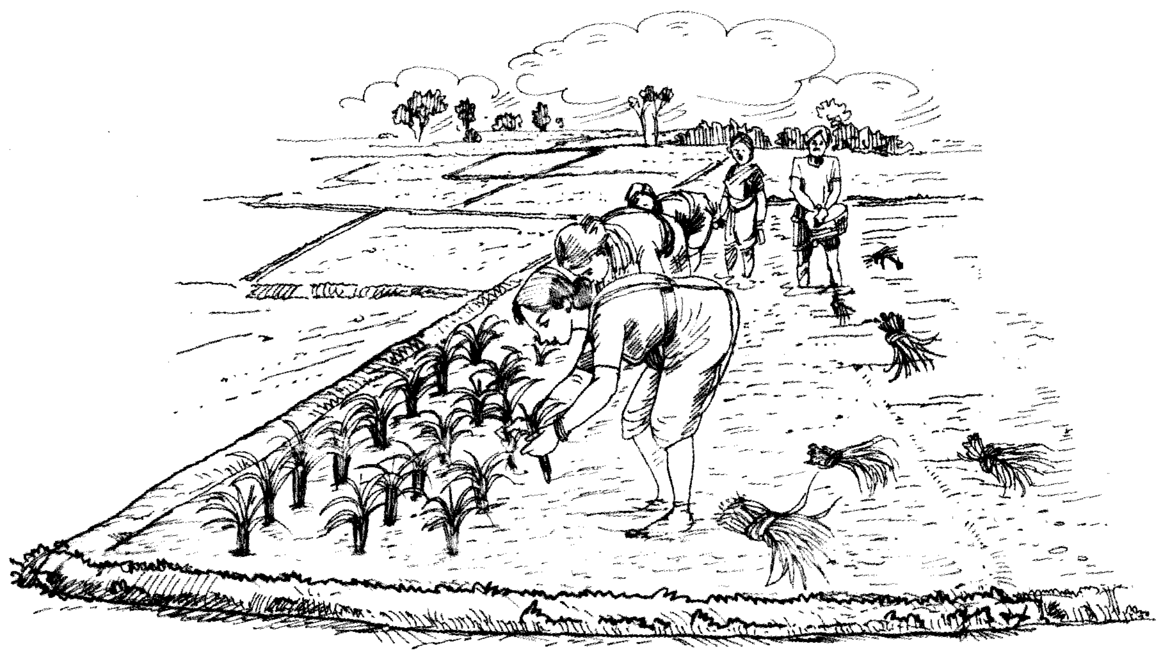
Rice Seedling Raising and Transplanting Techniques

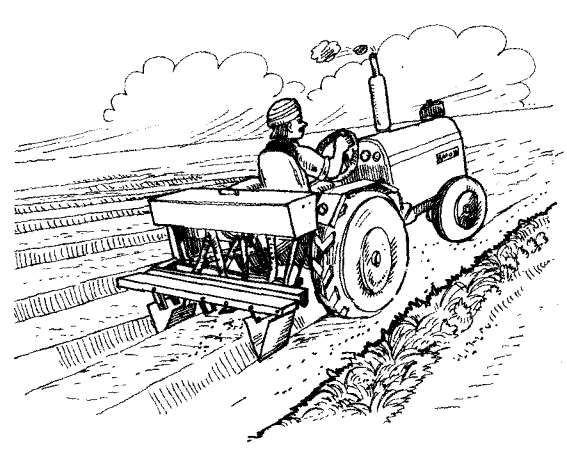


Rice seeds are sown in nurseries to raise healthy seedlings for transplanting in flat puddled beds or, more recently, in furrow irrigated raised beds (FIRB) or bed planting system. Healthy rice seedlings play a great role in increasing the yield of transplanted rice. In the traditional method, farmers use a very high seed rate (80-100 g/m^2) in the nursery mainly because of two reasons, i.e., to overcome the weed problem and for easy uprooting. Transplanting of seedlings so raised results in up to 20% mortality after transplanting. To compensate for the seedling mortality in the field, planting of several (4-5) seedlings per hill is required. This increases the seed rate.

Improved Nursery Practices

Soil Preparation

Nursery practices are based on soil conditions in the field. Whenever soils are fine-textured, i.e., clayey, sand is added to the raised nursery beds to facilitate uprooting of seedlings without damaging the root system. Enough compost or farmyard manure is added to the nursery beds, which are raised 15-20 cm above native ground level. Each bed should be of 1m wide and about 20m long. The central tyne of the tractor-drawn bedshaper can be removed to make raised nursery beds of about 1.1 m wide for raising rice seedlings.



Seed Treatment

To reduce failure of seed germination and mortality of seedlings in the nursery due to fungal diseases, mix fungicides such as Carbendazim are mixed thoroughly with the seeds before sowing. The rate of fungicide application is 2g per kg seed. Seed priming, i.e., soaking of seed in water for 10-12 hours and treatment with Vitavax improve seedling vigor.

Solarization

Covering of the raised seedbed with polythene sheet, i.e., solarization, in rice root knot nematode-infested fields is reported to improve seedling growth.

Sowing

Seeds are broadcast thinly at 40-50 g/m^2 over the raised seedbeds to provide enough space between seedlings. This reduces competition for light, nutrients and water among the young seedlings and encourages good seedling vigor.

Weed Management

Weeds are a major bottleneck in raising healthy seedlings, specially when low seed rate is used. Due to the similar morphology of rice and weed plants in the initial stages, it is difficult to remove the weeds manually in the nursery. A new herbicide Pretilachlor + Safner (Sofit) when applied at 500g a.i. (1500g of product) per hectare within three days after sowing i.e., before weed emergence, effectively controls weeds in rice nursery. For control of *Echinocloa colonum,* apply Cyhalafop butyl (Clincher) at 120g a.i./ha (1200g of product) 10-12 days after sowing. Use of Butachlor after seedling emergence is recommended with sustained submergence for the next 2-3 days.

Seedling Vigor

Seedlings from treated seeds grown on raised beds mixed with manure and with proper, weed control attain good growth and 3-4 tillers within 20 days after sowing. These seedlings can be planted singly without adverse effect on plant population. Tillered seedlings are easy to plant and save costly seed.

Land Preparation

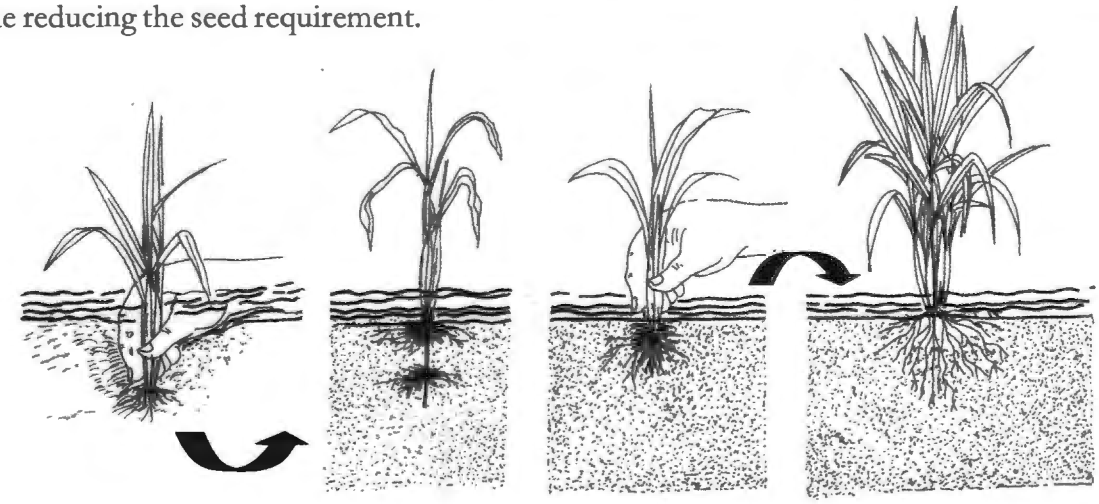
In the traditional practice, the soil is plowed and puddled after ponding water. The soil is brought to a fine tilth to enable easy transplanting. Raised bed planting is recommended.

Transplanting Healthy Seedlings

One single vigorous seedling is transplanted per hill or spot. This brings about significant saving in the seed requirement per hectare. The traditional practice involved transplanting 2-8 seedlings per hill to compensate for mortality, weak seedlings and poor tillering.

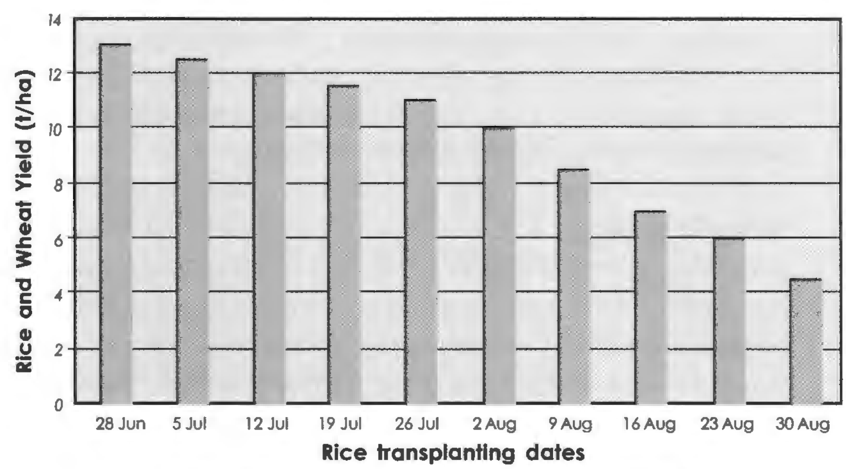
Shallow Planting of Seedlings

The traditional practice of deep (usually more than 5cm below the soil surface) planting of seedlings results in poor or delayed establishment after transplanting. This practice also reduces tillering. Shallow planting of a single healthy seedling encourages tillering and yield while reducing the seed requirement.



Deep planting produces weak plants **Shallow planting promotes tillering**

Timely Planting, Improved Productivity



Effect of Planting Dates on Yields of Rice and Wheat in the Eastern Indo-Gangetic Plains

More than half the precipitation received during monsoon period in the eastern parts of the Indo-Gangetic Plains is wasted in raising rice nurseries and tillage operations. Development of groundwater source, for raising nurseries of rice seedlings and for providing supplementary irrigation can be a good strategy to promote efficient use of rainwater and the monsoon rains in subhumid regions. Timely transplanting of rice into the main fields immediately after the first or second rains permits maximum use of the rainwater for the rice crop. This crop can be harvested earlier to permit timely planting of the succeeding wheat crop. As the wheat crop cannot be planted unless the field is vacated of the preceding rice crop, the timely planting of rice effects the productivity of both the crops and thus the total system productivity, transforming "unfavorable zones" into "favorable ecozones" for rice-wheat production.

Adapted from:

Gupta, R.K., A.K. Shukla, M. Ashraf, Z.U. Ahmed, R.K.P. Sinha and P.R. Hobbs. 2002. Options for Establishment of Rice and Issues Constraining Its Productivity and Sustainability in the Eastern Gangetic Plains of Bihar, Nepal and Bangladesh. Rice-Wheat Consortium Travelling Seminar Report Series 4. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

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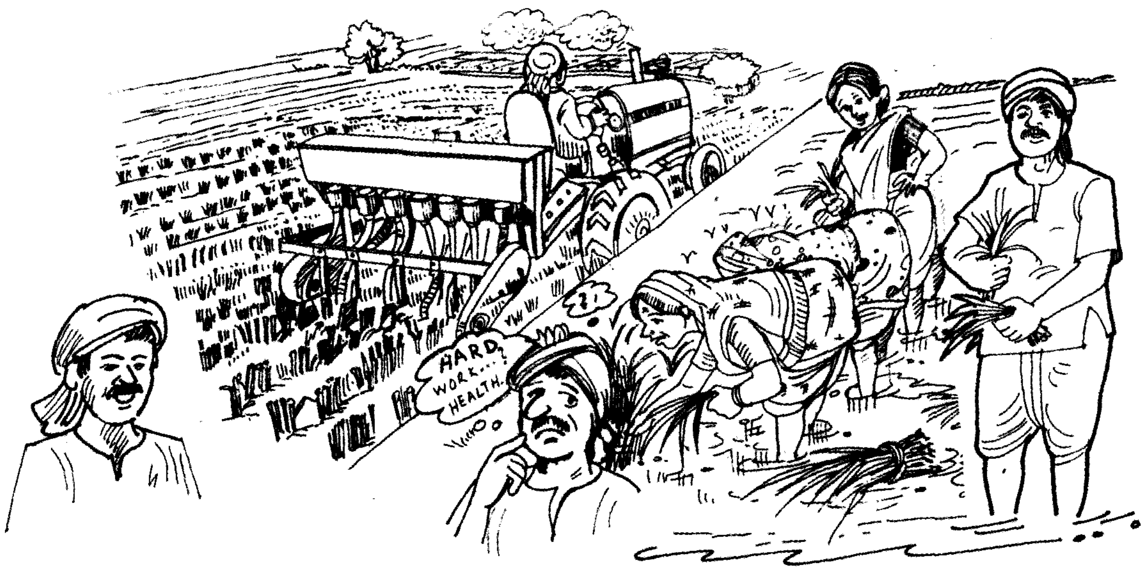
Raj K. Gupta

Alternatives to Puddling and Manual Transplanting

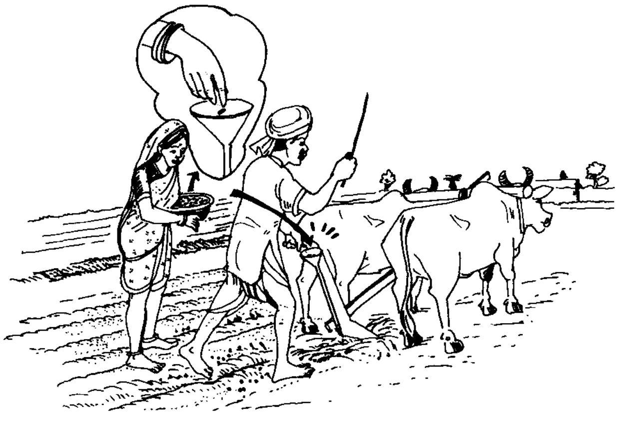


Puddling of soil and manual transplanting of 4-6 week old rice seedlings is a tradition. However, this system is labor-intensive and requires a lot of water and power at critical peak times of the season. Long-term experiments suggest that continued puddling of fields for rice destroys soil physical properties and negatively affects yields of both the puddled rice and the following crop. Alternative technology options are needed that can be used to substitute for this drudgery-ridden and costly manual transplanting method.

Puddling	
Advantages	**Disadvantages**
• Reduces soil permeability • Preserves aquatic, anaerobic conditions • Controls weeds, improves water and nutrient availability • Facilitates transplanting	• Destroys soil aggregates • Breaks capillary pores • Disperses fine clay particles • Lowers soil strength in the puddled layer • Plow pan (compacted layer) resists root penetrations of following crop • Causes waterlogging • Forms large clods in finer-textured soils preventing seed-soil contact • Forms impermeable clayey layer on the surface in coarser soil

Efforts are underway to search technology options to achieve alternative crop systems establishment. The following systems are being reached and have the potential to **replace the puddling** in the ricefields.

Alternatives to Puddling



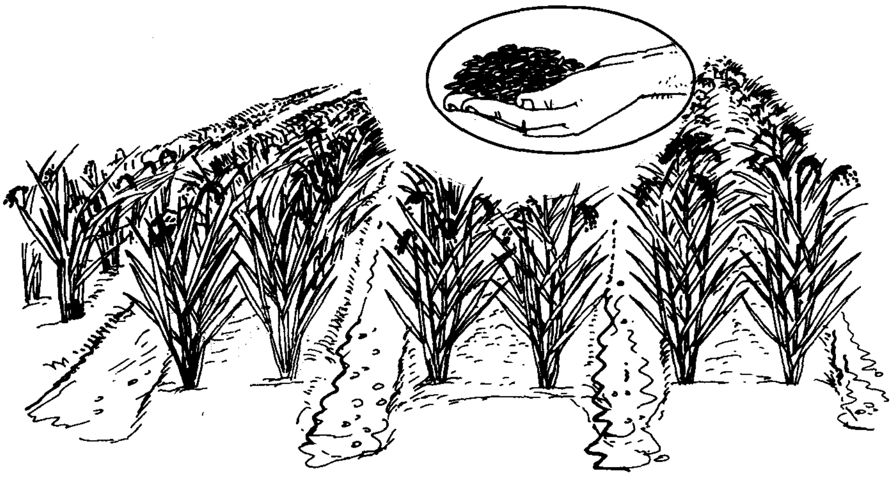
Dry-Seeded Rice

Growing rice without puddling with the possibility of intermittent flooding is called dry-seeded rice. In this system, rice is grown like any other upland crop with seed placed in the soil with or without plowing but not puddled plowing when the soil is flooded. This system delays the seed to seed time in the field and does not have weed problems that need effective control. Weed control is a major issue and scientists are finding ways to overcome this.

Growing rice with this method, after an upland crop, will result in better soil properties for establishment and growth. Saving of water by not puddling will depend on soil texture and how water is managed for the upland rice crop. Direct-seeded rice may need extra water early in the rice growth to help control weeds, but will use less water after the crop is established. Fertilizer chemistry will be different but in dry-seeded rice, the crop will be able to utilize the nitrates lost when soils are puddled. In aerobic conditions, availability of some micronutrients like zinc and iron may be a problem.

Dry-seeded Rice

Advantages	Disadvantages
• Better yield of the crop.	• More difficult weed control
• Saving on water	• Zinc and iron may become a problem
• Less drudgery and less labor needed	• More insect (termites) and disease problems



For actual seeding of rice without puddling, the Chinese hand tractor seeder and the Pantnagar drill could be used.

Zero-Till Rice

Another sub-system of dry seeded rice is zero-till rice. In this system, weeds are allowed to germinate and then controlled with a non-selective herbicide like *Glyphosate*. A zero-till drill is then used to seed the rice. Because the soil is least disturbed in this method, fewer weeds germinate.

Bed-Planted Rice

This practice is very similar to the bed planting as done in the wheat crop. It has been tested by the Rice-Wheat Consortium (RWC) partners and farmers with success. In this method, beds are prepared afresh or the beds prepared for the previous wheat crop are used for seeding. The older beds are reshaped before use and rice is planted as a dry-seeded crop or transplanted in the form of seedlings. Although data is not yet available, both systems seem to be equally effective.

Farmers have given a positive feedback on this system. According to them, saving of water has been the main advantage. As compared to the flat system, there is a saving of at least 30%-50% of water. The movement of the tractor in the furrows (bottom) may have made the soil compact and reduced water percolation to some extent. Impact of this kind of compaction of soil is yet to be established through long-term research.

Weeds are still a problem and need integrated management to control them. Besides enjoying the advantages of controlling weeds through direct seeding, mechanical weeding can also help reduce the weed menace. However, this is only possible when the field is dry enough to allow movement of tractor in the furrows.

Bed planting makes fertilizer placement, weeding and spraying easy. Farmers have to remedy the problems of zinc deficiency and iron chlorosis in some fields. Termites often appear in the fields and have to be controlled.

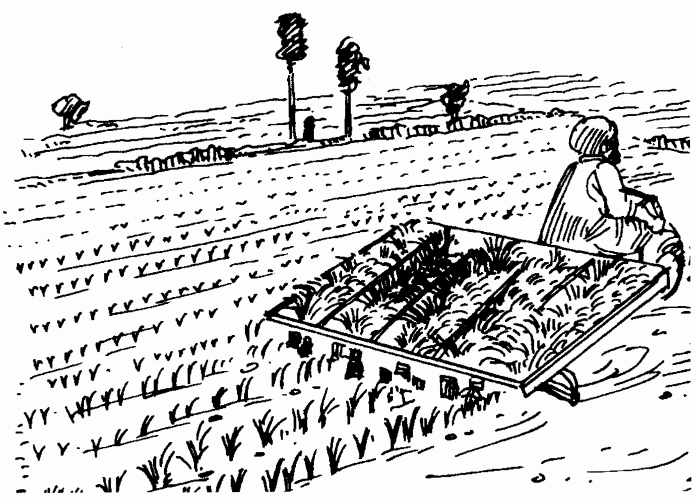
> Bed planting is more successful in case of **hybrid rice** as it has the capacity to use nitrate nitrogen better. Plants recover very fast and produce tillers profusely. Use of plastic bubble sheet to raise single hybrid seed seedling-plugs may be one way to get higher yields and save on costly hybrid seed.

Alternatives to Manual Transplanting

Replacement of manual transplanting is necessary to save labor, cost, time and reduce the drudgery of growing rice. Three systems have been suggested to replace manual transplanting.

Mechanical Transplanter

This equipment has been developed in Japan, Korea and China in response to decline in availability of labor. This system involves raising rice seedlings in a mat form. Several such mats are raised for transplanting purposes. The mats are placed in a specially devised machine used to plant the seedlings in the field at pre-determined spacing. Farmers in the IGP have been advised to use the Chinese model as it is ten times cheaper than other models. Manual system is still being tested.

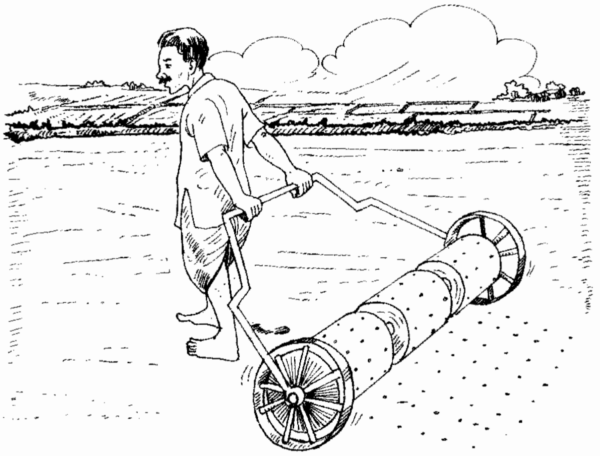


The key to success of this system is the raising of the seed mats. This may have to be done commercially so that the cost of production could be reduced. Even landless laborers could be tapped for this purpose. Settling time after preparing the field and water level in the field are the key factors for the success of the mechanical rice transplanting, though it would not be an issue in mechanical transplanting on zero-tilled soil.

Wet-Seeded Rice and Drum Seeder

In this system, the field is puddled and then sprouted seeds are placed on the wet soil. This is either done by broadcasting the seed or by using a drum seeder. Wet seeding is more popular in Asia as it reduces labor cost. Improved availability of new rice varieties for direct seeding and also effective herbicides for weed control has helped making this system more popular. Wet seeding is more eco-friendly as seeds are sown in rows which facilitates the use of rotary/conical weeders. Periodic inter-row cultural operations for weeding may also aerate the root zone.

In spite of the advantages, this system extends the field-time for growing rice. This is an important consideration where triple cropping is used or the climate is cooler.



There are two types of wet seeding:
(a) surface or aerobic seeding; and
(b) sub-surface or anaerobic seeding.

Surface or Aerobic Seeding

In this method, pre-germinated seeds are sown on the surface of well-puddled soil. This is done preferably one day or at the most two days after the last puddling and levelling has been done. The technique involves uniform broadcasting of seeds either by hand or by a motorized sprayer. Alternatively, a drum seeder can be used to sow the seeds in rows. High quality, clean seeds are soaked for 24 hours in case of hand-broadcasting and only for 12 hours in case of drum seeding.

> **How to Pre-germinate the Rice Seed**
>
> - Incubate the seed for 12 hours.
> - Take out after the seed imbibes moisture.
> - Heap the seed and cover with gunny bag.
> - Water the bag frequently.
> - After 24 hours, it will germinate and radical will come out.
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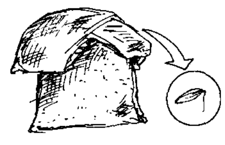
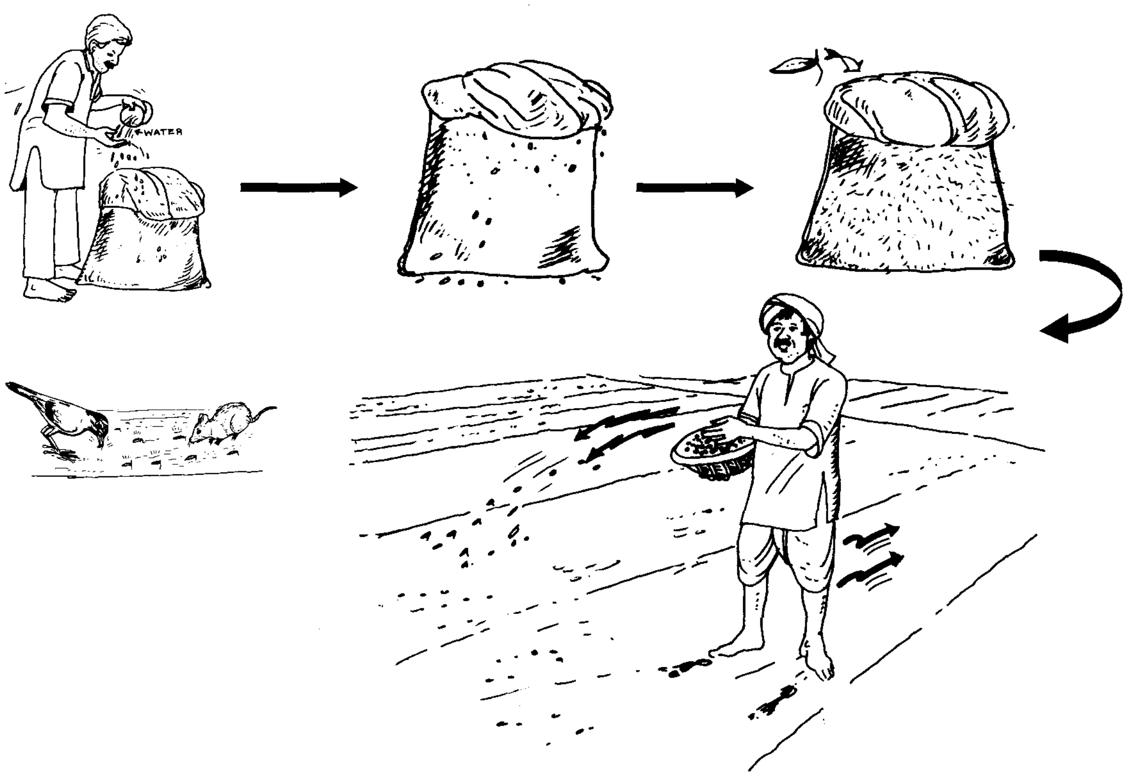
> 

In case of hand-broadcasting, the person sowing the seeds either by hand or drum, has to walk backwards. He has to avoid making too many depressions in the soil so that water does not accumulate in them and rot the seed. Seeds in this method lay only half buried into the soil thus exposed to damage by birds, rats, snails, ants, etc. Torrential rain or longer dry weather will easily spoil the seed.

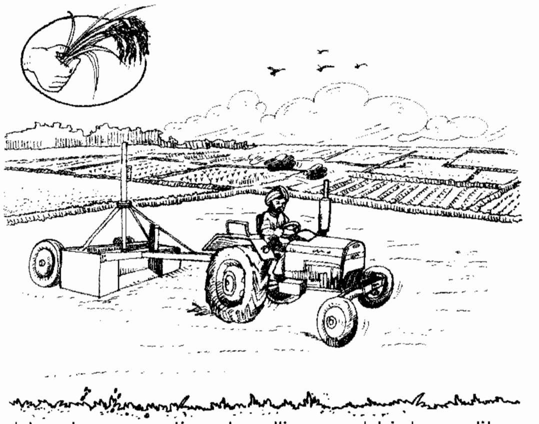
Seed rate varies from 100 to 150 kg/ha for broadcasting and half as much for drum seeding.



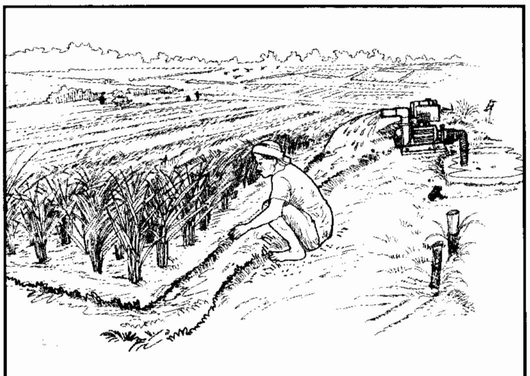
Sub-Surface or Anaerobic Seeding

The main aim in this method is to broadcast the seeds and provide a protective cover over the seeds against damage by weather conditions and/or pests. This can be achieved by broadcasting the pre-germinated seeds after puddling and allowing a thin layer of mud to settle on them. Alternatively, pre-germinated seeds can be sown in rows one to two days after puddling by an anaerobic seeder fitted with furrow openers and closers. Seed rates are similar to that of surface seeding.

Crop Establishment by Wet Seeding



Good land preparation, levelling and high quality seeds are vital for a successful crop stand.



Keep the soil saturated with flush irrigation (but not flooded) to facilitate seedling emergence and early growth. Later, the water level can be increased to 5-10 cm as the crop grows.

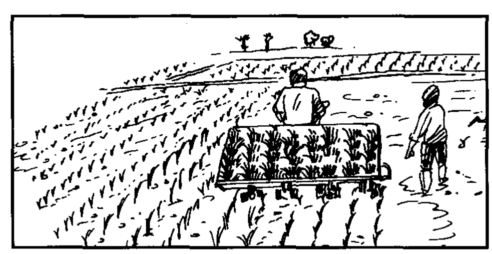
Use pre-emergence herbicides or inter-row cultivators in row-seeded rice to control weeds.

Apply N in three split doses at 21, 35 and 49 days after seeding. Practice pest management as in other transplanted rice.

Broadcast Seedlings

This is an innovation from China. In this system, seedlings are prepared on plastic bubble sheets on raised beds. The seedlings thus prepared are lifted easily along with some soil (these are known as plugs) and used for either broadcasting or transplanting in the soil. The seedlings are thrown in the air and they fall in the muddy soil with the heavier roots facing downwards. Thus, the seedlings penetrate and get encased in the soil reducing the transplanting shock period. A mechanical blower is also available to help in broadcasting the seedlings. This system when used for sowing hybrid seed, specially on beds, has been proven very productive.

There is a hole at the base of each bubble to allow roots to penetrate and get nutrients and water from the raised beds on which the sheets are placed. The raised beds need to be properly fertilized to provide the needed nutrients.



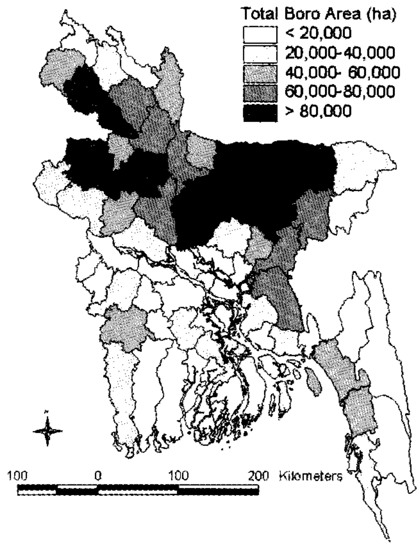
Plastic bubble sheets for this purpose were brought from China by the RWC for conducting experiments. Although the results are satisfactory, yet the scientists are in the learning phase. Technology of gap filling and evenly spreading the seedlings has to be worked out. Seedlings must be prepared on the raised beds as wide as the plastic sheet and need to be placed in the shade. They are easy to uproot and transport to the field.

Adapted from:

Hobbs, P. R., R. K. Gupta, J. K. Ladha and V. Balasubramanian. 2000. Crop Establishment and Management: New Opportunities. Paper Presented at the International Workshop on Developing an Action Program for Farm-Level Impact on Rice-Wheat Systems of the Indo-Gangetic Plains. 25-27 September 2000. New Delhi, India.

Corresponding author:
Peter R. Hobbs

Boro Rice: An Opportunity for Intensification



Boro rice is cultivated in waterlogged, low-lying or medium lands with irrigation during November to May. This type of rice has been cultivated traditionally in river basin deltas of Bangladesh and Eastern India including Eastern U.P., Bihar, West Bengal and Assam. In these regions, water accumulates during monsoon months and cannot be drained out in winter months. This practice is spreading even to those non-traditional areas where irrigation is available.

Boro rice system takes advantage of residual moisture after the harvest of *kharif* rice. Such areas with high moisture retention capacity are low-lying ditches where water is stored or gets accumulated, areas adjoining canals and roads, *Chaur*-lands/*Tal*-lands, etc. With the increase in irrigation facilities, boro crop is now being taken in areas outside its traditional boundaries and a new cropping system is emerging.

"Boro" is a Bengali language word derived from a Sanskrit word "BOROB". This means a special type of rice cultivation on residual or stored water in low-lying areas after the harvest of *kharif* rice.

Boro rice in India

1991	1.35 million ha
1995	1.60 million ha
2000	2.95 million ha

Boro is a winter season, photo-insensitive, transplanted rice cultivated on supplemental irrigation. This gives the farmers a chance to grow a *rabi* season crop which normally they could not grow. Rapid expansion of boro rice cultivation has taken place in recent years in West Bengal and Bihar, it is likely to expand further to more areas in West Bengal, adjoining areas of Assam, parts of Eastern U.P., coastal areas of Orissa and Andhra Pradesh.

Productivtiy of Boro Rice

State	Productivity (t/ha)
West Bengal	3.5
Orissa	3.0
Assam	3.5
Bihar	3.0
Eastern U.P.	2.0
Average	**3.0**

Advantages of Boro

Boro rice is known for high productivity (5-6 t/ha) in deepwater areas of Eastern India, where productivity has traditionally been very poor (<1 t/ha) during the *kharif*. This is mainly because boro is more manageable than *kharif* rice. For example, water management in boro is more systematic as it is an irrigated crop. Consequently, this crop responds well to higher doses of fertilizers resulting in higher production. Being a winter season crop, it is spared from insect-pest infestation.

Major Areas Growing Boro Rice

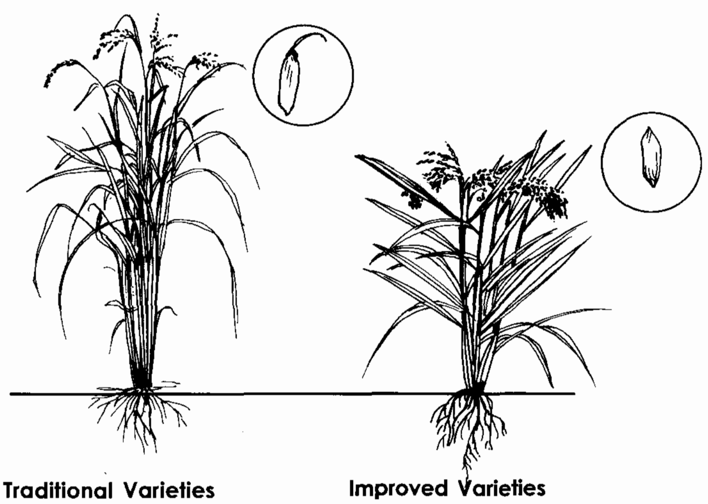
State	Districts
Eastern U.P.	Ballia, Basti, Gorakhpur, Deoria, Gazipur (Lake, rivers, *nalahs*, etc.)
Bihar	Purnia, Katihar, Madhepura, Madhubani, Darbhanga, Saharsha (Low-lying *chaurs* and *chauri*)
West Bengal	Baredwan, 24-pargana, Nadia, Midnapur, Bhankurh
Orissa	Balasore, Bhadrak, Kendrapara (Low-lying areas of coastal belt)
Assam	Nawgaon, Karimganj (Lake areas)

More important advantage is the lower winter temperature during the earlier crop growth. This facilitates the accumulation of photo-synthates, thereby increasing carbon: nitrogen ratio. During the ripening period, the temperature rises facilitating the process. Variations in these parameters explain variation in yields across the boro growing areas.

Increased adoption of boro rice cultivation, both within and outside its traditional boundaries, has helped in the emergence of many local cropping patterns. This has also helped in transforming the economy of the farmers.

Agro-Technology for Boro Rice

Even a marginal increase in the productivity of boro rice in Eastern India will significantly increase the total rice production in the country. Therefore, a sustainable agro-technology for boro rice is imperative.



Traditional Varieties

- Tall
- Weak stemmed
- Awned
- Cold-tolerant
- Grain quality poor
- Low yield

Improved Varieties

- Early to mid-early in maturity
- Dwarf and sturdy
- High yield
- Better grain quality

Desirable Traits for Boro Rice Cultivars

The boro rice cultivars have additional desirable traits over those of irrigated rice varieties grown during *kharif*. The cultivar has to be of short duration having physiological and plant type parameters to shorten the vegetative growth phase and more efficient dry matter accumulation. These would mean cold tolerance, lower loss of water due to transpiration, shade efficiency, less tillering and more effective tillers. Quick establishment capability after transplanting is also a desirable trait.

Popular Varieties

Gautam, Prabhat, IR 64, Krishna Hensa, IR-36, Joyamati, Vishnu Prasad, Jyoti Prasad, Chinsura *Hybrid-3* and some other varieties that do well under irrigated conditions.

As boro rice seeds are sown in early winter, the seeds of the cultivar should be able to germinate at lower temperatures say, ranging between 12-14°C. The shape of vacuoles and thickness of mesophyle layer in the internal structure of the leaves need to be bigger enough to make the cultivar more cold-tolerant.

The cultivar needs to have low amylase content (20%-50%) in the grain. The expected yield level has to be 6-7 t/ha with harvest index of 0.50 to 0.55.

Cultural Practices

Nursery management

- Nursery for boro crop is sown in the last week of October to mid-September before onset of the winter season.
- Prepare the seed bed in low-lying areas near the source of irrigation.
- Irrigate seed beds frequently.
- Dust the seedlings periodically with fuelwood ash, straw ash, cattle dung ash, etc.
- Cover the seedlings with a plastic sheet at night to avoid yellowing of seedlings.

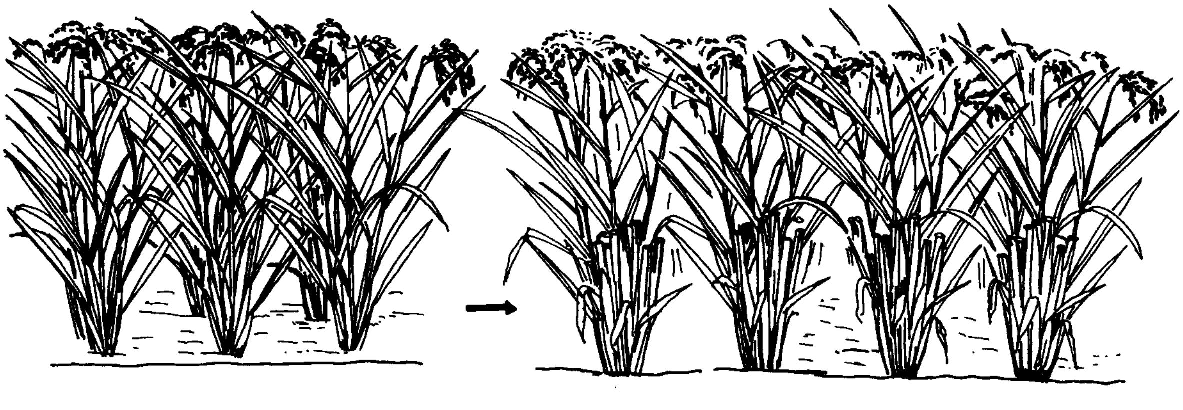
Transplanting

- The seedlings are transplanted in mid-January to February.
- Keep seedlings 18-20 cm high (75-85 days).
- Keep seedlings 5-6 cm in standing water.
- Place the seedlings 4-5 per hill at a spacing of 20x10-15 cm.
- Dense planting and/or higher number of seedlings are required to maintain the plant population.
- Depending upon the soil condition, apply 120-150 kg N, 60-75 kg P_2O_5 and 50-80 kg K_2O.
- Need-based irrigations are given from groundwater sources/canals/low-lying catchments.

Boro-Boro Ratoon

Boro-ratoon refers to the crop which grows from the stalks left after the harvest of the main boro rice crop. Ratooning is possible only when boro rice is harvested before middle of May and field is not inundated up to June. Irrigation facility is an important pre-condition for taking a ratoon crop.

In this system, the main crop is harvested leaving stalks 30-45 cm high. Soon, new tillers re-grow and the boro ratoon crop is ready within five to six weeks.



Constraints to Boro Rice Cultivation

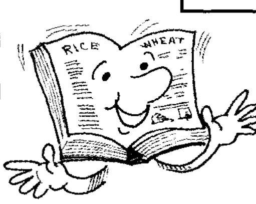
Boro crop is a 190-200 days crop and may require more resources and care for a longer period. Moreover, improved varieties and agro-techniques are not available for boro rice cultivation. Lack of credit facilities and the small size of holdings are major challenges. Some of the environmental constraints are as follows:

Weather fluctuations

Low temperature at seedling stage can cause poor germination, slow and stunted seedling growth, yellowing of leaves, leaf spots, slow and delayed tillering and non-synchronous and delayed flowering. Dense fog, coupled with greater temperature fluctuation or high day temperature at flowering may cause sterility of flowers.

Pre-monsoon rain

If seed has no dormancy, early pre-monsoon rain may affect gemination. In coastal areas, it may cause grain shattering.



Long cold spells

Seedling mortality takes place during nursery stage due to long cold spells. Duration of panicle initiation and maturity period also increases. This increases expenditure on additional irrigation and care. Cold spell also restricts root growth delaying proper establishment of the seedlings. To compensate, the farmer has to do dense transplanting and use more number of seedlings/hill.

Insect-pests and weeds

Plant hoppers, leaf hopper, leaf folder, grass hopper, Gandhi bug and yellow stem borer are some of the major pests of boro rice. Bird damage is also common at the time of grain ripening. Major plant diseases are sheath blight and blasts which appear during ripening or maturity stage. Problematic weeds also grow.

Strategies for Increasing Boro Rice Production in Eastern India

Characterize Boro Rice Agro-ecosystem

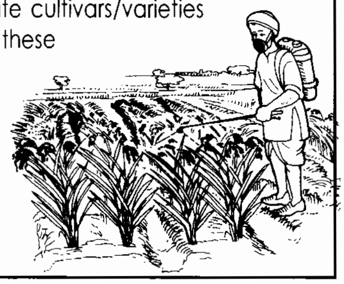
Undertake agro-ecosystem analysis through rapid rural appraisal (RRA)/ participatory rural appraisal (PRA), system diagnosis, remote sensing and geographic information system (GIS) to prioritize the problems and issues faced by farmers and find out possible solutions.

Identify Appropriate Varieties

This may be done through germplasm collection, evaluation, selection and varietal/cultivars testing.

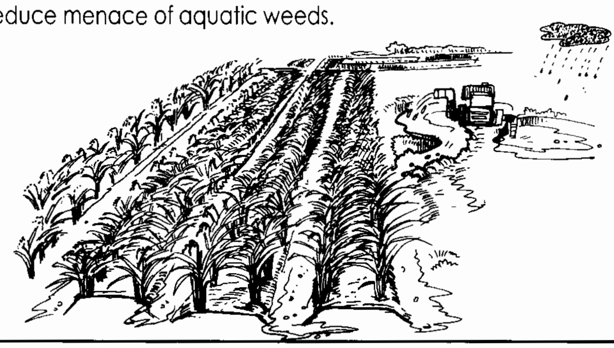
Develop Crop Management Practices

There is a need for a crop management package which may include nursery management, optimum planting time, plant population, planting geometry, fertilizer and irrigation requirements, weed management and integrated pest management (IPM). Evaluate cultivars/varieties in relation to these parameters.



Develop Appropriate Water Management Techniques

Such techniques for varying low-lying water bodies help in better land utilization. Management of groundwater is equally important in medium lands. Proper drainage and pumping water from central portion to establish the crop and irrigation reduce menace of aquatic weeds.



Develop Rice-fish Culture

Viable rice-fish culture enhances the income of poor farmers owning deepwater/low-lying waterlogged areas. Boro rice-fish culture technology package helps farmers in increasing their incomes.

Encourage Farmers' Participatory Research

Technology transfer is an important component of agricultural development. Technologies should be well-tested on the farmers' field before those are passed on to other farmers for adoption. This is better done by farmers' participatory approach including on-farm trials and demonstrations to test the technology's adaptability, compatibility and feedback information for refinement of technology according to farmers' needs.

Adapted from:

Singh, U.P. 2002. Boro Rice in Eastern India. Rice-Wheat Consortium Regional Technical Coordination Committee Meeting. 10-14 February 2002. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

Corresponding author:

U. P. Singh

Interactions of Tillage and Crop Establishment with Other Management Practices

Tillage and crop establishment practices interact strongly with other management practices. Variety selection, seeding date, seed rate, fertilizer and water management, weed, pest and disease control are all affected by zero-tillage and surface seeding. For example, fertilizer cannot be incorporated in surface seeding but research shows it is better to delay nitrogen fertilizer application until the first top-dressing. Planting date can be closer to the optimal in zero-till and surface seeding leading to higher yield and efficiencies. Water use is less and needs different timings.

Issues

- Problems of fertilizer application and timing for surface-seeded rice
- Residue/stubble management
- Insect pest and disease management under zero-tillage
- Varietal choice to combat diseases, pests and weeds, and to suit reduced or zero-tillage planting systems
- Problems of labor cost and labor availability
- Deleterious effect of puddling on succeeding wheat

Residue management is important in rice-wheat systems because large quantities of crop residues are produced, especially where combines are used for harvest or where taller, local, or *basmati* rice is grown. Incorporation of straw into soil after harvest is possible in conventional tillage, but studies have shown that incorporation of crop residues leads to a decrease in yield of the next crop because of nitrogen immobilization.

Other studies have shown that retaining crop residues on the soil surface, rather than burning them or incorporating them by tillage, increases organic carbon and total soil nitrogen in the top 5-15 cm of soil.

An Example of How Improved Practices Developed and Delivered by the Rice-Wheat Consortium Interact and Help Farmers

New tillage methods ...

Slash costs, raise yields, and enable earlier sowing

This improves farmer incomes through less cost and improves livelihood

Tillage and land management changes raise plot-level water use efficiency

Less tractor use results in less use of diesel fuel and less greenhouse gas emissions. Less weeds result in less herbicide use. Planting into surface residues reduces the need for burning residues and thus reduces air pollution. Residues left on the surface favor more beneficial insects and less insecticide use.

Improves environmental quality

Earlier sowing ...

Improves water and N use efficiency

and

Creates "system space", enabling farmers to try new rotations

New rotations help improve soil fertility and reduce the build-up of pathogens and pests

New rotations are fostered by small-scale mechanization

Mechanization helps crops get to the market

Management of Residues

Management of residues has become a major problem for farmers. Many farmers dispose of residues by burning, especially in fields that are combine harvested. Burning can result in up to 80% loss of tissue nitrogen by volatilization and can also be a significant source of air pollution.

Rice residues harbor rice stem borers, and if residues are not plowed, the larvae potentially have a greater chance of surviving to deplete the next rice crop. When a crop of wheat is grown in rice stubble with irrigation and fertilizer, the stubble decomposes and the larvae dies before spring, when they would have hatched out. Recent data show that in zero-tillage, where the rice residues are left on the surface as anchored straw and not burnt, more biodiversity of beneficial insects occurs that helps control stem borers and other deleterious insects.

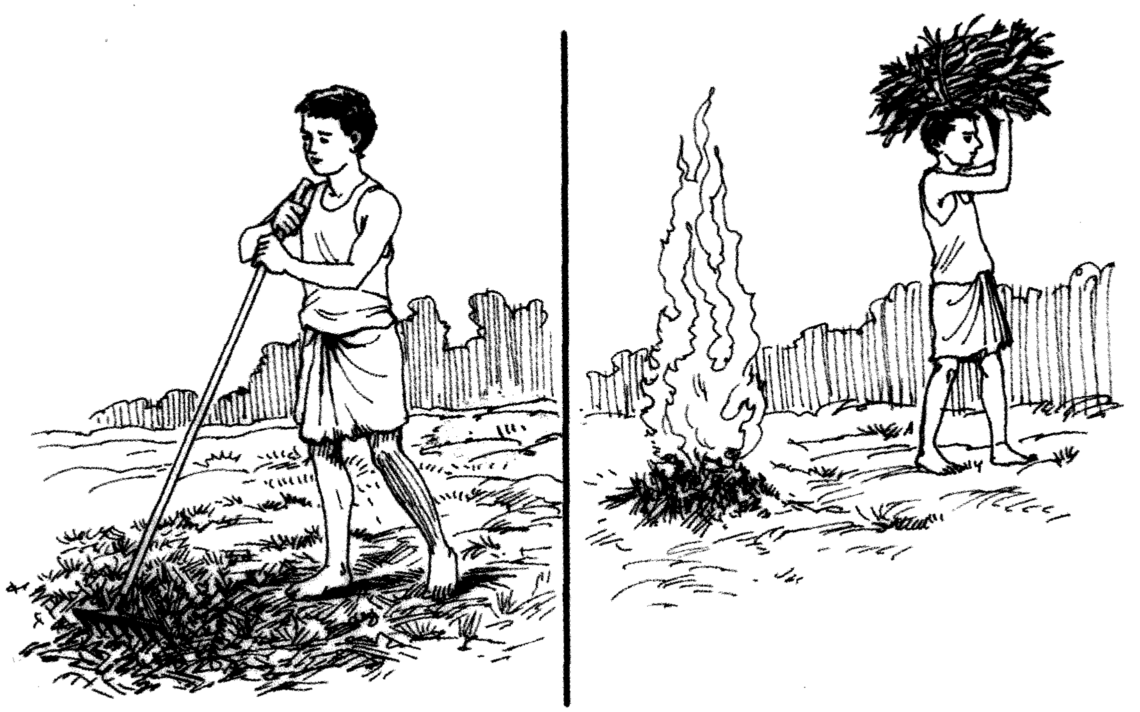
Diseases such as leaf blight (*Helminthosporium* spp.) are also more likely to proliferate on crop residues and to be more of a problem in zero-tillage systems. Here, wheat varieties with greater resistance to leaf blight may become more important than previously thought.

Some varieties of wheat do much better under zero-tillage than others. The difference in performance may be related to rooting. There is also an interaction between wheat variety and performance on beds, where taller, less upright varieties yield better. Variety also plays a role in insect, disease, and weed control and is a necessary component for a successful crop establishment under reduced tillage.

> The control of weeds in dry-seeded rice is probably the most important constraint for its successful adoption by farmers.

Most rice in the rice-wheat tract is transplanted, but as labor becomes more expensive and water becomes less available, farmers have to switch to other methods of rice establishment, such as direct seeding, both wet and dry.

Dry seeding of rice can benefit the subsequent wheat crop. If puddling is not done for rice production, the deleterious effect of this practice on soil disaggregation and wheat establishment can be prevented.



A. good practice

B. bad practice

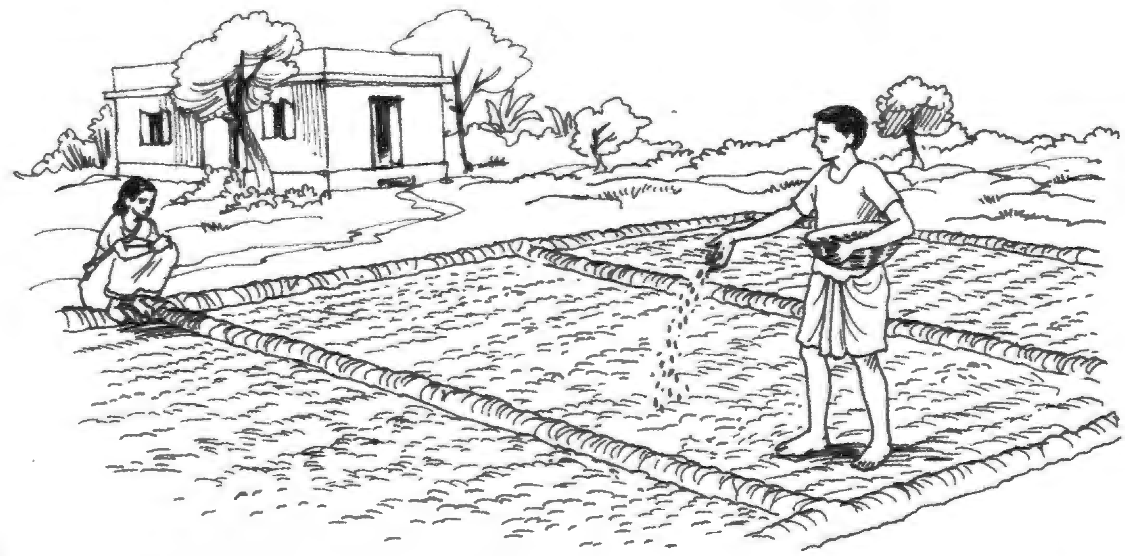
Stubble Management

Adapted from:

Hobbs, P. R., G. S. Giri and P. Grace. 1997. Reduced and Zero-Tillage Options for the Establishment of Wheat after Rice in South Asia. Rice-Wheat Consortium Paper Series 2. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

Corresponding author:
Peter R. Hobbs

Regional Impact of Simple Changes: Benefits of Conservation-Tillage Technologies



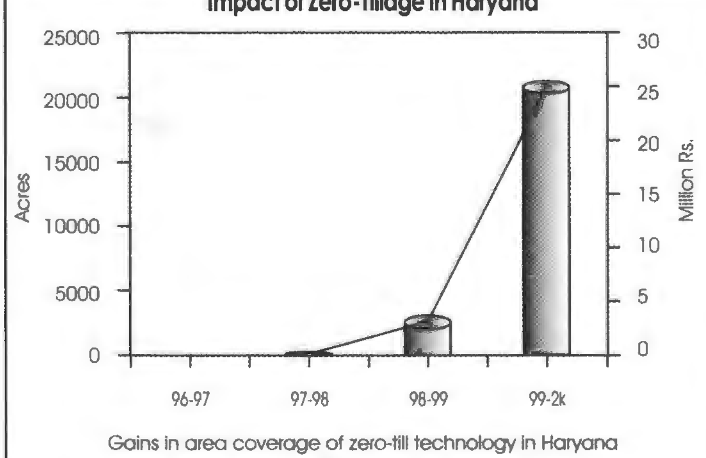
Alternative tillage practices that reduce costs and raise productivity are fast catching up in Haryana, India. The zero-tillage technology adopted in the state has a positive impact on wheat productivity, labor and fuel costs and creation of additional capital.

From only a few acres in 1997-98, zero-tillage technology has spread in Haryana to more than 20000 acres in 1999-2000 with a saving of INR 25 million. Changing to a zero-tillage system on one hectare of land would save 60 liters of diesel and approximately 1 million liters/ha of irrigation water.

Using a conversion factor of 2.6 kg of carbon dioxide per liter of diesel burned, this represents about a quarter ton less emissions of carbon dioxide per hectare, the principal contributor to global warming.

Current land preparation practices for wheat after rice involve as many as 12 tractor passes, and preparatory irrigation for sowing wheat. If zero-tillage would be practiced over an area of 0.5 m ha (1.25 m acres), this would generate a net wealth of nearly INR 170 crores including a saving in foreign exchange of INR 30 crores through reduced fuel consumption.

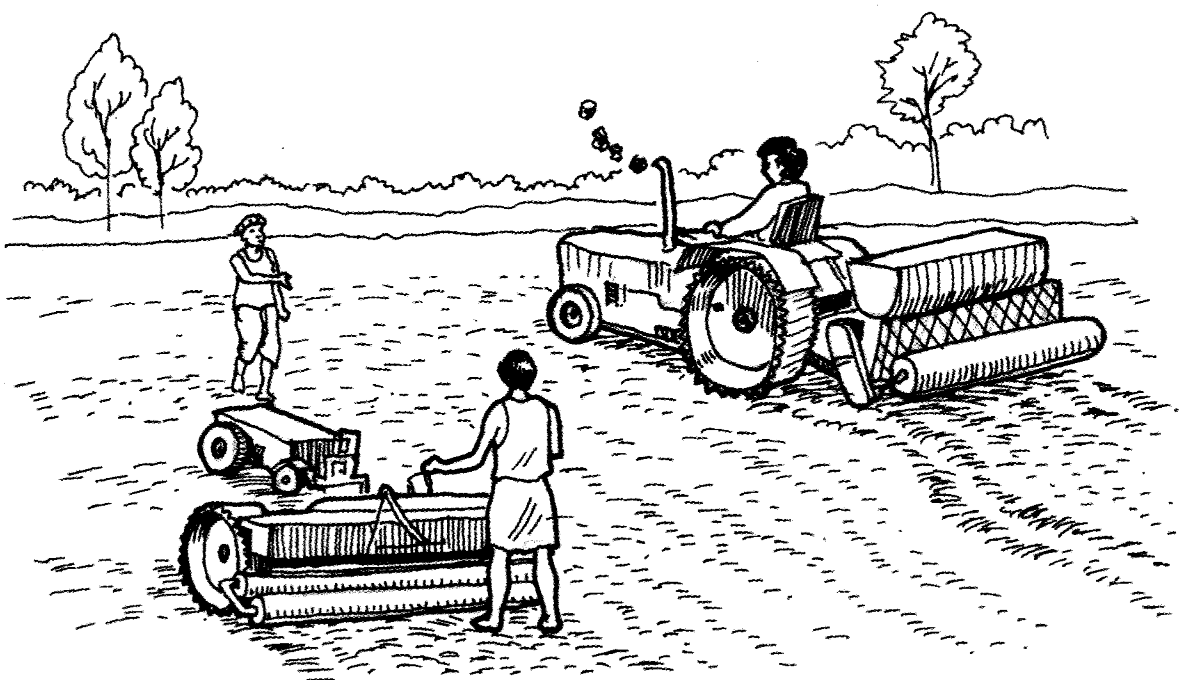
Impact of Zero-Tillage in Haryana



Gains in area coverage of zero-till technology in Haryana in different years

Projected Area Coverage, Savings in Fuel and Labor and Additional Gains in Productivity of Wheat Under the Special Project of RWC					
Year	Acres under zero-tillage	Total net saving (million Rs)	Additional gains in wheat production (t)	Fuel saved (1)	Time saving (days labor)
2001	60,000	80	65,790	1,440,000	3,500,000
2002	180,000	240	197,370	4,320,000	10,500,000
2003	540,000	720	592,110	12,960,000	31,500,000
2004	1,250,000	1,667	1,370,625	30,000,000	72,916,667
Total	2,030,000	2,707	2,225,895	48,720,000	118,416,667

1. Because zero-tillage takes immediate advantage of residue moisture from the previous rice crop, and cuts down on the subsequent irrigation requirements, water use is reduced by about 10 cm-hectares



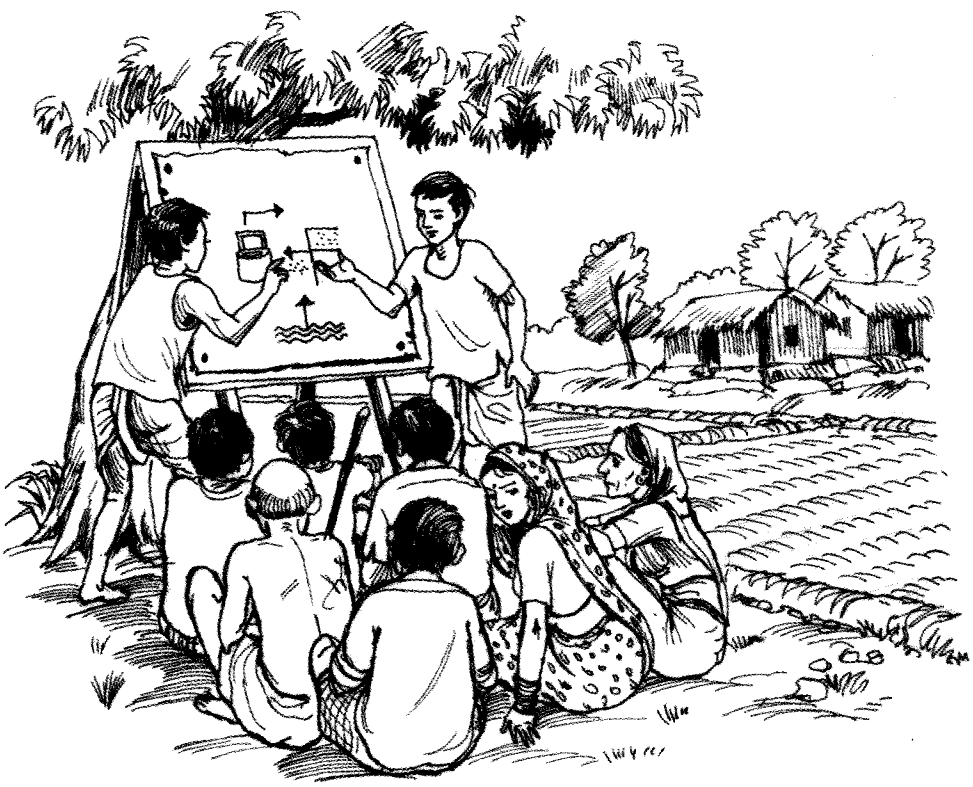
Benefits of lesser emissions increase dramatically if extended across even a portion of the rice-wheat region's 13.5 million ha.

The scientists of the Rice-Wheat Consortium are working with farmers to cut down on the burning of crop residues, which amount to as much as 10 tons/ha, producing some 13 tons of carbon dioxide. Non-burning on just 2 million ha would reduce the huge flux of yearly CO_2 emissions by 17 million tons.

Adoption of zero-tillage on, say, 5 million ha would represent a saving of 5 billion cubic meters of water each year. That would fill a lake 10 km long, 5 km wide, and 100 m deep. In addition, annual diesel fuel savings would come to 0.5 billion liters —equivalent to a reduction of nearly 1.3 million tons in CO_2 emissions each year.

What Needs to be Done Now?

- Increase the availability of prototypes of implements or tools for achieving more effective tillage for improved crop stands and yield gains.
- Promote greater interaction between public/private sectors and research/extension specialists.
- Work out site-specific crop- and soil-management practices to restore soil productivity.



Adapted from:

Mehla, R. S., J. K. Verma, R. K. Gupta and P. R. Hobbs. 2000. Stagnation in the Productivity of Wheat in the Indo-Gangetic Plains: Zero-till Seed-cum-Fertilizer Drill as an Integrated Option. Rice-Wheat Consortium Paper Series 8. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

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Nutrient Imbalance and Mining

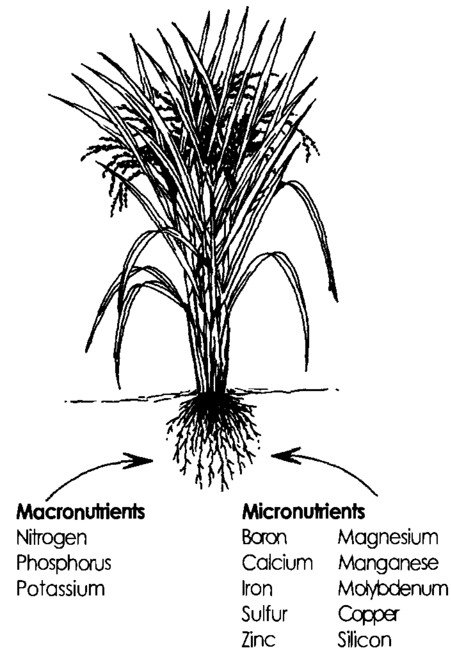
Rice and wheat are heavy users of nutrients. Nutrient imbalance and mining by these cereal crops had led to nutrient deficiencies and poor soil quality in some areas. In many areas, most of the crop residues are removed for animal feeding especially in the eastern Indo-Gangetic Plains (IGP).

Nutrient Problems and Some Solutions

Application of organic and/or inorganic fertilizers can correct the deficiency of nitrogen and phosphorus, the two most important macronutrients that are becoming limiting in the rice-wheat soils. Potassium is usually present in adequate amounts in the IGP soils. When farmers remove the entire crop residue and do not apply potassium, the imbalance leads to potassium deficiency. Boron deficiency leads to sterility in cereals (e.g., wheat), legumes (e.g., chickpea), oilseeds (e.g., sunflower) and vegetable crops (e.g., cauliflower). Zinc fertilization is essential for rice yield in most areas, having calcareous alkaline soil.

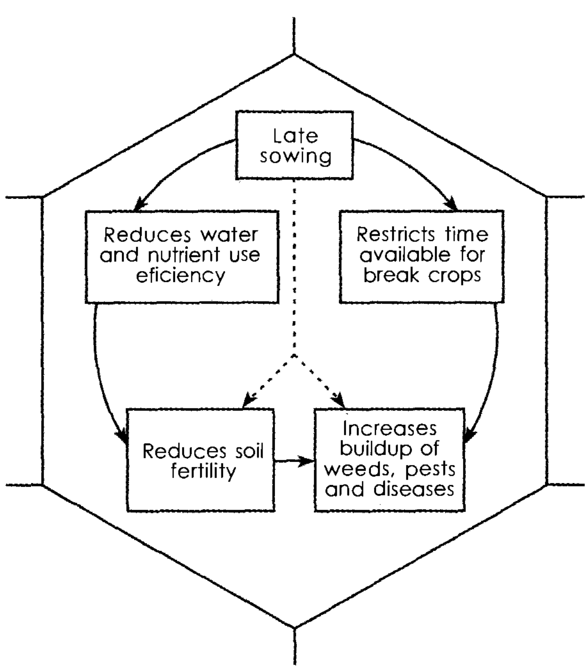
Decline in soil organic matter is also a serious problem in the rice-wheat system. Farmers can use a combination of organic and inorganic fertilizers to overcome this problem. However, there is a shortage of organic manures as they are mostly used as fuel, and their transportation to the fields is costly.

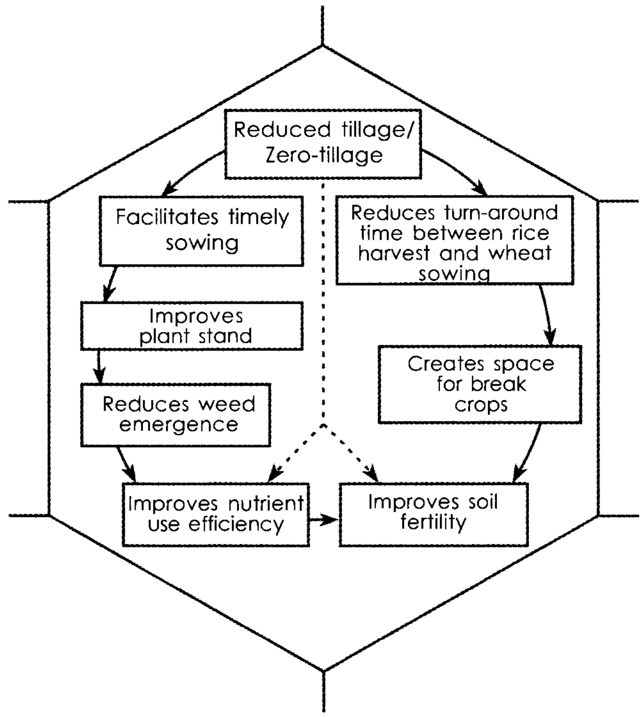
A system is needed to maintain a balance between nutrient inputs and removal. The nutrient supplying capacity of individual soils should be determined. Based on this, the amount of external nutrients needed to obtain a certain yield level can be calculated. The recommended dosage should not cause an imbalance in soil nutrients. The decline in productivity of the rice-wheat system is due to a shortage of resources, and changes in physical and chemical properties of the soil thereby reducing nitrogen-supply capacity of the soil. Increase in crop productivity can be sustained by conserving the natural resource base and increasing the quantity and quality of nutrient inputs used.



A Web of Interactions

Rice-wheat systems in the IGP appear simple, but in reality they are enormously complex, with numerous productivity and sustainability problems. Some of these problems are late sowing, low water and nutrient use efficiency, groundwater depletion (in some areas) or waterlogging (in other areas), salinity and sodicity (in specific areas), and buildup of weeds, pests, and diseases. These problems are closely linked through system interactions; e.g., late sowing (Harrington, 2001).





Reduced and zero tillage improve timelines of sowing and through the same system interactions, help farmers cope with crop production problems. These practices improve nutrient use efficiency and reduce weed germination (Harrington, 2001).

Low soil fertility in the rice-wheat systems is due to the increasing micronutrient deficiencies, imbalanced fertilizer use, and decreased use of organic manures. These problems are varied but the causes are similar:

- Reduced levels and frequency of farmyard manure applications to crop fields is attributed to changes in livestock herd size and composition; and increased use of manure for household fuel.
- Fewer crop residues (incorporated into the soil or used as surface mulch) are attributed to their increased use for livestock fodder (due to reduction in grazing/ pasture area); and increased burning of crop residues.
- Increased reliance on continuous rice-wheat rotations and a decline in the attractiveness of break crops are attributed to low yields and profits from break crops; and market access problems and associated policy issues.
- Intensive nutrient mining in the surface soil is attributed to restricted root growth associated with the plow pan created during puddle rice culture.
- Low application levels of inorganic fertilizers, insufficient to replace nutrients extracted during crop production.
- Use of inorganic fertilizer sources that do not contain secondary elements or micronutrients (Harrington, 2001).

Reference

Harrington, L. 2001. Synthesis of Systems Diagnosis: "Is the Sustainability of the Rice-Wheat Cropping System Threatened?" -An Epilogue. pages 119–132 *In:* The Rice-Wheat Cropping System of Asia: Trends, Constraints, Productivity and Policy (Kataki, P.K., ed.). Food Products Press, New York, USA.

Adapted from:

Kataki, P.K., P.R. Hobbs and B. Adhikary. 2001. The Rice-Wheat Cropping System of South Asia: Trends, Constraints and Productivity - A Prologue. pages 1-26. *In:* Kataki, P.K. (ed). The Rice-Wheat Cropping Systems of Asia: Trends, Constraints, Productivity and Policy. Food Products Press, New York, USA.

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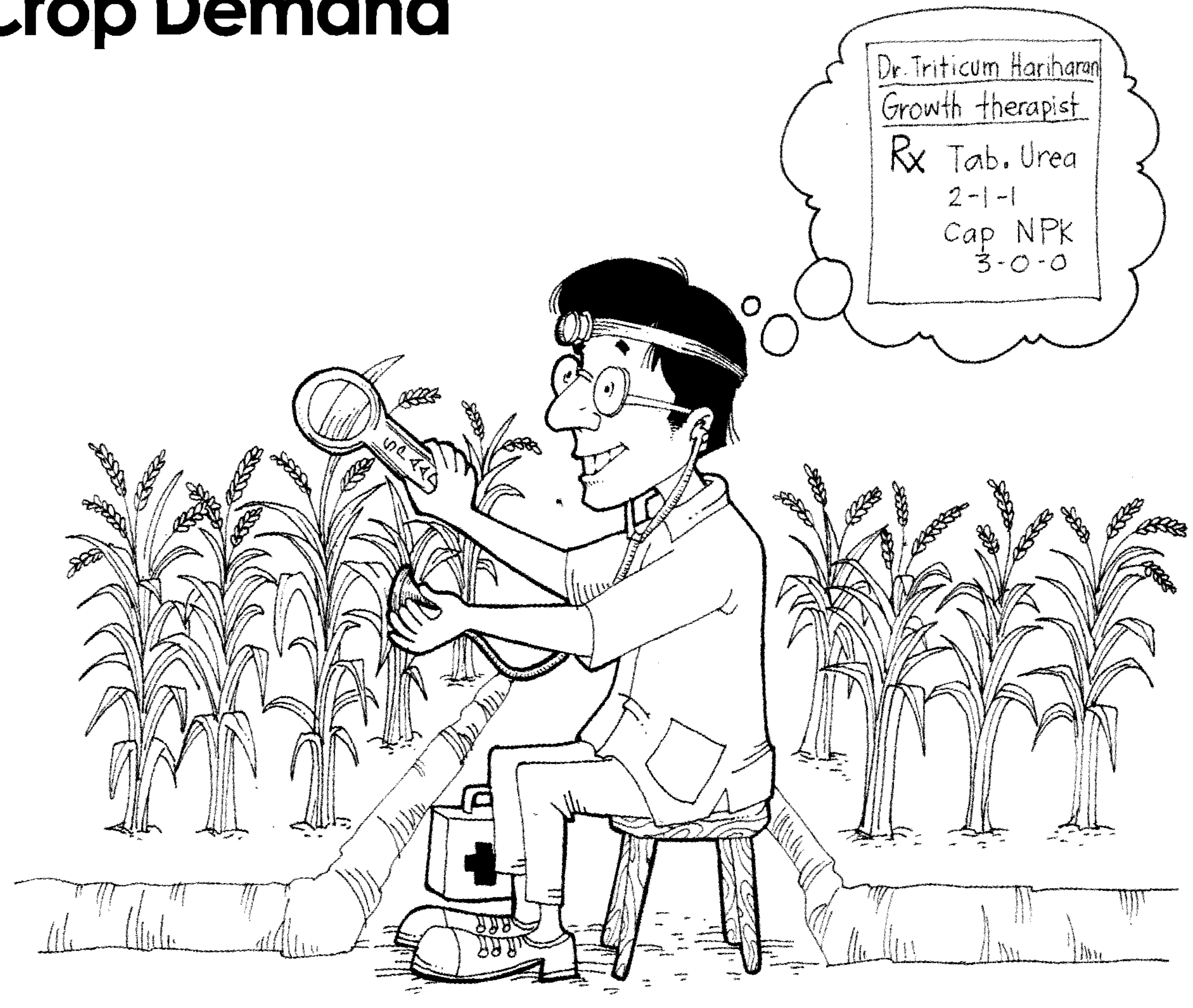
Synchronizing N Supply with Crop Demand



Leaf color is a fairly good indicator of the nitrogen (N) status of a plant. The leaves turn pale green at low levels of nitrogen and dark green at higher nutrient levels under normal soil conditions. Nitrogen use can be optimized by matching its supply to the crop demand as observed through changes in the leaf chlorophyll content and leaf color. The timing of nitrogen application is as important as the type and quantity of nitrogen applied to the crop. In many field situations, up to 50% of applied N is lost due, in part, to the lack of synchrony of plant N demand and N supply. This lack of synchrony reduces the physiological use of N available to the crop.

Local Approach

A growing body of evidence indicates that there are large farm-to-farm and plot-to-plot variations in N supply and the capacity of the soil to meet the crop demand. The regional recommendations used up to now for timing N-fertilizer application do not take these variations into account. A crop demand-driven, site-specific application can add to the farmers' profits. Tools to assess crop nitrogen demand are easily available.

Leaf N Status

The nitrogen status of the crop becomes visible in the intensity of the green color due to chlorophyll in the leaves. This can be measured by using a chrorophyll meter or by comparison with an inexpensive leaf color chart (LCC).

Chlorophyll Meter (SPAD)

The chlorophyll meter is a non-destructive and reliable tool to quickly determine the N between the chlorophyll content and leaf N status and this helps to determine the right time for application of N topdressing to rice and wheat crops (Peng, *et. al.,* 1996; Balasubramanian, *et. al.,* 1999).

Leaf Color Chart (LCC)

The International Rice Research Institute (IRRI), in collaboration with the Philippine Rice Research Institute (PhilRice), has adapted and simplified a leaf color chart from a Japanese prototype that can help farmers measure the leaf color intensity and relate it to leaf N status in rice (IRRI, 1999). It has several advantages:

- The LCC bas a nominal cost of less than $1 per piece, and a non-destructive method for assessing N requirements of plants.
- The LCC is an ideal tool to optimize N use, irrespective of the source of N-organic, biological or chemical fertilizers.

More than 150,000 LCC were distributed to farmers in several rice-growing countries through field researchers, extension workers and private sector agencies.

Crop Differences

Nitrogen application in wheat is linked to irrigation, unlike in rice where N can be top dressed two to four times during the growth period. Experiments in wheat using chlorophyll meter indicated that wheat yield is likely to respond to a top dressing of 30 kg N per ha when the SPAD chlorophyll meter reading at maximum tillering is less than 44. However, a chlorophyll meter is expensive for the farmers to use. Hence, a leaf color chart (LCC) is being standardized for use in wheat.

Slow Release Fertilizers

Deep placement of urea supergranules (USG), tablets or briquettes at 8-10cm depth below the soil surface can improve fertilizer N efficiency in rice by:

- increased N uptake by rice;
- reduced N losses, particularly from ammonia volatilization; and
- a steady and adequate N availability over a longer period of time.

A single application of N by deep placement at transplanting or direct seeding of rice can increase grain yield and N-use efficiency while also reducing fertilizer requirement of the crop by 30% to 50% in clay, clay-loam and loamy soils with low percolation rates (Mohanty *et. al.*, 1999). A hand applicator for deep placement of briquettes has been developed in Indonesia.

Urea Briquettes

In Bangladesh, the Agrobased Industries Technology Development Project (ATDP) and a private sector company perfected a urea briquette machine with the collaboration of IRRI. Each unit costs about $2,200 and produces 250kg of urea briquettes per hour. More than 100 machines were made and sold to private entrepreneurs who produce urea briquettes for rice farmers. In 1999 alone, more than 100,000 hectares of Boro rice was fertilized with urea briquettes.

Controlled Release Fertilizers

Controlled-release (CR) fertilizers are available that have an ultra thin membrane polymer coating that encapsulates the urea granules. The release of the nutrients through this polymer membrane occurs in a predictable manner. It also provides an opportunity for placement of fertilizer with seed (Shoji and Kanno, 1994).

Advantages of CR Urea

- Reduces N fertilizer requirement by 30% to 50%.
- Single basal application and hence saving on labor otherwise needed for split doses.
- Release of N is in a predictable manner.
- Provides opportunity for common placement of seed and fertilizer and thereby reduces labor.
- Nitrogen is available to the plants throughout the growth period.
- Leaching of nitrates is reduced.
- Emissions of nitrous oxide is reduced.
- Controlled release reduces chances of phytotoxicity due to high ionic strength.
- No drastic changes in pH occur.

SSNM Approach

Site-specific nutrient management (SSNM) in rice-wheat systems was developed to take into account variations in the indigenous supply of N, P, and K among farms in both crops (Adhikari *et al.*, 1999, IRRI, 1999).

In the SSNM approach, scientists quantify crop nutrient requirements based on an economically-efficient yield target; measure the potential indigenous supply of N, P and K; estimate the P and K balance for sustaining soil P and K reserves without depletion; monitor plant N status during critical periods of rice growth to optimize N efficiency; and apply diagnostic criteria for identifying micronutrient disorders.

Source:

Dobermann A. and P.F. White. 1999. Strategies for Nutrient Management in Irrigated and Rainfed Lowland Rice Systems. Nutr. Cycl. Agroecosys. 53:1–18

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Ladha, J.K., K.S Fisher, M. Hossain, P.R. Hobbs and B. Hardy (eds). 2000. Improving Productivity and Sustainability of Rice-Wheat Systems of the NARS-IRRI Partnership Research. IRRI Discussion Paper Series 40. International Rice Research Institute, Los Banos, Philippines.

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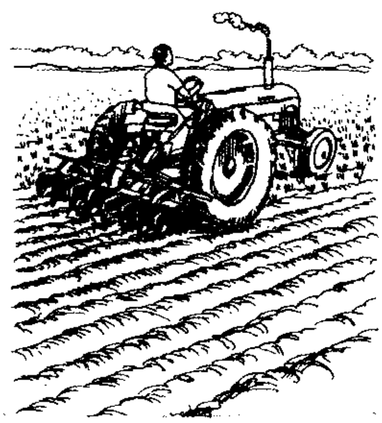
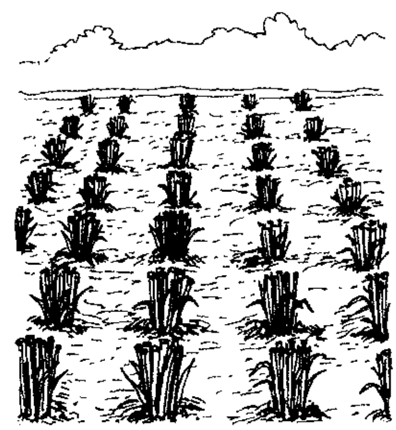
Crop Residue Management in Rice-Wheat System

Crop residues are good sources of plant nutrients and are important components for the stability of agricultural ecosystems. About 400 million tons of crop residues are produced in India alone. In areas where mechanical harvesting is practiced, a large quantity of crop residues are left in the field, which can be recycled for nutrient supply. About 25% of nitrogen (N) and phosphorus (P), 50% of sulfur (S), and 75% of potassium (K) uptake by cereal crops are retained in crop residues, making them valuable nutrient sources.

Both rice and wheat are exhaustive feeders, and the double cropping system is heavily depleting the soil of its nutrient content. A rice-wheat sequence that yields 7 tons per ha of rice and 4 tons per ha of wheat removes more than 300 kg N, 30 kg P, and 300 kg K per ha from the soil.

Fertilizer Use in the Indo-Gangetic Plains (IGP)

Fertilizer use is more in western IGP than in eastern IGP. Continuous government subsidies on nitrogenous fertilizers have helped create imbalanced N, P, and K fertilizer use by farmers. Removal of P and K by the rice-wheat system far exceeds its additions through fertilizers and recycling of organic materials. Governments in Asia are now moving away from fertilizer subsidies, a practice initiated in the 1970s.

Application of fertilizer N at 120 kg N per ha has been the recommended level for rice and wheat in most of the IGP. However, recently, more than 150 kg N per ha is being applied particularly to rice grown in northwestern India, where more than 10 tons per ha grain yield is obtained from the rice-wheat system.

Incorporation of Cereal Straw

Traditionally, wheat and rice straw were removed from the fields for use as cattle feed and for other purposes in South Asia. Recently, with the advent of mechanized harvesting, farmers have been burning *in situ* large quantities of crop residues left in the field. As crop residues interfere with tillage and seeding operations for the next crop, farmers often prefer to burn the residue *in situ*, causing loss of nutrients and organic matter in the soil. Unlike removal or burning, incorporation of straw builds up soil organic matter, soil N, and increases the total and available P and K contents of the soil.

The major disadvantage of incorporation of cereal straw is the immobilization of inorganic N and its adverse effect due to N deficiency. Incorporation of cereal crop residues immediately before sowing/transplanting into wheat or rice significantly lowers crop yields. Due to straw incorporation, wheat yield depression (mean of 10 years) decreases from 0.54 tons per ha to 0.08 tons per ha with the application of 60 kg N per ha and 180 kg N per ha, respectively.

Residue characteristics and soil and management factors affect residue decomposition in the soil. Under optimum temperature and moisture conditions, N immobilization can last from four to six weeks. Adverse effects of wheat straw incorporation can be averted by incorporating both green manure (having narrow C:N ratio) and cereal straw (having wide C:N ratio) into the soil before rice transplanting.

Legume Crop Residues and Green Manures

In northwestern India, short-duration legumes (e.g., mungbean and cowpea) can be grown in the fallow period after wheat harvest. In the rice-wheat system, incorporation of mungbean residue after picking pods, significantly increases rice yield and saves 60 kg N per ha. The advantages of incorporation of legume crop residues and green manuring to rice are similar.

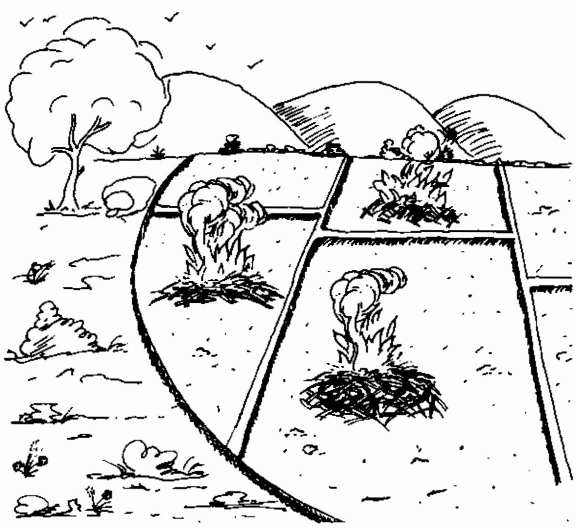
Green manures are a valuable potential source of N and organic matter. Green manure crops (e.g., *Sesbania* sp.) can be used in rice-based cropping systems. A 45- to 60-day-old green manure crop can generally accumulate about 100 kg N per ha, which corresponds to the amount of mineral fertilizer N applied to crops. Sometimes green manure crops accumulate more than 200 kg N per ha. Integrated use of green manure and chemical fertilizer can save 50%-75% of N fertilizers in rice. Green manuring also increases the availability of several other plant nutrients through its favorable effect on chemical, physical, and biological properties of soil. In Bangladesh, N supplied by *Sesbania* green manure was effective for rice grown in coarse-textured soils but its residual effect on the following crop of wheat was negligible.

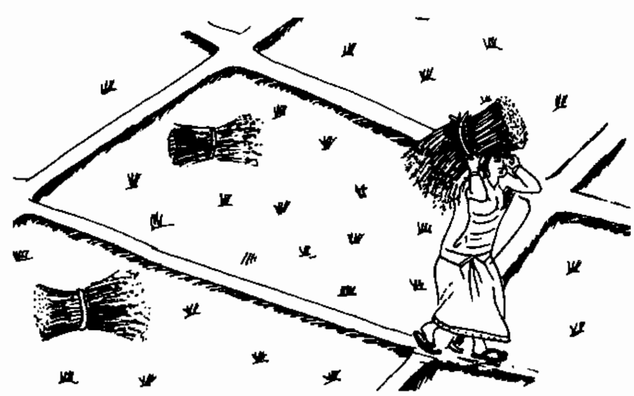
Rice Straw Management Practices

Incorporation of rice straw before wheat planting compared to wheat straw before rice planting is difficult due to low temperatures and the short interval between rice harvest and wheat planting. Farmers use different straw management practices: burning, removal, or incorporation. Rice and wheat yields under these practices are generally similar.

In few studies, wheat yields were lower during the first one to three years of rice straw incorporation 30 days prior to wheat planting, but in later years, straw incorporation did not affect wheat yields adversely. In contrast, rice straw incorporation gave significantly higher wheat yields of 3.51 tons per ha compared to 2.91 tons per ha with straw removal in Pakistan.

Incorporation of rice straw three weeks before wheat sowing significantly increases wheat yields on clay loam but not on sandy loam soil. About 10%-20% of N supplied through organic materials having high C:N ratio such as rice straw and stubble is assimilated by the rice crop, 10%-20% is lost through various pathways, and 60%-80% is immobilized in the soil. Addition of 10 tons per ha rice straw at four to five weeks before transplanting rice is equivalent to the basal application of 40 kg N per ha through urea.





Proper fertilizer management practices can reduce N-immobilization due to incorporation of crop residues into the soil. These practices include appropriate method, time, and rate of fertilizer-N application. The following options can reduce the adverse effects of N-immobilization:

- Place N-fertilizer below the surface soil layer which is enriched with carbon after incorporation of crop residue.
- Apply N-fertilizer at a higher dose than the recommended dose.

Starter N-Fertilizer Effects on Crop Residue Management

Application of 15 to 20 kg N per ha as starter dose with straw incorporation increases yields of wheat and rice compared to either burning of straw or its incorporation in the soil. At recommended fertilizer-N level, rice straw incorporation reduces rice yields than urea alone. Therefore, a higher dose of urea-N application with rice straw incorporation is necessary to get good yields. The beneficial effect of straw incorporation before rice planting does not carry over to the succeeding wheat crop. Application of 30 kg extra N per ha than the recommended fertilizer dose increases rice yields only slightly.

Beneficial Effects of Wheat Crop Residues

During a 10-year (1984 to 1994) long-term field experiment conducted in India, comparisons were made between the application of wheat crop residues versus inorganic fertilizers on rice and wheat. In the first year of this study, inorganic fertilizer-treated plots of rice and wheat yielded the highest. However, in the second and third year of this study, yield from the treatment with combined application of wheat straw and inorganic fertilizer was similar to that with inorganic fertilizer alone. Beyond the fourth year of this experiment, plots treated with a combination of wheat straw and inorganic fertilizer outyielded all other treatments. Another long-term study (1988 to 2000) conducted in Punjab, India showed that wheat straw could be combined with green manure with no adverse effect on rice yield. Yield and N-use efficiency in rice, however, were reduced with wheat straw incroporation.

Results from the All India Coordinated Agronomic Research Project showed the beneficial effects of wheat crop residues when applied as a substitute for chemical fertilizer needs of rice in the rice-wheat cropping system. In another study, incorporation of wheat straw (10 tons per ha) saved 50% of the recommended fertilizer dose (60 kg N + 13.1 kg P + 25 kg K per ha) and helped achieve higher yield of rice.

Adapted from:

Singh, Y. and B. Singh. 2001. Efficient Management of Primary Nutrition in the Rice-Wheat System. pages 23–85. *In*: Kataki, P.K. (ed). The Rice-Wheat Cropping Systems of South Asia: Efficient Production Management. Food Products Press, New York, USA.

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Soil Micronutrient Deficiencies in the Rice-Wheat Cropping System

Zn deficient | Unaffected | $ZnSO_4$ treated

Micronutrient deficiencies in the Indo-Gangetic Plains (IGP) started emerging with the adoption and spread of intensive agriculture in the region. Imbalanced use of macronutrient fertilizers, decreased use of organic manure, reduced recycling of crop residues, and bumper harvests in the past three decades have induced secondary and micronutrient deficiencies in the IGP. In several areas with intensive cropping, zinc (Zn) deficiency appeared initially and subsequently the deficiencies of iron (Fe), manganese (Mn), boron (B), and molybdenum (Mo) were recorded. The severity of these deficiencies depended on the soil conditions and the crop grown. Rice crop removes larger quantities of micronutrients compared to wheat. Increase in fertility levels progressively increases the total removal of micronutrients due to increased dry matter production.

Uptake (kg/ha) of Micronutrients by Rice and Wheat

Fertility	Biomass (t/ha)		Rice				Wheat			
level*	Rice	Wheat	Zn	Cu	Mn	Fe	Zn	Cu	Mn	Fe
Control	6.5	4.1	0.12	0.09	0.35	1.68	0.07	0.03	0.11	0.70
Low	8.8	7.5	0.17	0.13	0.57	2.51	0.12	0.05	0.21	1.30
Medium	12.9	10.2	0.25	0.19	0.80	3.43	0.17	0.08	0.28	1.83
High	14.5	12.4	0.30	0.22	0.97	4.06	0.20	0.09	0.33	2.33

* Control = 0:0:0;
Low = 60:30:30
Medium = 120:60:60
High = 180:90:90 of $N:P_2O_5:K_2O$

Source: Gupta and Mehla, 1993

Rice and wheat are important in the national food security of the IGP. The rice-wheat system, though remunerative, has resulted in the over-exploitation of the natural soil resource base, which has been further enhanced by the imbalanced use of inputs. Continued emphasis on maximization of food grain production without appropriate management practies from a shrinking land resource base will result in further depletion of micronutrient reserves. The simplest solution to alleviate micronutrient deficiency is the application of micronutrient fertilizers to the crop.

Problems in Alleviating Micronutrient Deficiencies

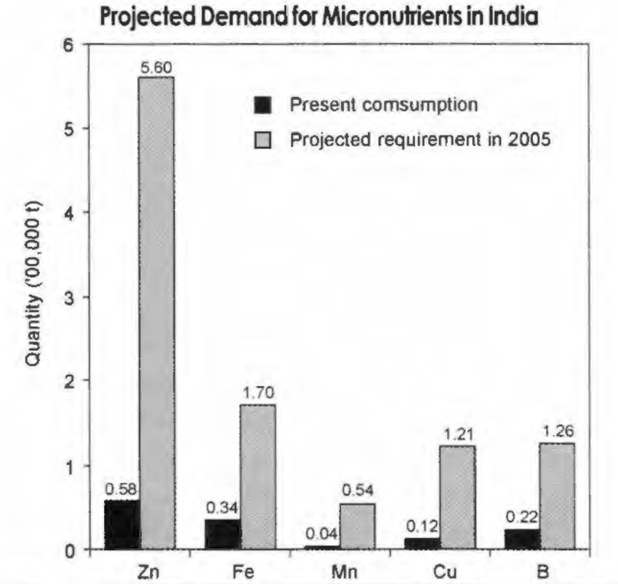
- Difficulty in the identification of field crop deficiency symptoms.
- Variation in soil micronutrient status, soil pH, rainfall duration and intensity, and seasonal fluctuations in the groundwater levels and temperature regimes in the region.
- Inadequate facilities and field tests to validate critical levels of soil and plant micronutrients in the region.

Source of Micronutrients in Soils

- Soil parent material
- Industrial and urban effluents
- Agricultural chemicals and fertilizers
- Irrigation water

If micronutrient deficiencies that constrain high productivity are not identified, monitored, and alleviated, the fertilizer use efficiency of costly chemical fertilizers and other agricultural inputs will be markedly reduced. The projected micronutrient demand for 2025 in India is expected to increase by five to 10 times the present consumption level (Sehgal, 1999). This would entail the use of fertilizer nutrients in the right proportion, with efficient application methods and at the appropriate time of crop growth. Also, it is essential to augment the availability of native nutrients by modifying soil environment through management practices in different crops and cropping systems.

Projected Demand for Micronutrients in India



Total and Available Micronutrient Content of Indian Soils

Micronutrient	Total content (mg/kg soil)	Available micronutrient (mg/kg soil)	
		Content	Mean
Zinc	2 to 1,019	0.2 to 6.9	0.9
Copper	1.9 to 960	0.1 to 8.2	2.1
Iron	2700 to 191,000	0.8 to 196	19.0
Manganese	37 to 11,500	0.2 to 118	21.0
Boron	3.8 to 630	0.08 to 2.6	-
Molybdenum	0.01 to 18.1	0.07 to 7.67	-

Source: Takkar, 1982; Singh, 1999

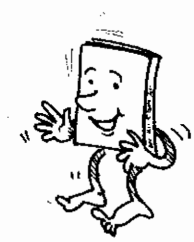
Extent of Micronutrient Deficiencies

The total micronutrient contents of soils are of limited value to plant growth and responses to their application. To match the levels of micronutrients in soil with plant requirement, their available contents in soils are determined. Like total contents, the available micronutrient status of soils is also highly variable. Soil properties exercise a considerable influence on the availability of micronutrients. Therefore, the extent of micronutrient deficiency varies not only in different states and districts but also in different blocks within the same district depending upon the soil characteristics and other management conditions.

Extent of Micronutrient Deficiency in the Soils of India

State	No. of soil samples	Percent soil samples deficient			
		Zn	Cu	Fe	Mn
Bihar	19214	54.0	3	6	2
Haryana	21848	60.5	2	20	4
Punjab	16483	48.1	1	14	2
Uttar Pradesh	26126	45.7	1	6	2
West Bengal	6547	36.0	0	0	3
Total	**90218**	**50.6**	**2**	**10**	**3**

Source: Singh, 1999



Areas of Deficiency

- Zinc deficiency is the most widespread in the four IGP countries (Bangladesh, India, Nepal, Pakistan).
- Some areas in Punjab, India revealed a marked decrease in the extent of zinc deficiency but there has been an increase in the deficiency of iron and manganese.
- The extent of iron deficiency is approximately a fifth that of zinc deficiency and is largely influenced by the vast areas under alkaline to calcareous soil tracts.
- Iron deficiency is only second in importance after zinc deficiency in Punjab and Haryana in India.
- Manganese deficiency is in localized sites where rice-wheat crop rotation is practiced in coarse-textured soils.
- Copper deficiency is not widespread in the IGP, but deficiency based on plant analysis is higher than soil analysis. The critical limits used for soil copper or plant copper need to be re-calibrated.
- The incidence of boron deficiency was highest in the acid soils of West Bengal followed by the calcareous soils of Bihar.

Diagnosis of Micronutrient Deficiency

The assessment of micronutrient deficiency can be made through visual leaf symptoms and soil and plant analyses. Response of crops to the application of micronutrients not only confirms the deficiencies but also helps in determining nutrient needs.

Deficiency Symptoms

> Visual symptoms of zinc deficiency in rice plants first appear on older leaves.

Visual recognition of leaf symptoms is important in the identification of nutrient disorders in crops. Nutrients like iron and boron, which are not readily translocated from old to young leaves under stress conditions within the plant are called immobile nutrients and their deficiency symptoms first appear on young leaves. Due to the variable mobility of zinc, copper, molybdenum, and manganese under conditions of their deficiency, the location of their symptoms in different crops and crop species may vary depending upon the degree of their mobility. Confident diagnosis by this method, however, requires much experience, as the symptoms of some nutrient deficiencies are difficult to differentiate without a thorough knowledge. Another limitation of this technique is that by the time the deficiency symptoms appear, the crop has undergone a marked set back and the corrective measures taken at that time may not produce optimum yields. The diagnosis by this method should be confirmed through soil and plant analyses followed by designing experiments of crop response to the added micronutrient of interest.

Plant Analysis

Plant analysis is widely used as a means of detecting micronturient deficiency and the need for fertilizing the crops. Under conditions of hidden micronutrient deficiency, plant analysis is the most effective method for diagnosis of micronutrient disorders. This is because neither the plant exhibits visual deficiency symptoms, nor do the soil tests precisely predict such situations.

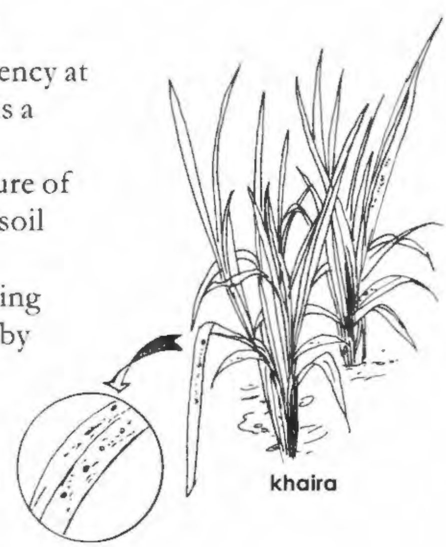
Soil Analysis

Soil analysis is an invaluable and convenient diagnostic tool for quick and timely assessment of micronturient availability. Several chemical extraction procedures have been used to measure the plant available micronutrients.

Critical Levels for Micronutrients in the IGP

Soil test method	Micronutrient	Critical level in soil (mg/kg)	Critical level in plant dry matter (mg/kg)
Diethylene triamine penta acetic acid (DTPA)	Zinc	0.45 to 1.20	15 to 20
Diethylene triamine penta acetic acid (DTPA)	Manganese	2 to 3.5	20 (10 to 25)
Diethylene triamine penta acetic acid (DTPA)	Iron	3.2 to 6.9	50 (25 to 80)
DTPA/ Ammonium acetate	Copper	0.14 to 0.60	4 (3 to 6)
Ammonium acetate	Molybdenum	0.2 to 0.5	0.8 to 1.8
Hot water soluble	Boron	0.5	11 to 18

Future Micronutrient Research Needs



The relatively minor problem of soil micronutrient deficiency at the begining of the Green Revolution three decades ago is a factor to reckon with in present times in sustaining the productivity of rice and wheat in the IGP. The monoculture of rice and wheat of the past has given rise to an exhausting soil micronutrient feeder rice-wheat cropping system of the present day. Proper management of the rice-wheat cropping system is a key to minimize crop yield reduction induced by micronutrient deficiency. There is a general lack of awareness among farmers on micronutirent deficiency problems. Except for the acknowledgment of zinc deficiency (commonly known as khaira) by farmers, existence of other micronutrient deficiencies is not a common knowledge and under a "perceived" optimum management condition, poor yields of rice and wheat are often described by farmers as being due to "sickly" soils.

The critical micronutrient values for both soils and plants in the IGP have not been extensively field tested; field validation will be of immense help to researchers and extension specialists. Information on crop response to micronutrients and soil micronutrient analysis in the IGP has been scattered. An ecoregional soil micronutrient status-analysis within the IGP and synthesis of this information using geographic positioning system (GPS) and geographic information system (GIS) will facilitate delineating regions of specific deficiencies. This will help formulate on-farm diagnostic and adaptive research, spreading of awareness amongst farmers, and extrapolating results to similar sub-ecoregions within the IGP where intervention programs on micronutrients can be undertaken.

More information on the transformation and availability of micronutrients for different soils and the effect of manipulating the soil physical environment and its moisture regimes on plant available micronutrients need to be generated. Continuous use of farmyard manure or of other organic sources arrests the depletion of available micronutrient pools from soils. Development of integrated micronutrient technology using available organic materials is needed not only to increase micronutrient use efficiency but also to decrease the pressure on the use of costly inorganic micronutrient carriers. Field experiments have proved the superiority of zinc sulfate as a zinc carrier. Increasing costs coupled with a shortfall in supply of zinc sulfate has necessitated investigations on evaluating sparingly soluble zinc sources or ores combined with zinc mobilizers. The residual availability of various sources of micronutrients for a cropping system needs to be worked out.

For soils marginal in micronutrient supply, new interventions like seed treatment need investigations to help save the costly micronutrient fertilizer. Micronutrients like boron whose deficiency and toxicity limits for crops are very narrow require careful investigations including its field testing for rates and frequency of application. Finally, the identification and/or breeding for micronutrient efficient crop cultivars having either low micronutrient requirement for potential yields or capable of mining micronutrients from the less available pools should be given priority.

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Adapted from:
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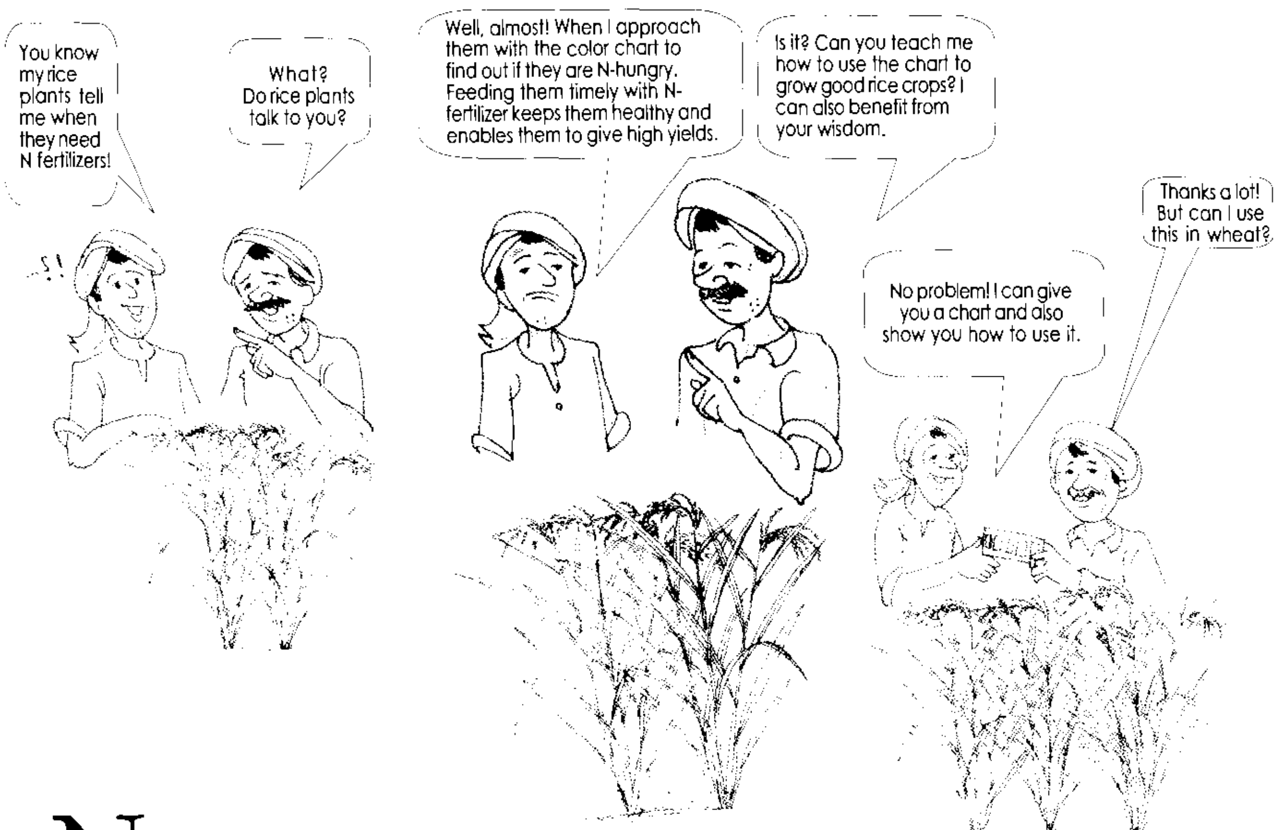
Leaf Color Chart for Real-Time N Management in Rice



Nitrogen (N) is the most important nutrient for rice but it is the most limiting element in almost all soils. Optimal N supply matching with the actual crop demand is thus vital for improving crop growth and maximizing production. Among the various strategies available for N management, leaf colour chart (LCC) for real-time N management in rice is a simple, easy and inexpensive option.

Major Management Strategies

Two major strategies followed in N management are:

- Blanket-fertilizer N recommendations
- Crop-need-based N management

Blanket-Fertilizer N Recommendations

Blanket-fertilizer N recommendations generally take into account crop response to applied N as basis to calculate the amount of N required to achieve a targeted yield. These recommendations do not consider variability in soil N supply and changes in crop demand. Farmers generally apply too much N (and little P and K and other nutrients) that results in high incidence of pests and diseases, besides lodging. The consequence of high N application is high pesticide use to control pests, more expenditure on pesticides, and reduced yield and poor grain quality due to lodging. In addition, excess N is leached into water sources that get polluted over time. Farmers suffer from more pesticide-related health risks.

Crop-Need-Based Nitrogen Management

Crop-need-based N management approach takes into account variability in soil N supply and crops' additional requirement for N fertilizer. This means that rice crops in different fields require different amounts of N input. Being need-based, it can treat deficiency on a timely basis but requires careful periodic monitoring of crop N status. The main tool used for periodic monitoring of N status is a chlorophyll meter, which can monitor plant N status precisely, but is expensive. Priced approximately US$1400 a piece, it is beyond the reach of most of the individual farmers in Asia.

The leaf color chart (LCC) is an alternative tool for real-time N management in rice. It is inexpensive (at approximately US$1 a piece), simple and easy to use. It measures leaf color intensity related to leaf N status. LCC is an ideal tool for individual farmers to optimize N use in rice at high yield levels irrespective of the source of N applied, i.e., organic manure, biologically fixed N, or chemical fertilizers. It is also ecologically-friendly.

Scientific Principle of LCC

Farmers generally use the leaf color as a visual and subjective indicator of the rice crop's need for N fertilizer. Leaf color intensity is directly related to leaf chlorophyll content which, in turn, is related to leaf N status. As indicated earlier, the two simple tools that can measure the leaf color intensity are: chlorophyll meter (SPAD) and leaf color chart (LCC). Both are related to leaf N status as follows: a leaf color reading of SPAD 36 or LCC 4 is equivalent to 1.4-1.5 g N per square meter of leaf area.

Crop Need-based N Management Main Strategy

- Matches external/fertilizer N supply to actual crop demand and crop growing conditions in the field.
- Treats N deficiency symptoms on time.
- Avoids overuse of N to prevent crop losses due to pests, diseases ond lodging.
- Monitors crop N status at regular intervals so as to apply N fertilizer as and when needed.

Chlorophyll Meter (SPAD)	Leaf Color Chart (LCC)
• It measures the leaf color intensity and thus crop N status accurately, *in situ* (in the field). • It helps determine the right time of N application to rice. • It is expensive ~ US$1400 a piece.	• It measures the leaf color intensity which is related to leaf N status, *in situ* (in the field). • It helps farmers determine the right time of N application in all practical situations. • It is simple, easy to use and inexpensive (US$1 a piece). • It is an ideal tool to optimize N use at reasonably high yield levels, irrespective of the source of N applied.

When we compare the chlorophyll meter or SPAD readings with LCC shades, the difference between two LCC shades is 4 to 5 SPAD units. Thus, the LCC cannot measure the greenness of rice leaves as accurately as the chlorophyll meter. However, field tests show that for all practical purposes, the LCC is as good as or even better than the chlorophyll meter to determine the right time of N fertilizer application for rice crops.

Suggested Critical LCC Values	
Variety/crop establishment method	**Critical value**
Semi-dwarf indica varieties, direct-seeded	3
Scented or aromatic varieties, transplanted	3
Semi-dwarf indica varieties, transplanted	4
Hybrid rice varieties, transplanted	4
Note: Local calibration is always necessary. Test different LCC threshold values.	

Development of LCC

The International Rice Research Institute (IRRI) and the Philippine Rice Research Institute (PhilRice) jointly developed the LCC from a Japanese prototype. The LCC is made of high-impact plastic. It consists of six color shades from yellowish green (No. 1) to dark green (No. 6). The color strips are fabricated with veins resembling rice leaves. The holder is grey in color.

How to Use the LCC

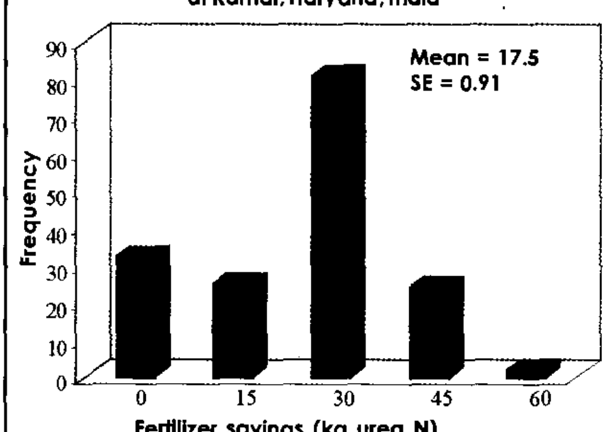
1. Start LCC readings from 14 days after transplanting (DAT) or 21 days after sowing (DAS). Take the last reading when the crop just starts to flower.
2. Randomly select at least 10 disease-free rice plants or hills in a field with uniform plant population. Select the topmost fully expanded leaf from each hill or plant.
3. Place the middle part of the leaf on a chart and compare the leaf color with LCC shades. When the leaf color falls between two shades, the mean value is taken as the reading, e.g., 2.5 for color between 2 and 3. Do not detach or destroy the leaf.
4. Measure the leaf color under the shade of your body, because direct sunlight affects leaf color readings. If possible, the same person should take LCC readings at the same time of the day every time.
5. Repeat the process at seven to ten days' intervals or at critical growth stages (early tillering, active tillering, panicle initiation and first flowering) and apply N as needed.
6. If more than five out of ten leaves read below a set critical value, apply:
   - 20-30 kg N/ha for wet season or low-yielding season
   - 30-35 kg N/ha for dry season or high-yielding season

A Typical Example of Decision-Making Process in LCC Method (TPR: S.D. variety)		
Time (DAT)	**LCC reading**	**Apply N? Yes/No**
0 (Basal)	**Nil**	**Based on local experience**
14	≥ 4.0	No
21	≥ 4.0	No
28	**< 4.0**	**Yes**
35	≥ 4.0	No
42	**< 4.0**	**Yes**
49	≥ 4.0	No
56	**< 4.0**	**Yes**

N Savings in Farmers' Fields

When averaged over 518 on-farm trials conducted in four countries during 1996-2000, farmers could save 8 to 22 kg N/ha with an increase in grain yield of 2% to 8% by using the LCC method. In Karnal district of Haryana (India) in 2001, 165 farmers evaluated the LCC method. Average saving in N was 25 kg/ha by using the LCC method without any reduction in yield (mean yield 6.37 t/ha).

N Saving by Using LCC, in Farmers' Fields at Karnal, Haryana, India



Limitations of LCC

Several factors influence LCC readings: varietal group; plant or tiller density; variability in solar radiation between seasons; status of nutrients other than N in soil and plant; and biotic and abiotic stresses that induce discoloration of leaves.

Users should clearly understand these limitations and know how to tackle them while using the LCC.

How to Overcome the Limitations

Training of national extension and development staff and farmers on the proper use of LCC is critical for its success. IRRI scientists train selected trainers in each country and they, in turn, train other local staff and farmers on the proper use of the LCC method. Often, farmers' meetings and discussion groups as well as farmers' field schools (FFS) are used for such training. During the training, they learn about the various interfering factors that affect the LCC readings and how to tackle them. They bêcome conversant with different LCC critical values for different crop-growing conditions. Both national extension staff and farmers are trained to appreciate the need for a combined use of LCC and other methods to optimize grain yield and N fertilizer use efficiency in rice cultivation. The users should understand not only the economic advantage of efficient fertilizer management techniques, but also their impact on resource base, environmental quality and human health.

Commercialization of LCC

During commercialization of the LCC, strict maintenance of the LCC color shades is vital for its reliable use in Asia and elsewhere. Therefore, a quality certification program is imperative to certify the charts produced by various agencies in different countries, with the IRRI-produced LCC as the standard.

Popularity of LCC

As of June 2002, more than 400,000 farmers use the LCC for real-time N management in rice in different Asian countries. The number of farmers using LCC varies from 1000 in Bangladesh and Myanmar to 10,000 in India, 30,000 each in Indonesia and Philippines, and 300,000 in Vietnam.

Adapted from:

Balasubramanian, V. 2002. Leaf Color Chart for Real-Time N Mangement in Rice. Go to 'KnowledgeBytes: Using Leaf Color Chart (LCC)'. *In:* http://www.knowledgebank.irri.org/. To find out more about LCC, go to 'A complete reference guide concerning the LCC." International Rice Research Institute, Los Banos, Philippines.

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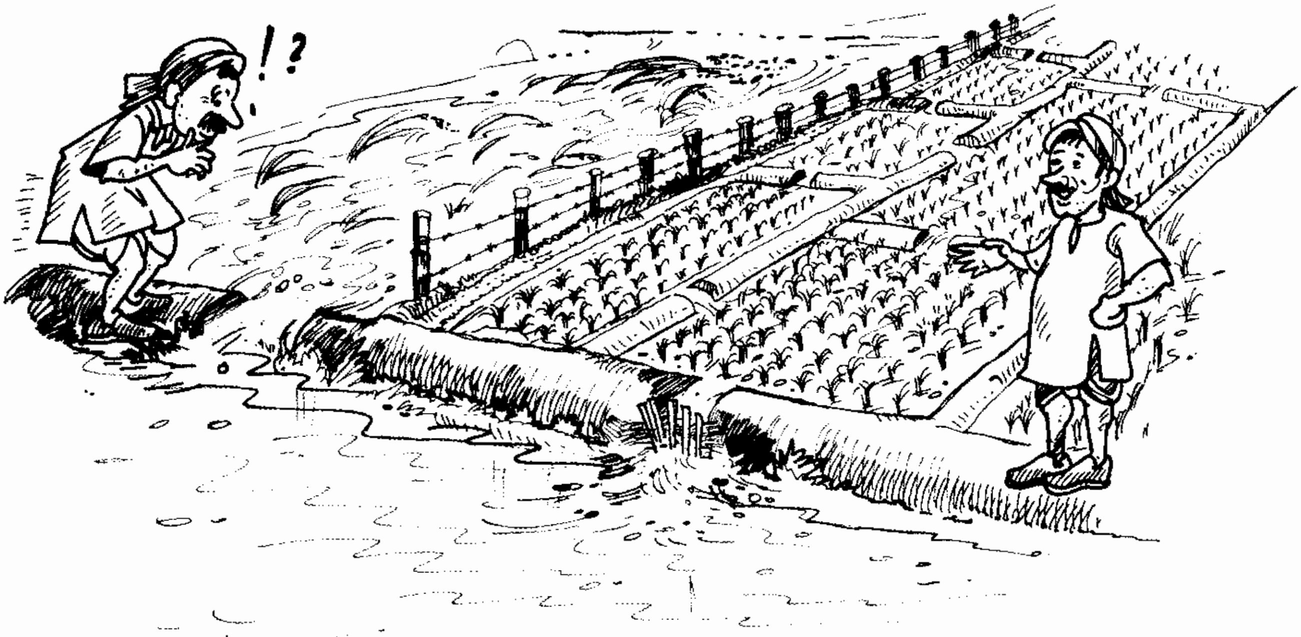
Strategies and Practices for Increasing On-farm Water Productivity

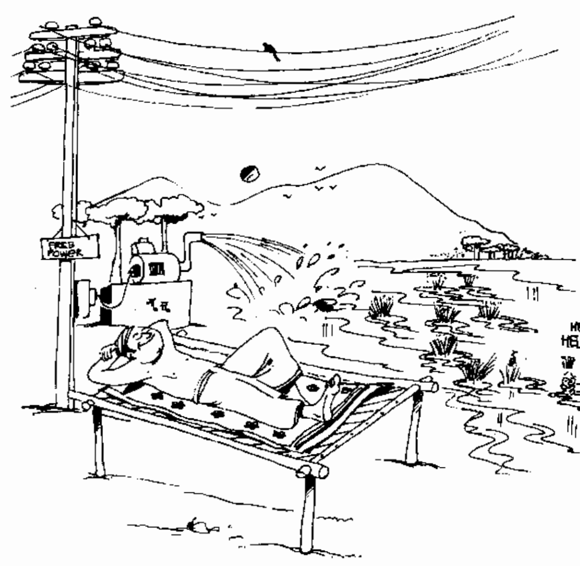


Rice flourishes in an abundant water environment that best differentiates it from all other important crops. This unique environmental adaptation, however, could lead to this crop facing the fate of the dinosaurs in an era where water is increasingly becoming scarce and there is competition from other sectors. Since 1980, the irrigated area per person has declined in a quick reversal of the trend in most of contemporary history when growth of irrigated area had outpaced population growth rates. Agriculture's share of water will decline at an even faster rate because of the increasing competition for available water from urban and industrial sectors (Tuong and Bhuiyan, 1994).

Potential Changes

Some strategies that can be adopted to increase the water productivity on-farm are:

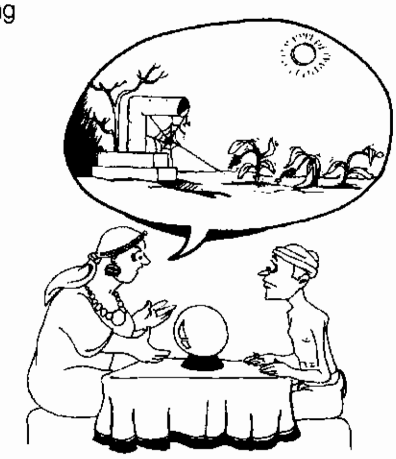
- Reduction of seepage and percolation losses of water during land preparation and crop growth periods.
- Reduction of water loss during land preparation.
- Reduction of surface runoff of irrigation water.
- Increase in crop yield per unit of evapo-transpiration during crop growth.

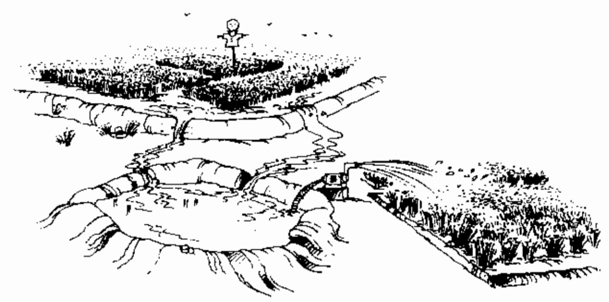


Irrigation Efficiency

The formulation of an action plan to achieve the objective of maximizing rice production with minimum water use raises a battery of pertinent questions to define who should do what, how it should be done, when ond why. Some of the relevant questions are:

- What ore the current levels of efficiency/productivity?
- What are the potential gains through adoption of infrostructural and management technologies and practices?
- Who should have the primary responsibility? What are the appropriate rules for farmer–users ond systems managers that will minimize transaction costs and management requirements?
- What is the probability of water savings at the farm level being translated into net gains for the irrigation system and the entire basin?
- How should appropriate actions or interventions be identified?
- How should actions and interventions be evaluated for successful achievement of the objectives?





On-farm water savings by reduction of seepage or drainage outflow may also reduce the recharge of groundwater aquifers and availability of water downstream. The effects on such interdependent systems within a basin must be considered while assessing the water productivity. In some cases it may be more worthwhile to focus on re-use of drainage water rather than improving management of water delivery and application systems.

Seepage and Percolation Reduction

Puddling or wet tillage creates a semipermeable hardpan that decreases percolation rate and can reduce input water requirement of rice crop by 40%-60% (Dayanand and Singh, 1980). Even if 1% of the area is left unpuddled over permeable subsoil, then the percolation rate could increase by a factor of five (Tuong, *et. al.*, 1994). Bunds can be sealed with clay taken from the plow layer to minimize lateral infiltration and underbund percolation. (Tuong *et al.*, 1994). Field bunds can also be lined with plastic sheets to reduce seepage losses.

In traditional transplanted rice, farmers prefer to maintain a relatively high depth of water. This leads to a high amount of seepage and percolation. However, continuous submergence is not essential for obtaining high rice yields. Water applied can be reduced by 40%-70% by maintaining saturated soil conditions or alternate wetting and drying of soil (Singh, *et al.*, 1996). The shallower the groundwater table, the longer the interval between irrigations (Mishra, *et al.*, 1990, 1997). In lighter soils, there is a greater reduction in water use. Soil nitrates and ammonium concentrations are not adversely affected by a saturated soil regime-instead of continuous flooding.

Land Preparation

Excessive amount of water is often used for land preparation. Reducing the period of land preparation would lead to substantial saving of water lost through evaporation, seepage, percolation and surface run-off. Shallow, dry tillage soon after harvesting the previous crop can minimize the formation of soil cracks and loss of water through bypass flow. This can reduce water input by 31%-34% which corresponds to 108-117mm of water (Cabangon and Tuong, 2000).

Surface Run-off

The shift from continuous submergence to a regime of saturated soil or alternate wetting and drying greatly reduces water loss due to surface run-off. More frequent application of smaller quantities of water, however, requires greater management capacity and more labor.

Increased Crop Yield

Adoption of improved, early-maturing dwarf, high-yielding varieties (HYV) of rice started the Green Revolution and has more than doubled the average yield of irrigated rice from 2-3 tons per hectare to 5-6 tons per hectare. Simultaneously, the crop duration has decreased from about 140 days to about 110 days. This has increased the water productivity by 2.5 to 3.5 times with respect to evapotranspiration during the crop season per unit yield. The availability of hybrid rice varieties which have 15%-20% higher yield potential than inbred HYV rice of comparable crop duration, offers another opportunity to increase water productivity in rice culture.

Development of drought and salt-tolerant high-yielding varieties of rice through advances in biotechnology will further enhance water productivity. Better soil nutrient management can contribute by increasing yields at the same level of water use. Addition of 1kg nitrogen can increase rice yield by 10-15 kg (Peng, 1997, pers. comm). With on-farm water productivity at 0.5 kg rice per cubic meter of irrigation water, about 20-30 cubic meters of water is needed to obtain the same increase in yield.

Direct Seeding

Direct seeding is a water-efficient method of rice establishment followed in several South and South East Asian Countries (Erguiza, *et al.,* 1990, Khan, *et al.,* 1992, Sattar and Bhuiyan, 1993). There are two forms: Wet Seeded Rice (WSR) and Dry Seeded Rice (DSR).

Wet Seeded Rice (WSR)

In this form, pre-germinated rice seeds are broadcast on saturated, and usually puddled, soil. WSR systems use less water than transplanted rice for both land preparation and crop irrigation. The total irrigation water requirement is reduced by about 20%-25 % and the irrigation duration reduced from 140 to 105 days (Fuji and Cho, 1996). Less water is required because of shorter time for land preparation (Bhuiyan, *et al.,* 1995).

Dry Seeded Rice (DSR)

Ungerminated rice seeds are sown on dry or moist, but unpuddled, soil. This form of planting uses rainfall more effectively and offers significant opportunity for conserving irrigation water. In DSR, early pre-monsoon rain is used effectively for crop establishment. Later, when the water reservoir is full, the crop can be irrigated as needed.

All methods for reducing water use in crop growth period by reducing losses and increasing yields help increase water productivity. Reduction of seepage and percolation in upstream farms may not improve the overall water use efficiency of the irrigation system if such water is normally re-used downstream. However, increases in yields due to use of HYV, efficient nutrient management, weed control, etc will improve both on-farm and system productivity.

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Adapted from:

Guerra, L.C., S.I. Bhuiyan, T.P. Tuong and R. Barker. 1998. Producing More Rice with Less Water from Irrigated Systems. SWIM Paper 5. International Water Management Institute (IWMI), Colombo, Sri Lanka. pp 24.

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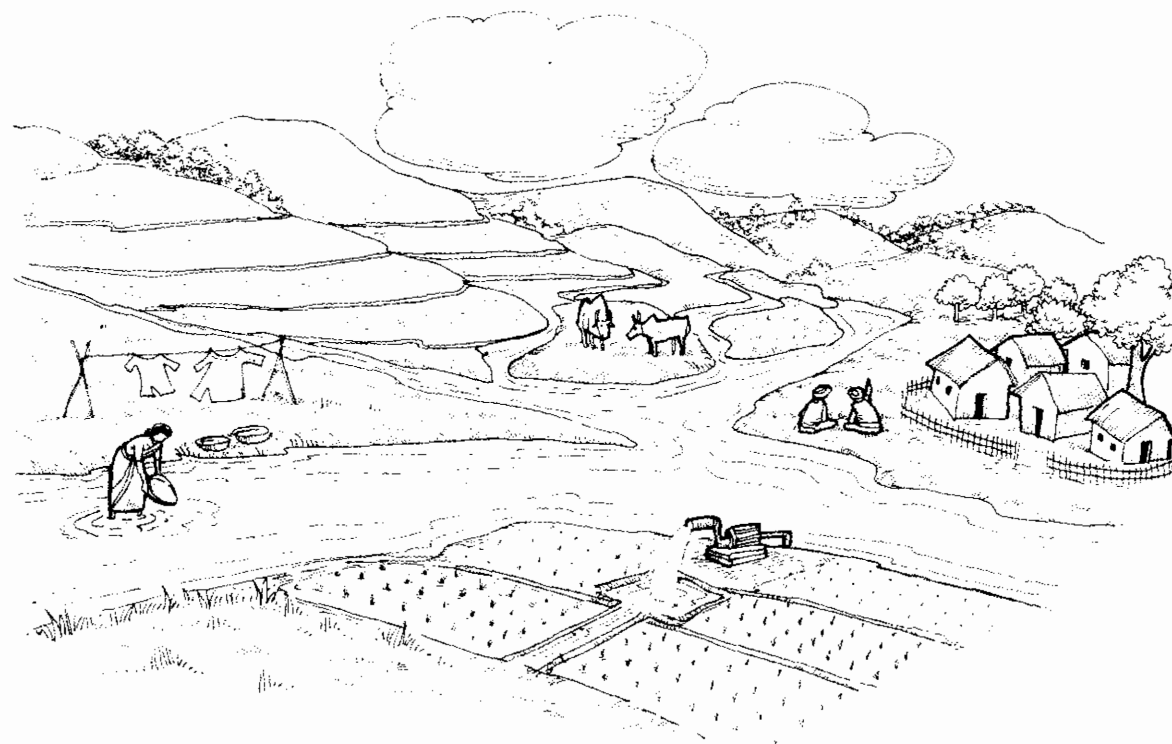
Basin-Level Use and Productivity of Water



Basin-level use and productivity of water considers a holistic approach as opposed to narrower on-farm approach. According to the International Water Management Institute (IWMI), 78% of the world's population is likely to live in areas facing physical or economic water scarcity by 2025.

Increasing the global average irrigated cereal yield from the 1995 level of 3.3 tons per hectare to 5.8 tons per hectare will eliminate the need to expand irrigated areas. To meet future population demands in India, an approximate doubling of yields from 2.7 to 4.7 tons per hectare would eliminate the need to develop more water for irrigation.

In physically water-scarce regions, there is simply not enough water to meet agricultural, industrial and domestic needs, while in economically-scarce regions, there has been relatively little development on water resources due to financial or human resource constraints. The IWMI estimates that the world's irrigated area would need to be increased by 29% from the level of 1995 to meet the food and nutritional requirements by 2025.

Water conservation is an appealing option compared to developing new storage and diversion facilities, as these often carry high financial, social and ecological costs. In essence, through real water savings, water is redistributed from a use of little or even negative benefit to one that has higher benefit.

If the societal objective of water resource development is targeted at eliminating poverty, water that provides more jobs and income to poor people is considered more productive than water that benefits wealthier people even though the value of output produced by rich and poor is the same.

It is comonly perceived that agricultural water users waste large quantities of water during the irrigation process and that simply increasing irrigation efficiency could save enormous amounts of water. This perception is derived from common knowledge that on-farm irrigation application efficiencies are often in the order of 20% to 50%, implying that the remaining 80% to 50% is somehow lost. When we move from an on-farm perspective to a basin perspective, we often find that, because of reuse of "lost" water, there is much less wastage than commonly perceived.

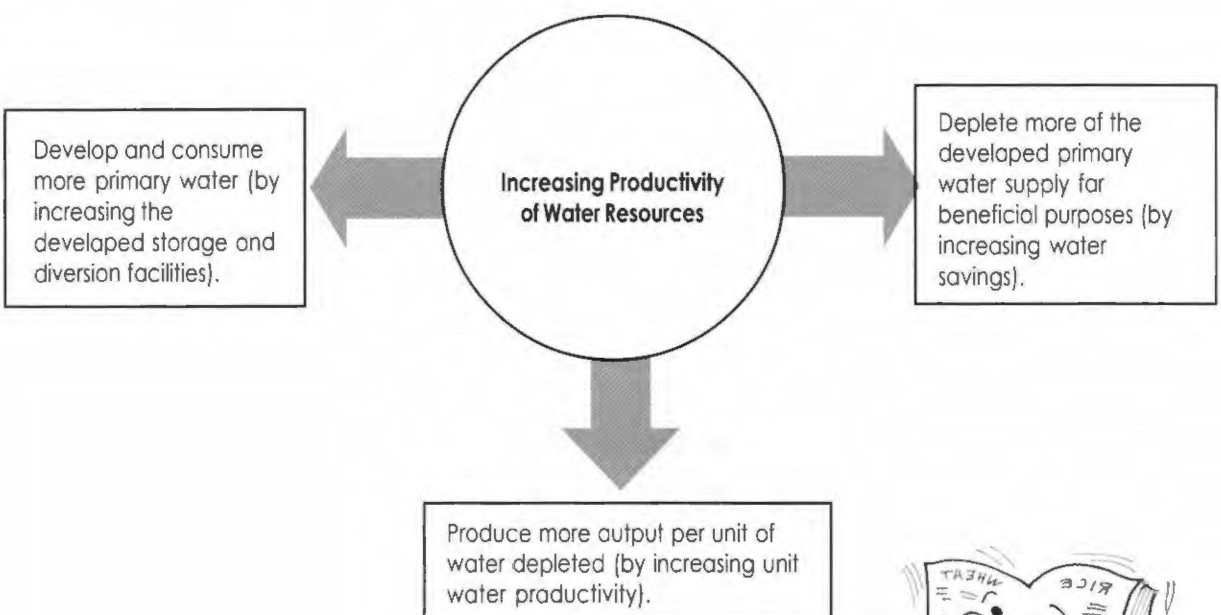
Increasing productivity of water in agriculture by producing more agricultural output with the same amount of available water is a key strategy for addressing water scarcity.

Different Ways of Increasing Productivity of Water

- Obtaining more crop production from the same amount of water.
- Obtaining more value per unit of water used.

"Real Water Savings"
"Real water savings" imply that we reduce wastage of water in one area to free it up for transfer to a beneficial use elsewhere.

Three Paths for Increasing Productivity Per Unit of Basin-Level Utilizable Water Resources

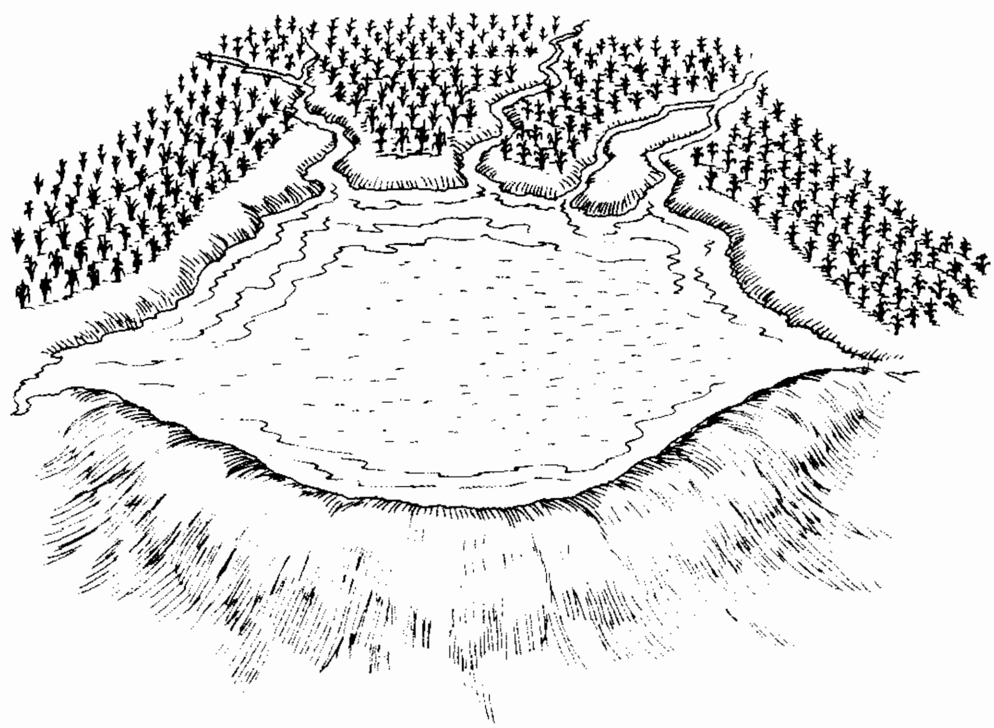


Accounting for Water Use and Productivity

The accounting procedure for water use and increased productivity utilizes a water balance approach and classifies different outflow components or flow paths into water accounting categories. Productivity of water is then related to various categories of use.

When analyzing a water basin, one of the first questions to answer is whether the basin is open or closed. In completely closed basins, all utilizable water is committed to present uses. An increase in depletive use in one part of a closed basin requires a decrease in another part. In an open basin, there is uncommitted but utilizable outflow even in low-flow periods. Thus, in open basins, it is possible to increase water consumption without adversely affecting downstream uses or to use the excess water to dilute pollutant loads.

In open basins, water managers generally have many more options for increasing overall water production from the water resource than in closed basins. As demands for water increase, basins move from being open to becoming closed basins.



In a closed basin, an increase in irrigated area that results in increased evapotranspiration in one part must be offset by a decrease in the area served in another (usually downstream) part of the basin. Concentration of pollutants toward the tail reaches of a system can be a serious problem in closed basins. In fully-closed basins, efforts should be made to identify non-beneficial or less beneficial depletions of water, and to implement water-saving programs to free up water for more beneficial uses elsewhere.

Water Accounting Definitions

- Gross inflow is the total amount of water entering into the water balance domain from precipitation, and surface and subsurface sources.
- Net inflow is the gross inflow plus any changes in storage.
- Water depletion is a use or removal of water from a water basin that renders it unavailable for further use. Water depletion is a key concept for water accounting, as interest is focused mostly on the productivity and the derived benefits per unit of water depleted. It is extremely important to distinguish water depletion from water diverted to a service or use as not all water diverted to a use is depleted. Water is depleted by four generic processes:
  1. Evaporation: water is vaporized from surfaces or transpired by plants.
  2. Flows to sinks: water flows into a sea, saline groundwater, or other location where it is not readily or economically recovered for reuse.
  3. Pollution: water quality gets degraded to an extent that it is unfit for certain uses.
  4. Incorporation into a product: through an industrial or agricultural process, such as bottling water, or incorporation of water into plant tissues.
- Process consumption is that amount of water diverted and depleted to produce a human-intended product (i.e., domestic, agriculture or industrial use).
- Non-process depletion occurs when water is depleted, but not by the process for which it was intended. Non-process depletion can be either beneficial, or non-beneficial.
- Committed water is that part of outflow from the water balance domain that is committed to other uses, such as downstream environmental requirements or downstream water rights.
- Uncommitted outflow is water that is not depleted, nor committed and is, therefore, available for a use within the domain, but flows out of the basin due to lack of storage or sufficient operational measures. Uncommitted outflow can be classified as utilizable or non-utilizable. Outflow is utilizable if by improved management of existing facilities it could be consumptively used. Non-utilizable uncommitted outflow exists when the facilities are not sufficient to capture the otherwise utilizable outflow.
- Available water is the net inflow minus both the amount of water set aside for committed uses and the non-utilizable uncommitted outflow. It represents the amount of water available for use at the basin, service, or use levels. Available water includes process and non-process depletion plus utilizable outflows.
- A closed basin is one where all available water is depleted. An open basin is one where there is still some uncommitted utilizable outflow.
- In a fully committed basin, there are no uncommitted outflows. All inflowing water is committed to various uses.

Adapted from:

Molden, D., R. Sakthivadivel and Z. Habib. 2001. Basin-Level Use and Productivity of Water: Examples from South Asia. Research Report 49. International Water Management Institute, Sri Lanka.

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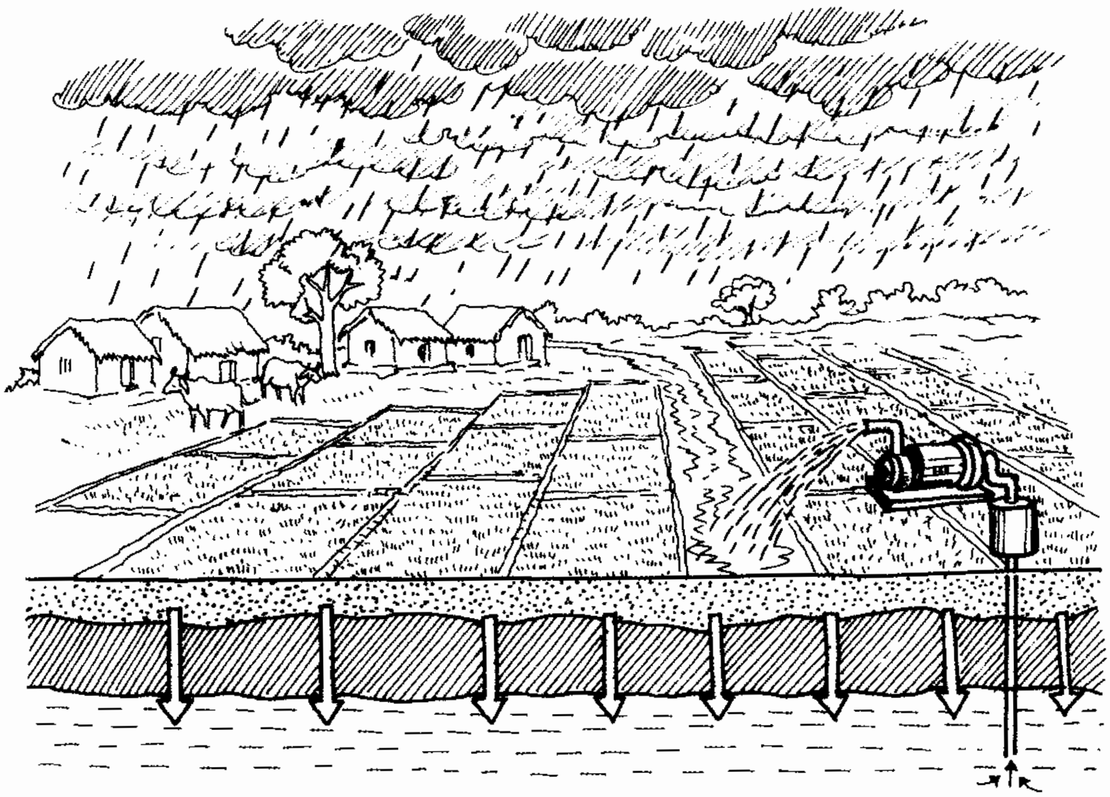
Saving Water and Increasing Water Productivity



Obtaining more benefits from each drop of water consumed will be the key to overcoming scarcity. When the saved water is transferred to beneficial use for more agriculture, protection of environment, or urban use, an increase in water productivity is achieved.

There are various ways of conserving water and increasing its productivity. They generally form four major categories:

- **Beneficial depletion**
  This takes place when water is depleted but for beneficial uses such as evapotranspiration from crops, use and evaporation of water for drinking, or evaporation and transpiration from wetlands.
- **Non- or less-beneficial depletion**
  This takes place when the depletion of water leads to very little or negatively perceived benefits such as evaporation from fallow lands, or evaporation from stagnant water, or flows into seas in excess of environmental requirements.
- **Uncommitted outflows**
  These are flows in rivers, or groundwater out of a stretch of a river basin in excess of downstream human or key environmental needs.
- **Committed outflows**
  These are outflows from a reach in the basin necessary to meet downstream water rights or requirements, or important ecological needs.

General Means of Saving Water

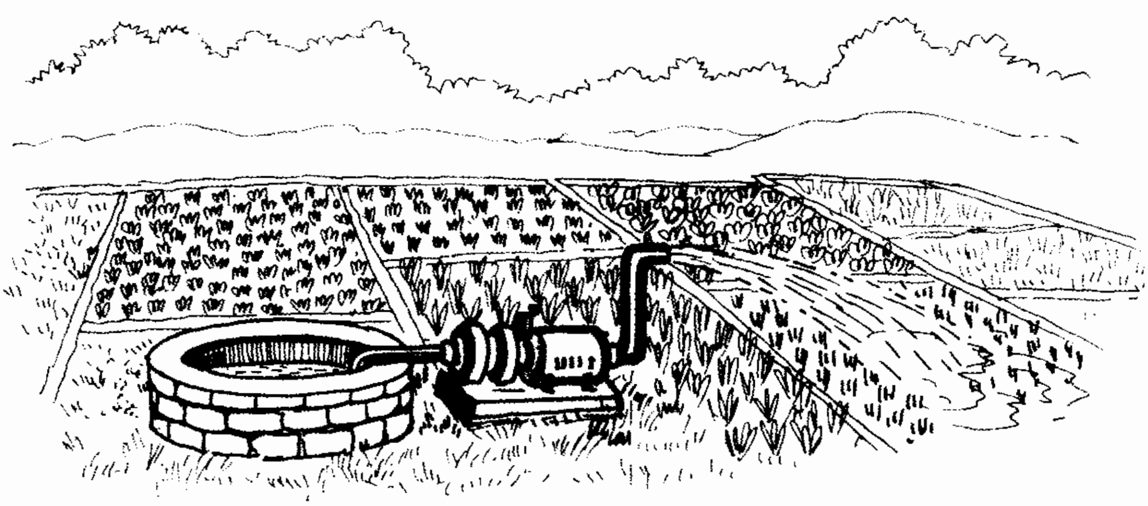
Water is saved when it is possible to reduce negative, non-beneficial, and low-beneficial depletion, and reduce uncommitted outflows either through improved management of existing facilities or through the addition of facilities for water control, storage or saving.

In certain situations, the societal preference of water may be to a use that produces less agricultural output, but benefits disadvantaged groups. It may be more cost-effective to reuse water through pumping from drains or groundwater than to modernize existing infrastructure to increase the beneficial depletion of water.

General Means of Increasing Water Productivity (Without Water-saving Measures)

The productivity of water is enhanced by increasing the productivity per unit of process depletion (crop transpiration in agriculture) or other beneficial depletion, and by reallocation of water to higher-value uses.

The strategy chosen for increasing water productivity will be guided by economic and social factors. Existing water rights will often constrain choices. Local availability of water may be an important consideration dictating irrigation strategy, while developing strategies, cost-effectiveness and social goals must be considered.



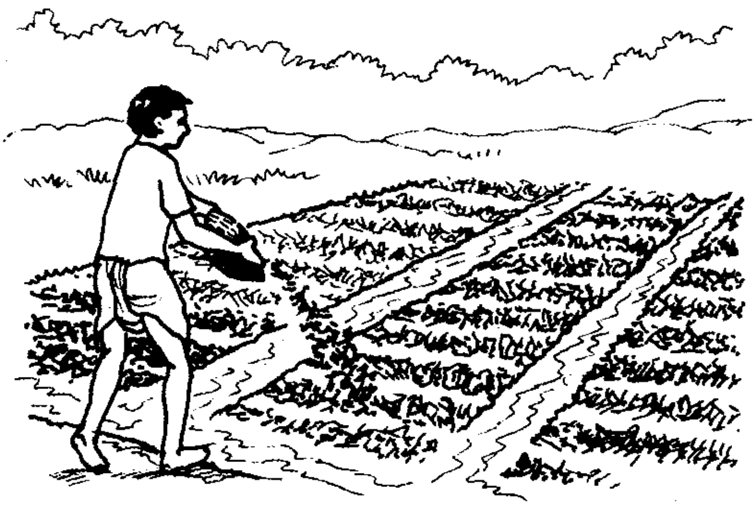
When water is transferred to a beneficial use for more agriculture, an increase in water productivity is achieved.

How to Increase Productivity Per Unit of Water Consumed

The productivity of per unit of water consumed can be increased by the following means:

- **Crop substitution** — by switching from high water-consuming crops to less water-consuming crops, or switching to crops with higher economic or physical productivity per unit of water consumed.

- **Changing crop varieties** — to new crop varieties that can provide increased yields for each unit of water consumed, or the same yields with fewer units of water consumed.



- **Deficit, supplemental, or precision irrigation** — with sufficient water control, higher productivity can be achieved using irrigation strategies that increase the returns per unit of water consumed.
- **Improved water management** — to provide better timing of supplies to reduce stress at critical crop growth stages, leading to increased yields, or, by increasing water supply reliability so farmers invest more in other agricultural inputs, leading to higher output per unit of water.
- **Improving non-water inputs** — in association with irrigation strategies that increase the yield per unit of water consumed, agronomic practices such as land levelling and fertilization can increase the return per unit of water.

Reducing Non-Beneficial Depletion

It is possible to lessen the non-beneficial depletion of water by:

- reducing evaporation from water applied to irrigated fields through specific irrigation technologies such as drip irrigation, or agronomic practices such as mulching, or changing crop planting dates to match periods of less evaporative demand;
- reducing evaporation from fallow land, decreasing the area of free water surfaces, decreasing non-beneficial or less-beneficial vegetation, and by controlling weeds;
- reducing water flows to sinks through interventions that reduce irrecoverable deep percolation and surface runoff;
- minimizing salinization or return flows through saline soils or through saline groundwater to reduce pollution caused by the movement of salts into recoverable irrigation return flows;
- shunting polluted water directly to sinks to avoid the need to dilute with freshwater; and
- reusing return flows.

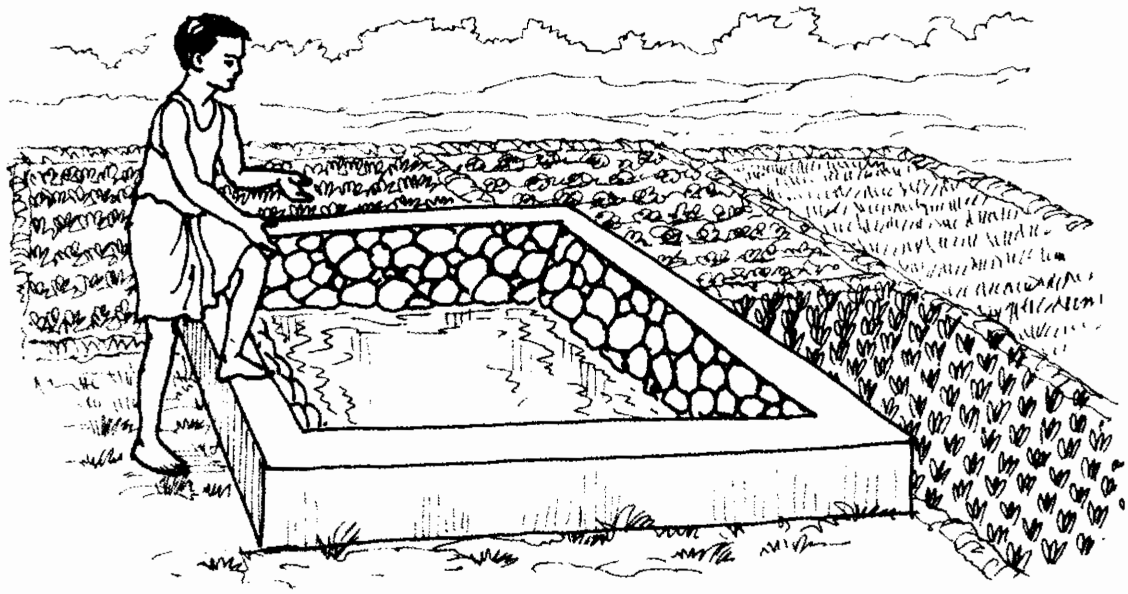
Because downstream commitments may change, reallocation of water can have serious legal, equity and other social considerations that must be addressed.

Reallocating water from lower-value to higher-value uses will generally not result in any direct water savings, but it can dramatically increase the economic productivity of water.

Tapping Uncommitted Outflows

Uncommitted outflows can be tapped through the following means:

- **Improved management of existing facilities** — to obtain more beneficial use from existing water supplies. A number of policy, design, management, and institutional interventions may allow for an expansion of irrigated area, increased cropping intensity, or increased yields within the service areas. Possible interventions are reducing delivery requirements by improved application efficiency, water pricing and improved allocation and distribution practices.
- **Reusing return flows** — through gravity and pump diversions to increase irrigated area.
- **Adding storage facilities** — so that more water is available for release during drier periods. Storage takes many forms, including reservoir impoundments, groundwater aquifiers, small tanks, and ponds on farmers' fields.



Adapted from:

Molden, D., R. Sakthivadivel and Z. Habib. 2001. Basin-Level Use and Productivity of Water: Examples from South Asia. Research Report 49. International Water Management Institute, Sri Lanka.

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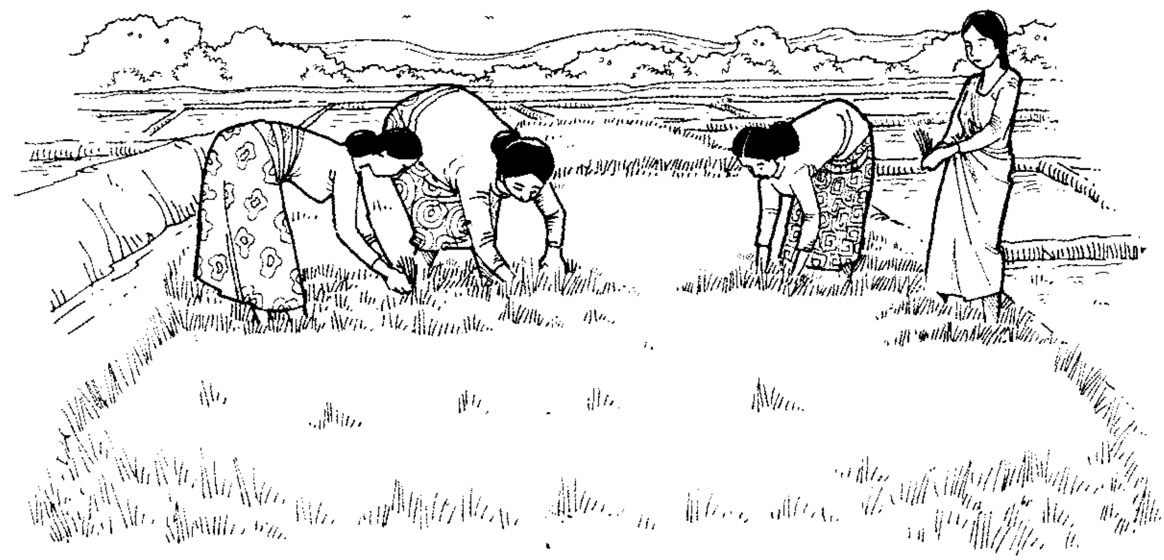
Innovations in Groundwater Recharge



The amount of water pumped by farmers from India's aquifers is greatly exceeding natural recharge in many areas. In the western part of the Indo-Gangetic Plain, where the recharge approach described here was initiated, rainfall ranges between 650 and 1,000 mm annually, but only 200 mm naturally percolate through the soil layer to replenish underlying aquifers. Most of this rainfall, which is concentrated during the three months of the monsoon, does not have time to be absorbed into already saturated soil and so runs off—eventually flowing unused into the sea. If a fraction of this runoff could be stored underground through artificial recharge, the problem of declining water tables that plagues much of the region could be solved.

Earthen irrigation systems can be transformed into highly productive region-wide groundwater recharge systems - at very little cost.

Recent research suggests that providing farmers with irrigation water during the monsoon offers a cost-effective option for harnessing this previously wasted resource to artificially recharge groundwater. If surplus river flows can be channeled through an unlined system to provide farmers with irrigation for monsoon crops, seepage water from the canals and fields will refill underlying aquifers (see Figure 1). This stored water can then be pumped up by farmers during the dry season for a second crop. The resulting drawdown of the aquifers maximizes their storage potential for the next monsoon and prevents waterlogging. This conjunctive management of canal water and groundwater has proved productive and, above all, sustainable.

Providing canal water only during the monsoon season has a number of advantages beyond aquifer recharge. Farmers are no longer at the mercy of monsoon rains, which sometimes fail to provide enough water when and where it is needed. They are guaranteed sufficient water to irrigate both a monsoon and a post-monsoon crop.

Head-tail differences are minimized: during the monsoon, there is enough water for users at the tail end of the irrigation system, and there is still plenty to recharge the aquifer. During the dry season, as there is no canal supply, all the farmers have to pump water if they want to irrigate a post-monsoon crop. Since pumping costs farmers money, they use the water more efficiently.

Domestic and industrial users also benefit from recharged groundwater.

Transforming Irrigation Systems Into Recharge Systems

The research by Roorkee University, the Water and Land Management Institute (WALMI) of Uttar Pradesh, and the State's Irrigation Department, in collaboration with the International Water Management Institute (IWMI), evaluated this ongoing experiment in large-scale recharge being carried out by the Government of Uttar Pradesh.

The recharge project involved the construction of a barrage across the river Ganga at Raolighat, which diverts 234 m^3/sec of water into the Madhya Ganga Canal when the monsoon raises river flows. The Madhya Ganga Canal feeds the existing Upper Ganga Canal system and the newly constructed Lakhaoti Branch Canal system. This water is supplied to farmers, who use it

Overview of Project Results-Benefits to the Region

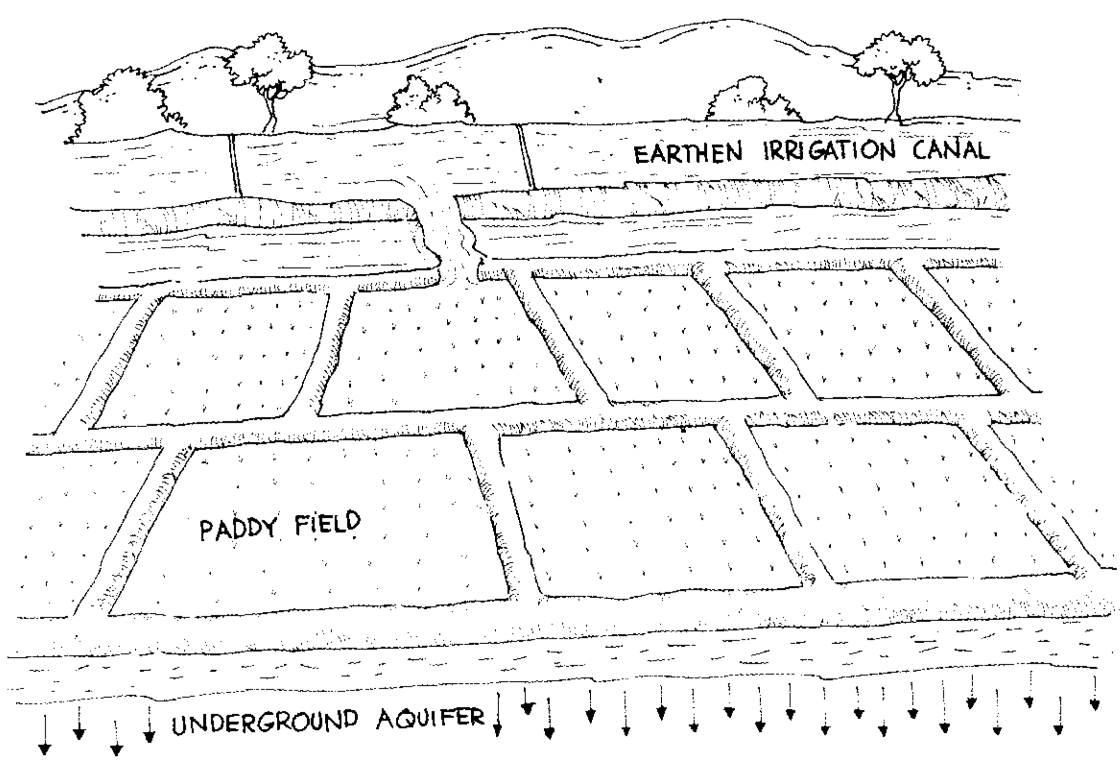
- 26% increase in average net income per ha for farmers.
- Average depth to groundwater decreased from an average of 12m below ground level (1988) to an average of 6.5m (1998).
- Annual pumping cost savings of Rs.180 million (900,000,000 m^3 of water pumped each year).
- Annual energy savings of 75.6 million kWh.
- Canal irrigated area increased—from 1,251 ha (1988) to 37,108 ha (1996).
- 15% increase in cropped area for rice—83 ha (1988) to 14,419 (1999)—with potential for further 30,000 ha. Irrigated sugarcane area increased by 1,000 ha.
- Canal water input increased from 27,202,000 m^3 (1988) to 643,010,000 m^3 in (1996).
- Reduction of 50% in water conveyance losses with potential for further improvement.

to irrigate such water-intensive monsoon crops as paddy rice and sugarcane. The research documented how this diversion of surplus Ganga water during the monsoon season has affected groundwater levels, land use, cropping pattern, and the costs and benefits of agricultural operations—focusing specifically on the Lakhaoti Branch Canal system.

The research showed that the water table, which had been progressively declining, has been raised from an average of 12 m below ground level to an average of 6.5 m. A simulation of the groundwater system suggests that without the artificial recharge provided by the monsoon irrigation, the water table would have fallen to an average depth of 18.5 m below the surface during the course of the 10-year study period.

Farmers have benefited from the corresponding reduction in pumping costs and the improved cropping pattern. With the introduction of monsoon irrigation, the average net income has increased by 26% to Rs 11,640 per hectare. In addition, the recharge benefits other water users in the area—water demand for domestic purposes and industrial use are also met from recharged groundwater.

Figure 1. Paddy Rice Irrigation Aids Recharge



For paddy rice, around 60% of the irrigation water applied is used by the plants; most of the remaining 40% filters through the soil to recharge the aquifer below. Combined with seepage from unlined canals, these "losses" provide farmers with groundwater to irrigate dry season crops.

Saving on Water Storage Infrastructure

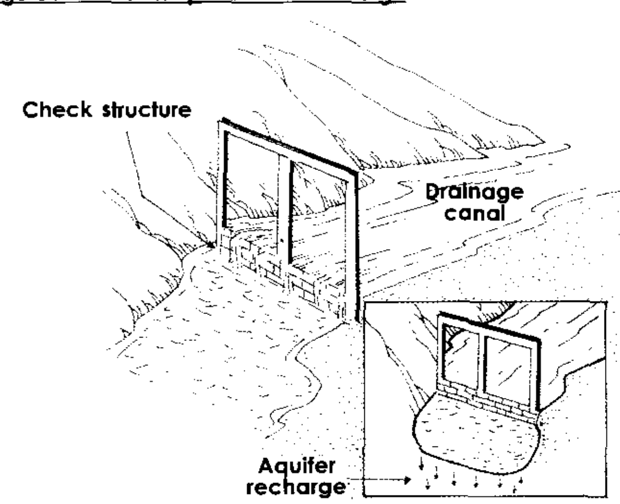
The recharge effort described here can be duplicated using existing canal schemes of any size. The Lakhaoti is a medium-sized, unlined system, with a command area of about 206 thousand hectares, but any irrigation system in an area where there are viable aquifers and surplus monsoon water is a good candidate for this approach. The Indo-Gangetic Plain is ideal because it is underlain by a thick stratum of sandy soils, which readily holds and transmits groundwater.

The most effective way to recharge groundwater in the Indo-Gangetic Plain, this research suggests, is to modify the operation of unlined irrigation systems.

The recharge approach has allowed the Government of Uttar Pradesh to increase agricultural production and provide farmers with irrigation water in previously existing dry pockets—without constructing dams or new reservoirs. In the area now covered by the Lakhaoti scheme, existing water rights precluded providing farmers with Ganga water for irrigation during the dry season. Building surface storage dams was not an option in this flat alluvial terrain. Even if suitable sites for such structures could be found, escalating costs of construction and stringent environmental requirements would be prohibitive.

How Unused Drainage Canals Can Help Maximize Recharge

Recently published research from Punjab Agricultural University, Ludhiana suggests that the network of surface drains—that were constructed to control waterlogging and floods in the early 1950s but that are now rarely used—can be modified to catch monsoon rains and replenish falling groundwater tables in many areas of India. In effect, these unused drainage channels can be transformed into temporary reservoirs. Excess water not needed for irrigation can be diverted into these unused channels, where 'check structures' slow it for recharge.



Unused drainage canals can be modified to increase recharge. Research has shown that building check structures, which slow the water flow, can increase recharge by three-and-a-half times.

The research by S. D. Khepar and his colleagues shows how building check structures, at suitable intervals in the drainage canal, can increase the recharge capacity of a drain by three-and-a-half times over recharge under natural flow conditions. A model developed to estimate the recharge provides water managers with guidance for organizing canal water releases, while ensuring that there is no runoff at the outflow of the drain, under natural flow conditions and with check structures.

Using a combined approach-diverting monsoon water through earthen irrigation canals and the existing network of unused drainage canals offers several practical advantages. The most prominent is that the recharge 'infrastructure'-earthen irrigation and drainage canals and groundwater aquifers—already exists, and can be modified at a very low cost, compared to planning and building dams, tanks or other water-storage facilities.

See Khepor, S.D, A.K.Yadav, S.K.Sondhi, Arpan Sherring. 2000. Modelling Surplus Canal Water Releases for Artificial Recharge of Groundwater Through Surface Drainage Systems. Irrigation Science 19:95-100.

These problems are not unique. They have troubled planners and policy makers for years. Practical and economically viable solutions are required, backed by sound science and proven results. The potential to build on earlier investments and use existing structures to avoid large capital outlays certainly merits consideration. It could save money, conserve vital natural resources and improve the livelihoods of poor farmers.

The most effective way to recharge groundwater in the climatic and hydro-geological conditions of the Indo-Gangetic Plain, this research suggests, is to modify the operation of unlined irrigation systems to carry surplus monsoon flows. Even in cases where canals are lined or partially lined, there will still be beneficial recharge—though not as much as from an unlined scheme.

This type of recharge effort is also cost-effective. The total cost of canal water at canal head (capital cost + operation and maintenance cost at 1990 prices) is Rs 0.3162 per m^3. With each m^3 of water bringing an average return of Rs 8, the canal water is an extremely good investment.

> As a back-of-the-envelope calculation shows, for such staple crops as wheat, farmers are producing approximately Rs 8 worth of crops for every m^3 of water used. Farmers use around 6,000 m^3 of water per hectare, and their average yield is 5 tons per hectare. The value of 5 tons of wheat at current prices is Rs 49,500, making the value of each m^3 of water little over Rs 8.

If this irrigation policy shift is put into action on a large scale, the socioeconomic impact can be potentially huge. It will improve farmers' incomes, while helping save state expenditure on water infrastructure or dam construction, stabilizing power generation requirements, and lowering atmospheric emissions and environmental impacts. A strategy of combining groundwater recharge through monsoon irrigation with appropriate electricity pricing and groundwater use regulations, has the potential to drastically improve the productivity and sustainability of farmers' water use in areas where overpumping is currently endangering groundwater resources.

Indian Regions/Areas that Can Benefit from Groundwater Decline

- Where geology favors holding, storing, and allowing groundwoter to be extracted, including areas with deep alluvial soils, sandy loams with low clay and kankar contents that hove good potential to store water for later use.
- Riverine systems with high river flows during the monsoon where flows ore not used for crops, and run out to sea—conserving this floodwater is the main aim.
- Locations where constructing a dam or building a surface reservoir causes environmental damage or flat alluvial terrain where surface storage dams cannot be built.
- Locations where it is too expensive to build dams, or to transport woter over long distances, where land cannot be allocated for storage, and the land values are high.
- Areos with no soil salinity problems.
- Places where the ground slope varies gradually and where it is not subject to flooding and/or waterlogging.
- Command areas of existing canal irrigation systems where the canals can be better utilized for monsoon irrigation.
- Places where accurate information on hydrogeology and groundwater movement are available, thus saving the cost of detailed surveys.

Reversing Groundwater Decline

Before the introduction of monsoon canal irrigation, withdrawal of groundwater in the area was exceeding recharge, and the water table was declining by an average of 0.5 m per year. In 1984, the average depth of the water table was 10 m below ground level; by 1988, when the recharge effort began, it had fallen to 12 m. After 10 years of providing monsoon irrigation, the depth to groundwater has been almost halved—the average for 1998 was 6.5 m below ground level.

Groundwater hydrographs were prepared for five observation wells located from head to tail of the Lakhaoti Branch Canal. In the head-reach villages they show that the water table fell progressively until 1988, when the recharge effort began. Here the artificial recharge had an almost immediate impact. In the tail-end villages, it has taken longer for the water table to rise. In one tail-end village, for example, the watertable continued to decline until 1990, then remained constant until 1997, when it finally began to rise. The primary reason it has taken the tail reach areas longer to respond to the canal water recharge is incomplete infrastructure for water distribution in the tail reach.

The groundwater balance calculated for the Lakhaoti command area shows that in a normal year, rainfall recharge is 370 million m^3. Canal and field seepage contributes approximately 328 million m^3. Total recharge, without considering the lateral inflow of 63 million m^3 from other aquifers, works out to 698 million m^3. Net pumping for irrigation averages around 663 million m^3 - leaving 35 million m^3 to help raise depleted water tables. Once water tables have reached an optimal level (approximately 3 m below ground level), farmers will need to increase pumping to balance recharge and prevent water levels from increasing further.

Direct Benefits to Farmers

- Savings in pumping costs and stable pumpset locations.
- Better cropping patterns and operating conditions (availability of pumped groundwater for post-monsoon crop irrigation, and avoiding waterlogging).
- Stable irrigation supply guaranteed by canal water supplements.
- More annual income from additional rice and sugarcane.

Impact on Farm Budgets

When water tables drop, farmers' pumping costs go up. After the introduction of the recharge effort, the groundwater level rose and consequently the cost of pumping fell. A simulation of the groundwater system shows that without the artificial recharge the water table would have dropped to an average depth of approximately 18.5 m over the 10-year study period. Lower groundwater tables would have increased the cost of pumping, and forced users to deepen wells and lower their pumping sets.

The cost of pumping with the water table at 18.5 m would have been Rs 0.465 per m^3. Under current conditions, with groundwater at an average depth of 6.5 m, the cost of pumping groundwater is Rs 0.265 per m^3—a savings of almost 50%. Considering that altogether farmers pump close to 900 million m^3 (gross) annually, the amount saved in pumping costs comes to Rs 180 million per year.

Farmers' incomes have also benefited from the increased production and from the better cropping pattern enabled by the monsoon irrigation. In the past, there was not always sufficient water for a post-monsoon crop; now, farmers are guaranteed enough water for two cropping seasons.

With the additional water provided by the monsoon irrigation, farmers have been able to expand the area irrigated. The canal irrigated area increased from 1,251 hectares for the 1988/89 season, to a maximum of 35,798 hectares in the 1997/98 season.

Why is a Policy Change Needed?

Over the years, State Irrigation Departments have aimed to store and distribute water to farmers in the dry season, so that at least two crops can be grown in a year. It is generally assumed that the monsoon brings enough water to go round and that farmers do not need help. This is not always true. Monsoons are erratic and sometimes do not bring the promised rainfall.

Another fact is that the torrential monsoon rains bring vast amounts of water that are not needed for agriculture at that very moment. Most of the monsoon rains flood fields, filling rivers and streams that rush—unused—to the sea. This is the very water that could help the farmer year-round, if it could be diverted and its flows slowed down enough to percolate through to underground aquifers. Fast-flowing torrents wash away topsoil, and waterlogged fields are a farmer's nightmare for such crops as pigeon pea that cannot tolerate excessively wet conditions.

> Most monsoon rains flood fields, filling rivers and streams with water that rushes out- unused - to the sea. This is the very water that could help the farmer year-round

From the farmers' perspective, having better 'crop security' for monsoon crops by making irrigation water available to supplement an erratic supply of rain—and still having enough water stored in aquifers to grow another crop later—is an attractive proposition. But policy makers and water managers will have to clearly articulate the advantages and positive impact of the change if farmers are to be convinced. Farmers live with risks the year-round, so removing one of their main worries—the possibility of drought caused by monsoon failure—will give them the confidence to face their many other challenges.

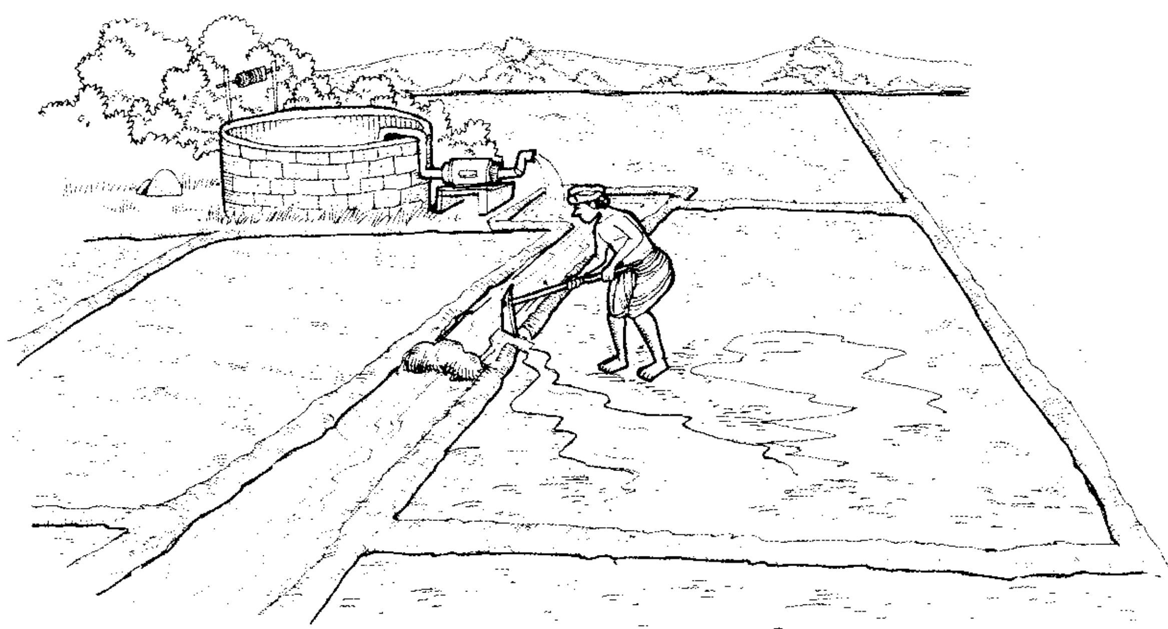
Farmers will need to be convinced that this new approach will work for them. If they can be sure that their hard-earned pumps will continue to find water in the aquifers after the monsoon, that the pumps will not need to be lowered into ever-deepening borewells, and that the stable water table means lower power costs, then they will support changing cropping patterns as part of a new groundwater recharge strategy.

This article has been adapted from an issue of Water Policy Briefing, based on research presented in the technical paper **Artificial Recharging of Groundwater: An Experiment in the Madhya Ganga Canal Project, India** by R. Sakthivadivel of the International Water Management Institute (IWMI) and A. S. Chawala formerly of the Water Resources Development and Training Centre (WRDTC), University of Roorkee, India. Readers interested in the details of this research are invited to read the full text of the technical paper at www.iwmi.org/iwmi-tata or request a copy at the address given below.

Questions and comments on this issue may be directed to Dr. R. Sakthivadivel c/o IWMI, Elecon, Anand-Sojitro Road, Vallabh Vidyanagar 388 001, Gujarat, India or iwmi-tata@cgiar.org.

Acknowledgement
We acknowledge with thanks the IWMI-TATA Water Policy Program for allowing us to use Water Policy Briefing Issue 1.

Improved Water Management Practices in the Rice-Wheat Zone of Sind, Pakistan



The current yields of rice and wheat in Sind, Pakistan are far below their potential yields partly due to improper water management practices. During the rice season, the major problem of water management is an early-season water shortage followed by excessive water with the onset of the monsoon season. During the wheat season, excess soil moisture in ricefields delays wheat planting, and later during the crop season, there is a shortage of irrigation water. Poor water management practices at the farm level cause wastage of limited irrigation water, whereas rice-wheat systems need promising water management practices at the farm level.

Water-Efficient Method of Rice Establishment: Direct Seeding of Rice

In Sind, the traditional practice of rice establishment is to transplant young rice seedlings from nurseries. Adoption of direct seeded rice method improves management of irrigation water. There are two systems of direct seeding of rice: wet and dry.

Under the wet direct seeding system, pre-germinated secds, obtained by soaking seeds for 24 to 36 hours are sown on the saturated field that has been prepared under wet condition. Land preparation is completed in about a week, avoiding long periods of water losses occurring in transplanted rice. About 30% less water is required to prepare a typical field up to the same puddled condition for wet-seeding of rice than for transplanting rice. Wet-seeded rice yields more in both water-sufficient and water-deficit situations, requires less labor, and produces a better return on investment than transplanted rice.

Adoption of Wet Direct Seeding System in Asia

Farmers in the Philippines, Malaysia, and Thailand are adopting wet direct seeded system instead of transplanting rice. Under this system, during the first four to five days after seeding, the field is kept moist, but not flooded. Later, 2 to 3 cm of water is allowed to flood the ricefield. About 10 days after seeding, the water level is increased and maintained at 5cm until crop maturity.

Wet direct seeding is faster and easier than transplanting rice and grain yield is similar or higher than transplanted rice. This technique requires better leveling of the field for good water management and crop establishment. Adequate plant stand establishment and weed control is possible with a recommended seed rate of 100 kg pre-germinated rice seeds per ha.

The technique incurs reduced labor cost because it does not include the steps used for transplanted rice, e.g., nursery preparation, care of seedlings in seedbed, and pulling of seedlings, hauling and transportation. Also, the cropping cycle is shorter because of the absence of transplanting shock. The technique requires shallow water depth to be maintained in the ricefields compared to transplanted ricefields, and thus improves water control and facilitates better water management.

In the dry direct seeding method, field preparation is done under dry condition, immediately followed by seed sowing either before irrigation water is applied or before rain occurs, to enable germination and seedling establishment. The total cropping season could be reduced by about two weeks avoiding nursery preparation and transplanting phase and the overall irrigation requirement is reduced, resulting in significant water saving of up to 25%. Transplanting rice requires more water and results in more wastage than the dry direct seeding system.

Land Leveling

Farmers should be encouraged to level farmland to improve water conservation. Land leveling effectively facilitates on-farm water control and management. It is a basic requirement at field level to avoid over- or under-irrigation due to the micro-undulations in the ground surface. To facilitate this activity, the local government agencies should provide subsidies, technical assistance, and training to the farmers. Due to clayey nature of the soils, land leveling by bullock and manual labor is very limited in Sind. Hence, farmers can benefit from laser technology for land leveling. Laser equipment is now being locally manufactured by the private sector. The improved irrigation scheduling and irrigation practices such as land leveling by laser technology and appropriate irrigation method result in reduced seasonal irrigation water requirements and consequently, help in controlling waterlogging and soil salinity in irrigated areas.

Irrigation Scheduling

Improved irrigation scheduling saves water considerably. Based on soil conditions, irrigation to rice can be delayed for varying periods after infiltration of water from rain or previous irrigation. In the rice-wheat zone of Sind, the entire rice crop is grown in flooded fields, which are initially irrigated individually. Later in the crop season, with the increase in water depth, a largely-uncontrolled water flow takes place from field to field, thereby resulting in continuous flow irrigation. This practice is followed because of the uncertainty of water availability, resulting in over-flooding of ricefields. At the tail end of water channels, the fields are irrigated wherever water is available. Generally, fields are not properly leveled. Consequently, to irrigate the high spots, the fields are over-irrigated resulting in prolonged periods of deep water at the lower spots.

Water-Saving Irrigation Regimes

Continuous submergence of soil is not necessary to obtain high rice yields. Once the transplanted seedlings are well established, irrigation could be delayed for some period after complete infiltration of ponded water without any yield loss. The potential saving of 20% to 50% in irrigation water primarily results from the reduction in percolation losses. To improve water-use efficiency of rice crop, farmers in Sind should adopt water-saving practices of maintaining a thin layer of standing water in the ricefield, saturated or alternate wet and dry soil regimes instead of the traditional practice of continuous submergence. These irrigation regimes can save 20%-70% of irrigation water without significant yield loss.

In the perennial irrigation areas, wheat is usually grown under the basin flood irrigation method. In these areas, more than 75% of the wheat receives a pre-sowing irrigation. The average interval between sowing and the first irrigation is approximately four weeks in the perennial irrigated areas, and five to seven weeks in the non-perennial areas. Generally, more irrigation is applied in the perennial than in the non-perennial areas. The average maximum interval between successive irrigations is six weeks in the perennial areas where there is a canal closure during January. The interval is slightly shorter in the non-perennial irrigated areas.

By adopting irrigation scheduling of wheat, about 17% of irrigation water could be saved compared to farmers' practices. The irrigation scheduling adjusts water application to climatic evaporative demand and soil water depletion, thereby causing considerable reduction in irrigation requirements for the growing season. Optimum irrigation scheduling prevents waterlogging and soil salinity, increases crop yields, and saves irrigation water.

Discontinuation of Pancho System

Some farmers in Sind practice the Pancho System of irrigation. This system involves draining of standing water from the field at intervals of four to five days and re-irrigating the same ricefields. The standing water in the ricefields is drained out to adjoining low-lying areas and freshwater is applied. In most of the ricefields, the groundwater table rises and in some areas, reaches the surface layer of soil. Under these conditions, percolation either slows down or does not take place.

The Pancho System has helped farmers in increasing rice production, but in the absence of an efficient drainage system, the water is drained to low-lying areas resulting in waterlogging. For this, the length of the watercourses should be reduced and farmers should irrigate each field separately from the irrigation ditch. Also, minor channels should be constructed. Each field should have a separate water inlet from a watercourse for controlled irrigation.

Institutional Management Poses Threats to On-farm Water Management

Some institutional arrangements and policy decisions affect farm-level water management thus encouraging wasteful use. For example, when groundwater is perceived as a common property, it is in the interest of an individual farmer to pump as much as possible. Collective action arrangements (e.g., restrictions on tubewell installation) should be made for equal distribution of water at the village level. Subsidies on water and on electricity for tubewell pumping are also contributing to excessive use of water. Tradable water rights may ensure efficient use of water resources, while allowing farmers to benefit from their traditional water rights.

The capacity to examine the feasibility of new practices, e.g., conjunctive use of surface water and groundwater, is hampered by lack of sufficient communication and coordination among institutions responsible for management of surface water, public tubewells, electricity supply, drainage, on-farm works, extension, and the reporting of agricultural data.

Source: Harrington, L. 2001. Synthesis of Systems Diagnosis: "Is the Sustainability of the Rice-Wheat Cropping System Threatened?" – An epilogue. pages 119–132 *In:* The Rice-Wheat Cropping System of South Asia: Trends, Constraints, Productivity and Policy (Kataki, P.K., ed.). Food Products Press, New York, USA.

Improved Layout of Irrigation Ditches and Fields

In Sind, significant amounts of water are wasted due to negligence by farmers, bad layout of water channels, and weak bunds of ricefields resulting in low irrigation efficiency. The channels follow a zigzag pattern, which slow down water speed and cause siltation necessitating frequent cleaning of water channels. To improve the irrigation efficiency, layout of water channels should be straight and clear, and individual fields should be leveled. Farmers should construct proper field bunds to efficiently retain and control water to the required standing depth, and prevent or minimize water losses through reduced drainage effluent.

Improved Drainage and Reuse of Drainage Effluent

Surface drainage is required for removal of excess water from land currently flooded to excessive depths in kharif rice season. Thus, more land could be made available for cultivation during winter. Subsurface drainage systems should be intensified, supported by government subsidies.

Recycling of drainage water could be practiced for water saving and conservation in the rice-wheat areas of Sind. Besides meeting the water needs at peak demand periods, drainage water reuse would be a quick-response water supply solution during water shortage periods, increasing both the water reliability and rice-wheat crop security.

Farmers' Participation in Sind

Farmers should be organized to participate in the decision-making process for improving water management. The Irrigation Department should consider them as active partners in this process. This would improve equity and reliability of water distribution, which in turn would result in timely planting of rice and wheat. Subsurface drainage systems operated by the government perform poorly due to management and financial resource constraints. Therefore, participatory drainage management schemes should be established in which farmers share the capital cost and are responsible for operational and maintenance cost.

Adapted from:

Aslam, M. and S.A. Prathpar. 2001. Water Management in the Rice-Wheat Cropping Zone of Sind, Pakistan: A Case Study. pages 249–272. *In:* Kataki, P.K. (ed). The Rice-Wheat Cropping Systems of South Asia: Efficient Production Management. Food Products Press, New York, USA.

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Waterlogging and Salinity in the Rice-Wheat Zone of Sind, Pakistan

In the rice-wheat areas of Sind in Pakistan, extensive depressional areas, lack of adequate drainage, and improper water management practices cause widespread problems of waterlogging and salinity. Land should be leveled properly for efficient use of water. Poorly-leveled fields cause over-irrigation resulting in waterlogging and soil salinity, which are not favorable for optimum growth of most crops. About 32% land in the Sind rice-wheat zone is waterlogged and salinized causing considerable reduction in rice and wheat yields.

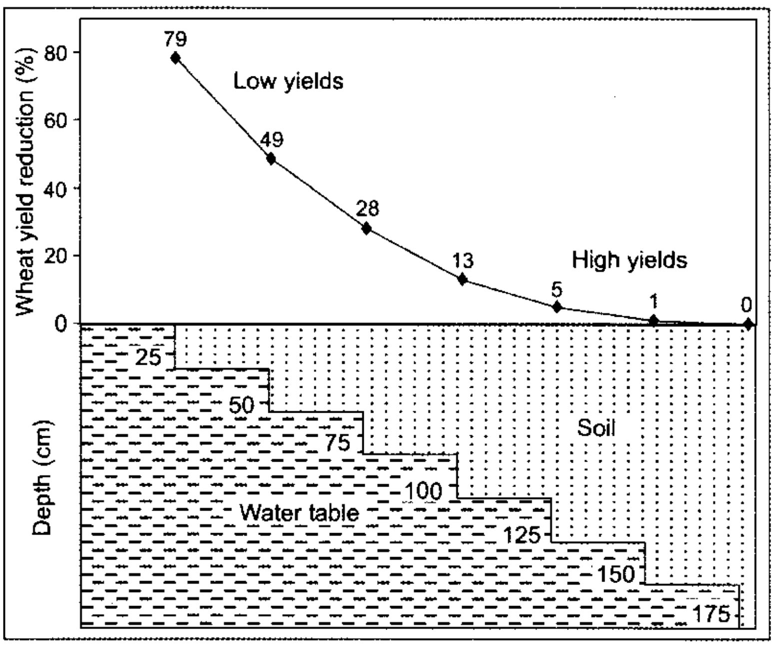
Canal Command Area in Sind, Pakistan Afftected by Waterlogging and Salinity

Canal Command	Total area (million ha)	Waterlogged area*		Salt-affected area (%)
		April	October	
Desert	0.1	0.04	0.1	19
Begari	0.4	0.04	0.4	18
North West	0.5	0.30	0.5	20
Rice	0.2	0.02	0.2	20
Dadu	0.3	0.08	0.2	28
Kalri	0.3	0.04	0.2	-
Lined Channel	0.2	0.06	0.2	49
Fuleli	0.4	0.20	0.4	57
Pinyari	0.4	0.10	0.3	49

* Area in million ha under <150 cm water table depth

Waterlogging in Wheat

Unlike rice, waterlogging is a major constraint for wheat production. Wheat cultivation can be done successfully when the watertable is below 150 cm. But yields decrease drastically when the watertable is within 100 cm depth. In Sind, the watertable is shallow in October during the rice season and recedes in summer. The watertable depth is the lowest in June after wheat harvest.



Groundwater Salinity

In many areas of Sind, groundwater is saline and unfit for irrigation. About 19% of the total culturable command area (CCA) of Sind rice-wheat zone has groundwater [total dissolved solids (TDS) <3000 ppm] and about 81% has saline groundwater (TDS >3000 ppm). About 63% of the CCA (1.6 million ha) has saline groundwater whereas in SRWS, nearly all of CCA (1.2 million ha) has saline groundwater. Wheat yields in the Sind rice-wheat zone is the lowest in the Basin due to canal water scarcity and saline groundwater.

Spatial Distribution of Groundwater Salinity in CCA (thousand ha) in Sind

Canal command	Total CCA	TDS<300ppm	Saline
Desert	157.8	157.8	-
Begari	340.8	170.4	170.4
North West	309.4	46.4	263.0
Rice	210.0	46.2	163.8
Dadu	244.8	39.2	205.7
Kalri	257.4	-	257.4
Lined Channel	220.1	-	220.1
Fuleli	360.6	-	360.6
Pinyari	323.3	-	323.3

Adapted from:

Aslam, M. and S.A. Prathpar. 2001. Water Management in the Rice-Wheat Cropping Zone of Sind, Pakistan: A Case Study. pages 249–272. *In:* Kataki, P.K. (ed). The Rice-Wheat Cropping Systems of South Asia: Efficient Production Management. Food Products Press, New York, USA.

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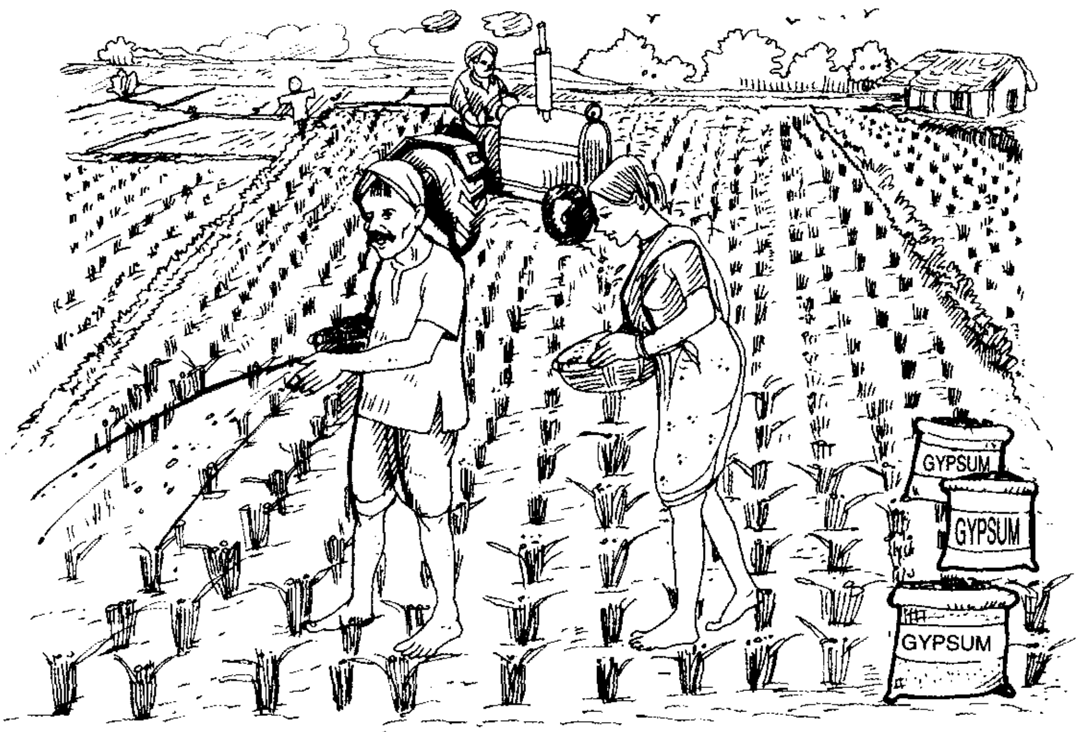
Reclamation and Management of Alkaline Soils



Salt-affected soils have excess of soluble salts and/or excess of exchangeable sodium with accompanying high pH. Both these conditions degrade the soils and render them inhospitable for normal crop production (in absence of special soil and crop management measures). Soils having soluble salts in excessive amounts are unable to supply water to plants due to osmotic stresses. As a consequence, plants are unable to grow normally in salt-affected soils. The salt content may be an inherent characteristic of the soil or the result of salts being brought up from the deeper soil layers through capillarity or directly due to application of saline or alkali groundwater for irrigation. Saline soils typically have salt encrustations on the surface.

Categories of Salt-Affected Soils

Salt-affected soils are categorized into two broad classes, viz (i) saline soils; and (ii) alkali (sodic) soils. Such a classification facilitates understanding of the genesis and management of the salt-affected soils on the basis of the influence of two common kinds of salts (i.e., neutral and alkali salts) on soil properties and plant growth. In soil testing laboratories, using USSL Staff (1954) criteria often a third category of salt-affected soils, namely saline-alkali soil, are also designated. It only,

Classification of Salt-Affected Soils

Soil type	pH_s	EC dSm^{-1}	$\frac{Na^+}{(Cl^- + SO_4^{-2})}$	SAR $(mmol/L)^{-1/2}$	ESP %
Normal	<8.2	<4	<1	<13	<15
Saline	<8.2	>4	<1	<13	<15
Alkali	>8.2	<4	>1	>13	>15

Gupta R.K. and Abrol, 1990

however, complicates issues and provides no indication whether soils belonging to this group be managed as saline or as alkali soils. This leads to considerable confusion as to how these soils should be reclaimed and managed.

Reclamation and management of saline and alkali soils differ considerably in terms of gypsum usage, irrigation and leaching schedules and choice of crops and cropping system. It is, therefore, warranted that soils belonging to saline-alkali branch are correctly diagnosed for adopting effective reclamation measures. Soils in saline-alkali branch can be easily apportioned into saline and/or alkali soil class through use of electro-neutrality criteria. A sodium to chloride and sulphate ratio $\{Na^+/(Cl^- + SO_4^{-2})\}$ greater than 1.0 suggests that a part of the positive charge due to sodium ions, is neutralized by carbonate ions. This points to the presence of sodium carbonates, at time not so easily detected in aqueous soil paste extracts, even when it is present in soils (Gupta and Abrol, 1990). Use of $\{Na^+/(Cl^- + SO_4^{-2})\}$ ratio, together with other indices, differentiates soils in saline-alkali branch into saline and/or alkali soils, an essential prerequisite for their proper management and reclamation for crop production.

Reclamation of Alkali Soils

Gypsum ($CaSO_4 2H_2O$) or other relatively calcium salts or acid formers like elemental sulphur and pyrites of iron can also be used to reclaim alkali soils and to treat irrigation water having residual alkalinity. Gypsum is applied onto properly-leveled and bunded fields and water is ponded for several days for salts to leach the reaction products down through the profile. Application of gypsum is often not required for management of all of the so-called "saline-alkali" soils as mentioned above. Saline-alkali soils with predominantly the neutral soluble salts (high SAR saline soils) behave like saline soils. They may not need gypsum usage and can be reclaimed by leaching with good quality waters. Provision or improvement of drainage in saline soils, having shallow water table, produces the desired results of speeding up the reclamation process in such soils.

Damage

For reclaiming saline and alkali soils, good drainage is the most important consideration. Often, provision of drainage and supply of fresh irrigation water are sufficient measures to reclaim saline soils. Salts are washed down with the percolating water through the soil profile and are leached into the drainage.

Tillage

Application of gypsum changes the soil reaction (ESP and pH) in the surface layer to a greater extent than in the sub-surface soil layers. Tillage should be restricted to the top 10cm of soil in which the gypsum should be incorporated and planted with rice (*unpuddled transplanted rice*) to initiate the reclamation process. Deep plowing brings the partially reclaimed subsoil to the surface, adversely effecting yield of the following wheat crop. Reclamation programs will be more effective by not bringing soil from the deeper layers to the surface. The use of organics facilitates dissolution of naturally-present calcite and also the passage of water down into profile of the gypsum amended oils.

Bed Planting

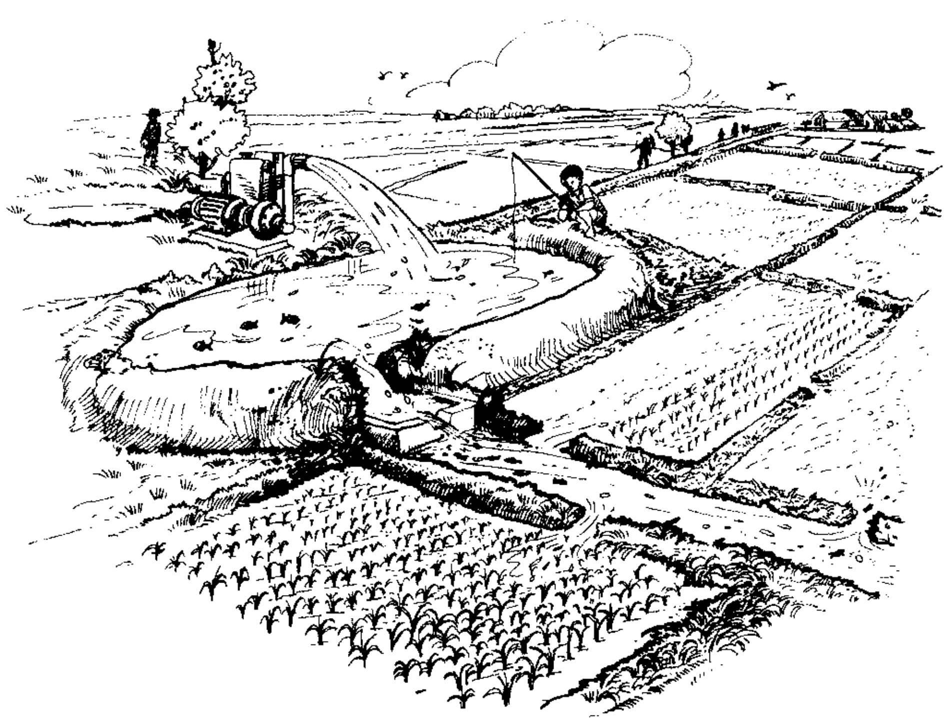
Furrow irrigated raised beds (FIRB) effectively double the depth of the reclaimed alkali soil rooting profile. Changing from flat layouts to raised beds alters the geometry and hydrology of the system and offers greater control over irrigation, drainage and their impacts on transport and transformation of nutrients. Water moves horizontally from the treated furrow surface into the raised beds through subbing and is pulled upwards through capillarity, evaporation and transpiration. Bed planting reduces irrigation water requirement by 25%-50% while the growth and yields of transplanted rice on beds can be comparable or more than traditional rice culture. Permanent beds also avoid the need for deep plowing in subsequent years and excellent wheat crops have been obtained from FIRBs in partially-reclaimed alkali soils.

Puddling

Alkali soils already have poor drainage and are highly impermeable to water movement. Puddling of alkali soils further degrade the soil structure, and can facilitate the formation of subsurface plow pan further restricting the percolation of the water through the soil profile. Reduced infiltration and passage of water reduces leaching of the gypsum-reaction products out of the soil profile and thereby slows down the process of reclamation of alkali soils. Therefore, puddling should be avoided for several years after initiating reclamation program on alkali soils.

Rice as the Fist Crop

Rice likes ponded water conditions for longer periods and is a sodicity-tolerant crop. In alkali soils, not amended with gypsum or other ameliorants, water stagnates for long periods after an irrigation and rainfall event. Because of prolonged ponded water conditions generally prevailing during the monsoon season, rice is the preferred choice of the farmers in early stages of the reclamation programs. The rice crop should be transplanted on unpuddled soils. Deep plowing should be avoided and tillage should be restricted to the top 10cm depth in amended soils. Both deep plowing and puddling are counter-productive in reclamation and unhelpful in obtaining higher yields in the succeeding wheat crop.



Grouping Irrigation Waters

Irrigation with low quality irrigation waters may cause salinity, and infiltration problems or even cause specific ion toxicity. Such effects of irrigation may adversely affect crop production. Depending on the characteristic features of the groundwaters in use and the indices that describe restrictions in their use (salinity, sodicity hazards on crops and soils), low quality irrigation waters can be broadly grouped as (i)saline and (ii) alkali waters. Researches have shown that irrigation water quality standards which are unmindful of the monsoonal climate conditions of the Indian sub-continent, cannot adequately describe the salinity and sodicity hazards on crops and soils. Very often, the waters which would be termed unsuitable on the basis of criteria followed by USSL Staff (1954) are in continuous use with South Asian farmers.

Depending on the degree of restrictions, the two water quality classes have been further sub-grouped as in Table 1.

Table 1. Water Quality Groupings of Irrigation Waters

Water Quality Class	ECiw dSm^{-1}	SAR $(m\,mol/L)^{-1/2}$	RSC $meqL^{-1}$
Normal	<2	<10	<2.5
Saline			
i. Marginally-saline	2-4	<10	<2.5
ii. Saline	>4	<10	<2.5
iii. High SAR saline	>4	>10	<2.5
Alkali			
i. Marginally-saline	<4	<10	2.5-4.0
ii. Alkali	<4	<10	>4.0
iii. Highly alkali	<4	>10	>4.0

The problem of alkali soils is often aggravated when groundwater having more than 4.0 meq/L of residual sodium carbonates (RSC) are used for irrigation. Water termed as "alkali water or highly alkali" are unsafe for irrigation. The use of such waters for irrigation turns normal soils into alkali soils, necessitating gypsum use again after few years. On the other hand, irrigation waters in saline category have excess of neutral soluble salts and their continuous use causes salinity to the detriment of most crops except the salt-tolerant ones. If infiltration rates of soils are adequate, gypsum may not be needed for a long period.

The management of saline irrigations in crop production depends on the climatic and soil conditions, and the way these waters are used for irrigation. Therefore, besides chemical quality of irrigation waters, considerations of soil texture, crop tolerance, crop rotation, quantity of available canal water supplies, rainfall and concentration of solutions due to evapotranspiration (salt concentration factor) are of great importance. Accordingly, low quality waters are used either in cyclic use mode, or by blending them with fresh canal water supplies or both.

Blending Irrigation Water

On-farm storage tanks, used for captive fish breeding in canal water, can be conveniently used for blending water for irrigation (Gupta *et al.*, 2000). These tonks can also be used to store excess surface run-off flows during rainy season for irrigation use in the dry season. The alkali waters from tubewells, when mixed with canal water in appropriate proportions, reduce residual alkalinity to safe limits.

The general rule for blending saline water with canal water should be that the blended water supplies should be within the threshold salinity tolerance rating of the more sensitive crops grown in the cropping system.

Blended Benefits

The strategy of using tanks for blending surface waters with alkoli groundwater to irrigate soils has many benefits.

- Dilution of RSC makes the blended water safe for irrigation.
- Added groundwater provides additional head to the stored water for faster flow in the fields.
- Irrigation time is reduced.
- Blended water supplies make additional irrigation water available during crop season to improve yields.
- A variety of fish that feed at different depths can be grown in the tanks.
- On-farm water storage tanks can help avoid night irrigation vis-a vis improve irrigation efficiency.

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Gupta, R.K., P.R. Hobbs, M. Salim, R.K. Malik, M.R. Varma, T.P. Pokharel, T.C. Thakur and J. Tripathi (eds). 2002. Research and Extension Issues for Farm Level Impact on Productivity of Rice-Wheat Systems in the Indo-Gangetic Plains of India & Pakistan. Rice-Wheat Consortium Travelling Seminar Report Series 1. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

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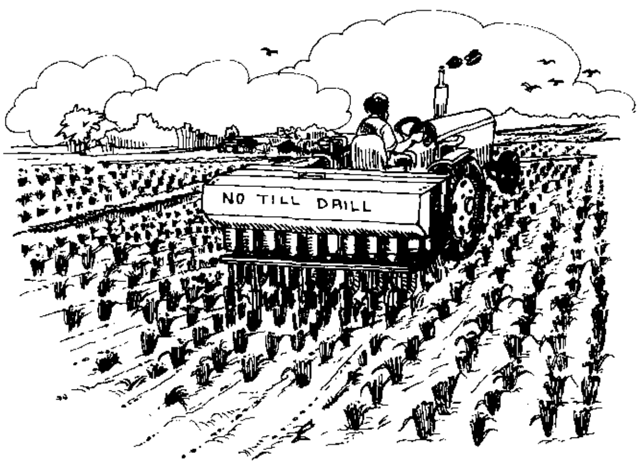
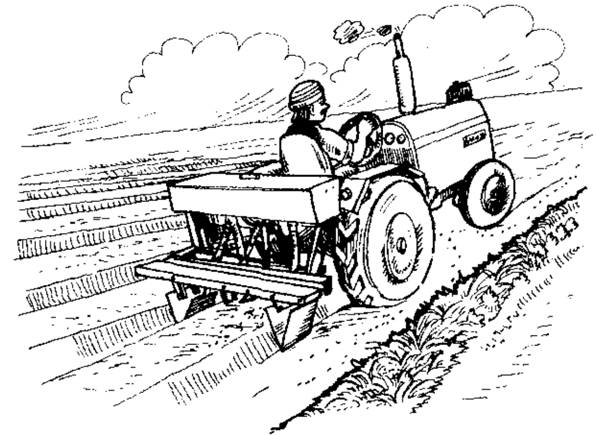
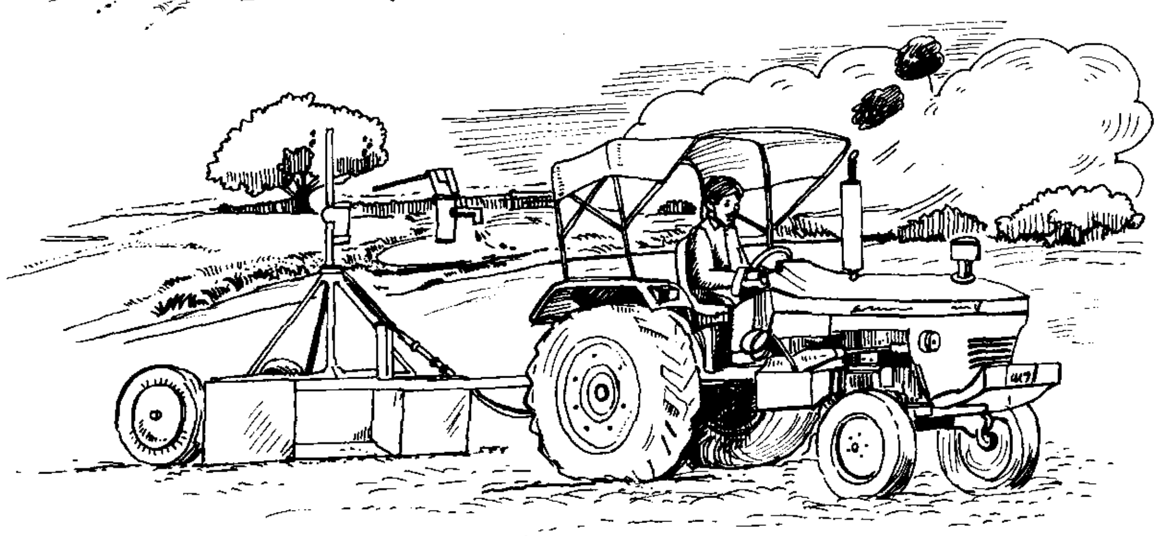
New Opportunities for Saving on Water: Role of Resource Conserving Technologies







Agricultural policy in South Asia during the 1960-70s focused on food security production through increased coverage of high-yielding varieties, expansion of irrigation and increased use of external inputs. This enabled rice-wheat (RW) to emerge as a major cropping system in the Indo-Gangetic Plains (IGP), ushering in "Green Revolution" (GR). It has been reported that nearly 85% of RW systems of South Asia are located in the IGP and evidence is now appearing that RW systems have fatigued the natural resource base. The major challenge for the countries under the Rice-Wheat Consortium (RWC), such as India, Pakistan, Bangladesh and Nepal, is to develop RW systems that produce more at less costs and improve profitability and sustainability. This suggests that agriculture in these countries will be in need of an infusion of new technologies that are able to tap new sources of productivity growth and are more sustainable and the IGP has continental monsoonal climate.

In the northwest Trans-Gangetic Plains, the average annual precipitation ranges from 400-750 mm per year and increases towards the Bay of Bengal, where the annual rainfall is as high as 1800mm per year. Nearly 85% of the total precipitation is received during the monsoon season between June and September. There are wide variations in soil types, generally coarser in the Trans-Gangetic Plains and becoming finer with the run of the river systems. Soils are primarily calcareous micaceous alluviums with sandy loam to loam in the upper reaches becoming finer textured in the distal plains. A significant observation is the greater reliance of farmers on tubewell irrigation in the northwestern parts of the IGP and in Bangladesh. Excessive groundwater development in freshwater aquifer zones has led to recession in water table, while in areas under laid with low quality aquifers having problems of residual alkalinity, high sodium adsorption ratio, and excess salts, canal irrigation had led to a rise in the water table. Low quality waters are interspersed with good quality aquifers in many areas of northwest IGP and are being used successfully in crop production by the farmers.

Some Water-Saving Options

Early Transplanting

In the eastern IGP, delayed onset of rains and the near lack of groundwater development during the monsoon season delays rice nursery and transplanting operations to set in a vicious cycle of late planting of crops. Long-term analysis of the rainfall data for this region clearly indicates that there are three distinct periods of moisture availability. The early moist period, wherein the evaporation exceeds rainfall, extends over the first 12-18 days. This is followed by 93-139 days of humid moist period wherein precipitation exceeds potential evapotranspiration. In the terminal moist period of 17-22 days once again rainfall is less than evapotranspiration. If the rice seedlings can be raised and transplanted with groundwater irrigation, and established early in the first moist period, the rice crop can benefit from the monsoon rain and grow without the need for irrigation during the humid period.

Timely transplanting of rice also results in earlier harvests and early vacating of the main field. This allows timely planting of the wheat crop that follows it. The results of farmer participatory field trials show that the strategy of timely transplanting of rice improves wheat yields. RW system productivity is nearly 12-13 tons per hectare when rice is transplanted before 28th June. This is reduced to about half when fields are planted after 15th August (to 6-7 tons/ha). This strategy has been tested in a few hundred hectares of farmer's fields in Bihar and has paid rich dividends. There are other options also to be more water-wise.

No Puddling

A lot of research is being conducted in the region to look at the possibility of establishing rice without puddling. The major hurdle has been paucity of knowledge regarding good weed management, as most of the rice herbicides available in the region have been developed for transplanted rice and these are not as effective in dry seeded rice. Experiments conducted at Pantnagar (India) and Bhairahawa (Nepal) on total RW system productivity show that tillage and puddling do not have much influence on rice yields. Wheat yields are, however, significantly better when rice soils are not puddled.

Dry Sowing with Zero-tillage

Direct dry sowing using zero-till seed drill, and use of permanent beds for planting can reduce the time lost, and irrigation water used in land preparation for the crop. Along with possibility of groundwater availability for protective irrigation, this can enable early planting.

Suitable Varieties

Given the prospect of early sowing, the question is whether certain cultivars of rice and wheat are especially suited for such practices. It is observed that two cultivars of wheat favored for timely (early) sowing, WH 542 and PBW 343, have a longer vegetative phase and shorter grain-filling phase than older varieties such as HD 2009 and HD 2329 (Mehla *et al.,* 2000).

In Situ Retention of Rainwater

Studies have indicated that raising of peripheral bunds to a height of 18-20cm around fields could store nearly 90% of total rainwater *in situ* for improved rice production and reduce the need for irrigation water.

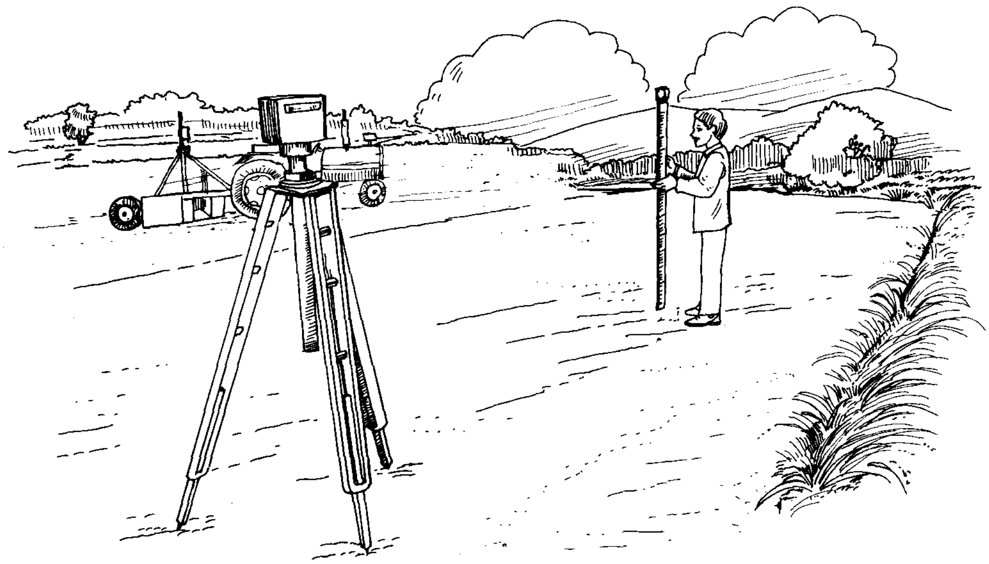
Intermittent Submergence

Whenever the rainwater does not meet the water requirement of rice and the soil develops hairline cracks, irrigation water is supplied to fulfill the demand of water. It is observed that a three-day drainage period is generally suitable and can easily effect more than 40% saving in water without compromising on rice yields (see table below).

Effect of Intermittent Irrigation on Rice Yield and Irrigation Water Requirement at Various Locations in the IGP

Location	Soil type	Yield in t/ha (WR in cm)				Saving in irrigation water*** %
		Continuous submergence	Irrigation after drainage period * of			
			One day	3 days	5 days	
Pusa (Bihar)	Sandy loam	3.6(81)	3.5(60)	3.3 (46)	2.9 (35)	43
Madhepura (Bihar)**	Sandy loam	4.0 (35)	-	4.0 (16)	4.0 (11)	54
Faizabad (UP)	Silt loam	3.8 (65)	2.9 (42)	-	-	-
Pantnagar (UP)**	Silt clay loam	8.1 (121)	7.6 (112)	7.4 (90)	6.9 (60)	44
Ludhiana (Punjab)	Sandy loam	5.5 (190)	5.4 (145)	5.1 (113)	5.2 (96)	40
Hissar (Haryana)	Sandy loam	5.7 (220)	5.2 (196)	4.7 (126)	-	43
Kota (Rajasthan)	Clay loam	5.4 (145)	5.3 (86)	5.1 (68)	-	53

Source: Chaudhary, T.N. 1997. Water Management In Rice for Efficient Production. DWMR Patna India.
Figures in paranthesis show irrigation water requirement (cm)
* Drainage period in days after disappearance of ponded water
** High watertable condition
*** With three-day drainage vs. continuous submergence



Precision Land Levelling

One of the reasons for over-irrigation is poor land levelling. Unevenness in the soil surface adversely affects even distribution of irrigation water in the fields and leads to poor crop stand. Levelling can help eliminate this inefficiency and reduce water requirement through transmission losses and uniformity in moisture distribution to ensure uniform crop establishment and growth through the season. On-farm trials in Cambodia using the same variety and fertilizer inputs showed that land levelling yielded 24% more grain. Part of this increase is due to more efficient weed control in level fields. Levelling enables increase in the plot size and increases the available planting area by 5%-7%. It also reduces operating time for farm machinery (Rickman, 2002).

Laser Levelling
Laser levelling requires conventional farm equipment and laser equipment to efficiently shift soil from the higher levels to the lower levels in a cost effective way. The physical levelling should always be preceeded by a topograhic survey of the land proposed to be levelled.

Saving on irrigation water can easily be obtained by precision land levelling. This is being promoted as a means to improve water efficiency and crop yields through improved nutrient-water interactions. When land levelling is combined with zero-tillage, bed planting and non-puddled rice culture, the plant stands are better, growth is more uniform and yields higher. In Pakistan's Punjab, average water saving with laser levelling, zero-tillage and bed planting over the traditional method was 715, 689, and 1329 m^3/ha for the year 1999-2000.

Save Water in Rice Season

Under the All India Coordinated Research Project on Water Management, the total water requirement for wheat is estimated to range from 238 mm in Bihar to 400 mm in Punjab. It is generally observed that farmers make provision for irrigation water for the wheat crop. It is for this reason that irrigated area is much higher for wheat than for rice. Similarly, the total water requirement of rice is estimated to vary from 1144 mm in Bihar plains to 1560 mm in Haryana. The variations are due primarily to the different rates of deep percolation losses in clay loam and sandy loam soils. A total of 1382 mm to 1838 mm water is required for RW system at different locations in the IGP, with the rice crop accounting for more than 80% of the water use. To save on water, saving must be effected during rice growing season, the major user in RW system.

Irrigation Requirement of Rice and Components of Water Loss (mm) Under Continuous Submergence in Texturally Variant Soils

Particulars	Clay loam	Silt clay loam	Loam	Sandy loam
Irrigation requirement (mm)	1125	1200	1500	1777
Effective rainfall (mm)	358	402	495	485
Total WR (mm)	1566	1657	1955	2262
Percolation as % of total WR	57.0	52.5	60.0	66.9
ET as percent of WR	44.0	44.2	41.3	32.9

Source: Tripathi, R.P. 1996. Water Requirement in Rice-Wheat System. Rice-Wheat Workshop, Modipuram, UP, Oct. 15-16 (recasted table).

Benefits of the RCTs in Terms of Water Use

Farmers are adopting the new RCTs quickly. Nearly 300,000 ha of wheat were grown using this mechanism and this is expected to increase to a million hectares in the next few years. Farmers' feedback on water savings with these new technologies essentially indicates that they save water.

Wheat Yield with Zero-tillage Technologies in Farmer Participatory Trials

Parameter	Paired planting@	Controlled traffic**	ZT	FP-CT
Water saving, %	26.2	30.8	35.4	#
Yield (q/ha)	65	58	57.8	51.9

Compared with conventional tilled wheat planted a week later
** One row behind each tractor tyre not sown
@ Spacing between set-rows (14 cm); and between paired sets (25 cm)

Zero-tillage

Farmers report about 20%-30% water savings with zero-tillage. This comes in several ways. First, wheat sowing with zero-tillage is possible just after rice harvest and residual moisture is available for wheat germination. In many instances where wheat planting is delayed after rice harvest, farmers have to pre-irrigate their fields before planting. Zero-tillage saves this irrigation. Savings in water also comes from the fact that irrigation water advances faster in untilled soil than in a tilled soil. That means farmers can apply irrigation much faster. Because zero-till wheat takes immediate advantage of residual moisture from the previous rice-crop, as well as cutting down on subsequent irrigation, water use is reduced by about 10cm-hectare, or approximately 1 million liters per hectare. One additional benefit is less waterlogging and yellowing of the wheat plants after the first irrigation that is a common occurrence in conventionally-planted wheat. In zero-tillage, less water is applied on the first irrigation and thus yellowing is not seen.

Crop Residue Management

Management of crop residues and plant into loose residues is a key issue not only to avoid burning and environmental pollution but also for addressing issues of organic matter decline and nutrient depletion/mining in the IGP and promoting groundwater recharge. Strategy of incorporating the silica-rich rice residues seems inevitable in acidic soils of Eastern Gangetic Plains to address the liming problems. Liming of these soils reportedly improved the yields of wheat and other upland crops. Incorporation of silica-rich rice residues into isoelectric soils manipulates the charge characteristics in a manner that improves the net negative charge, base saturation on the exchange complex and reduces fixation of applied P. Although incorporation of silica-rich organics is widely practiced in the hills, it needs more rigorous testing for its effects on physico-chemical properties of acidic soils, commonly found in sub-humid and humid Eastern Gangetic Plains.

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Legumes: Crops for Improving Human, Animal and Soil Nutrition

Legumes are important as food for human nutrition, as feed and fodder for animal nutrition and as soil ameliorants for soil nutrition. Several grain legumes (chickpea, pigeonpea, mungbean and black gram) originated and were adopted in West and South Asia around 2000 to 1000 BC, thereby providing inexpensive protein sources to religious vegetarians and the poor. While cultivation of legumes specifically for fodder is a relatively recent practice, feeding legume residues to livestock is an ancient and common custom. Prior to the availability of chemical fertilizers, farmers in South Asia regularly cultivated legume species for green manuring as early as 1000 BC.

Legumes for Human Nutrition

Sources of Protein

Grain legumes are a good source of protein. The protein content in the seed is high, ranging from 17%-40%. But in cereals (rice, wheat), the protein content is substantially lower than in legumes. Also, there is a difference in the protein quality between cereals and legumes. Wheat is deficient in the amino acid lysine, while rice has indequate levels of lysine and threonine. On the contrary, grain legumes are deficient in the sulfur containing amino acids, methionine and cystine. Combined consumption of cereals and grain legumes is common in South Asia to overcome the amino acid deficiencies, thereby achieving almost complete protein balance and nutritional improvement in cereal-based diets. Maximum protein is obtained when the grain legume content is about 10% in a wheat-legume diet, and about 20% in a diet with rice, maize, or barley and legume.

Sources of Vitamins and Minerals

Legume seeds contain significant concentrations of minerals (calcium, zinc, iron) and vitamins (folic acid and vitamin B including riboflavin, thiamin and niacin). Iron, zinc, thiamin and niacin contents in wheat are at par with legumes, but calcium, folic acid and riboflavin contents are lower than legumes. Rice contains lower concentrations of minerals and vitamins when compared with legumes and wheat. Additional losses of minerals and vitamins in the grain occur during the rice-milling process.

Low Production of Legumes Leads to Health Problems

Although significant gains have been made towards reducing protein-energy malnutrition through dramatic increases in cereal production, consumption of vitamins and minerals in grain legumes is decreasing in South Asian diets. The current health status of the population in the region reflects the low supply of legumes. In 1996, a nationwide study by the Indian National Nutrition Monitoring Board observed that the diets of children and women only fulfilled 47%-59% of recommended riboflavin requirements. Estimates of anemia due to iron deficiency in children and women are 47%-77% in Bangladesh, 30%-95% in India, 60%-78% in Nepal and 45% in Pakistan.

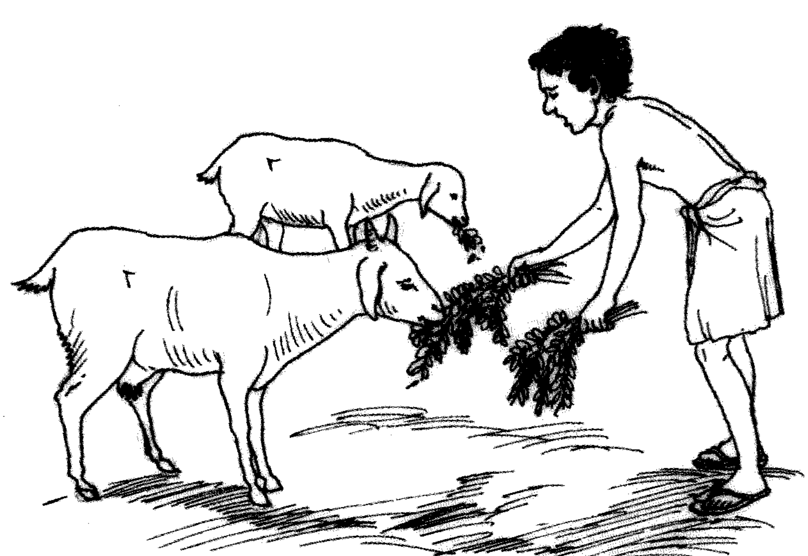
Antinutritional Compounds and Other Constituents

Antinutritional compounds found in seed of food legumes can reduce bioavailability or cause toxic reactions. Phytates combine protein and minerals into complex compounds making them unavailable for human nutritive benefit. Various cooking and processing techniques substantially denature phytates and other antinutritional compounds. Cooking common bean and black gram after soaking the seed reduces phytates by 50% to 80%.

Dietary fiber from chickpea and mungbean seeds reduces cholestrol, while chickpea *dhal* and common bean reduce blood sugar in humans.

Legumes for Animal Nutrition

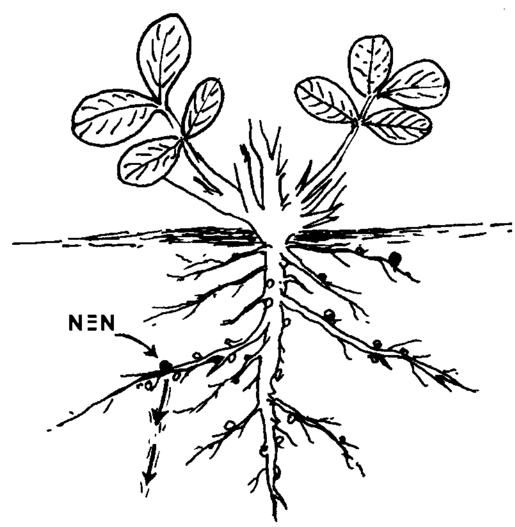
Despite a significant deficit of fodder, forage cultivation has never been extensive in South Asia. Traditionally, farmers have invested little capital in animal feed. They have been supplying tree loppings, grassy weeds, and crop residues, rather than high-quality forages.



Livestock diets dominated by cereal straws are generally low in palatability and digestibility, and deficient in protein and essential minerals. Poor quality feeds of livestock and small ruminants (goats, sheep) can be improved by supplementing with forage legume. Cereal crop residues supplemented with forage legumes significantly increased liveweight gains and overall animal productivity. Cowpea forage fed in combination with maize fodder increased liveweight gain in buffalo calves by 10% over maize fodder alone. Milk production of 4.5 liters per day was sustained, which gained the farmer a net profit of Rs 5600 per ha. In Bangladesh, increases in liveweight gains of chickens by 6% and egg production by 53% were obtained when legume seeds were included in the feed. Besides benefiting the health and production of livestock, consumption of forage legumes can help in reducing methane (CH_4) greenhouse gas emissions.

Legumes for Soil Nutrition

Legumes are important components in cropping systems as soil ameliorants. They improve the soil physical structure, increase acquisition and mobility of macro and micronutrients and reduce soil-borne pests and pathogens.



The ability of leguminous plants to biologically fix atmospheric nitrogen (N) provides a relatively low cost method for replacing N removed by crop production and for building soil N pools. Legumes contribute to significantly higher yields in succeeding rice or wheat crops. Rice after early summer grain legumes yielded 0.76 to 1.77 tons per ha higher than rice after fallow or fodder maize. Wheat after summer soybean, pigeonpea, or mungbean yielded 1.3 to 1.6 tons per ha higher than wheat after pearl millet or sorghum. Similarly, substituting winter grain legumes such as lentil, chickpea, or pea for wheat increased subsequent rice yields from 190 to 550 kg per ha. Yields of rice improved in soils amended with green manure legumes. Rice yields increased by 0.6 to 2.4 tons per ha following forage legumes. Incorporating berseem, a forage legume, between *aman* (summer) rice and *boro* (winter) rice increased the grain yield of the succeeding *boro* rice by 7%-18% and straw yield by 35%.

Long-term Residual Effects of Legumes

Residual effects in a second crop after a legume crop are much less dramatic than in the first crop. In Bangladesh, residual fertility from berseem, a forage legume, cropped before a *boro* rice crop increased the grain yield of the second rice crop by 4%-14% and straw yield by 2%-9%.

High yield responses in rice and wheat after legumes are often attributed to nitrogen contributed by legume crops. However, no amount of fertilizer nitrogen can produce a dramatic effect on the overall crop yield potential as legumes. Thus, legumes are often recommended as a low cost, sustainable means for improving soil fertility.

Biofertilizers: A Promising but Underutilized Technology

A reliable and cost-effective technology is now available for enhancing the inputs of nitrogen (N) into cropping systems in most of the agro-ecological zones using biological nitrogen fixation (BNF). The technology has been successfully demonstrated on farmers' fields. *Rhizobium* inoculation of legumes increases yields by 15%-30% with residual benefits of about 30 to 40 kg N per ha. Inoculation with *Azotobacter* and *Azospirillum* in cereals increases yields by 10%-15% with benefits of about 10 to 15 kg N per ha, primarily through promoting plant growth. Co-inoculation of *Rhizobium*, *Azospirillum*, vesicular arbuscular mycorrhiza (VAM), and phosphate-solubilizing bacteria (PSB) is significantly better than their single inoculation. Addition of 5t/ha farmyard manure along with inoculation significantly enhances nodulation, and legume yield, boosting BNF. A rich germplasm collection of effective strains of agriculturally useful microorganisms is available. Some of these strains are being produced commercially. Several stress-tolerant (temperature and salinity) microorganisms and strains efficient in fixing N in the presence of recommended dose of N fertilizers have been developed. The local isolates are more effective than the best of the introduced ones indicating the ecological adaptation of the strains in a given habitat and the difficulty of introducing an organism in a new environment.

Microbial preparations are essentially ecological inputs and not chemical inputs. These may not produce dramatic effects. Hence, lack of crop response to inoculation in some cases should not discourage the adoption of the technology. Even when yield benefits are not apparent, a hidden benefit of increased proportion of N from the atmosphere accrues. In due course, this "sparing of soil N" by the inoculated legume contributes significantly to improve the N balance. Inoculation with a good quality inoculant should be meticulously practiced to prevent failure of nodulation in many cases and improve current performance in many other situations.

(Source: DLN Rao, Project Coordinator, AICRP on BNF, IISS, Bhopal, India.)

Green Manure and Forage Legumes

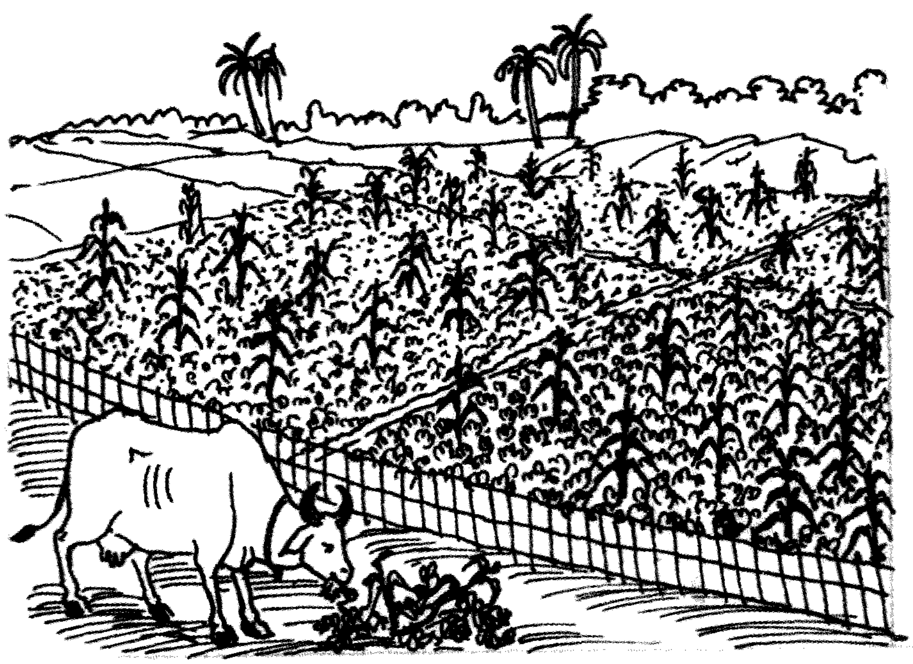
Legumes used as green manures in rice-wheat cropping systems can be broadly characterized as pre-rice or post-rice crops. Species such as *Crotalaria juncea, Sesbania aculeata, Sesbania rostrata, Cyamopsis tetragonoloba,* and *Vigna unguiculata* are used as 45- to 60-day catch crops in the pre-rice phase between wheat and rice. Biomass from these legumes is incorporated into the soil at the onset of the monsoon season, just prior to rice transplanting. Post-rice species include forage legumes such as *Stylosanthes* sp., *Trifolium alexandrinum, Trifolium repens, Vicia bengalensis, Vicia villosa, Clitoria ternatea, Desmanthus virgatus, Cyamopsis tetragonoloba,* and *Macroptilium atropurpure u m* which are substituted for wheat or other winter crops. *Lathyrus sativus* is cultivated in Pakistan during the winter months primarily as a fodder crop. Although green manure and forage legumes are valued as important components of cropping systems, they are often perceived as crops without any economic return, because of competition with cereal production. However, a thorough analysis of the positive and negative trade-offs of increasing forage or green manure legume area has not been undertaken. Some issues that need to be addressed are the following:

Grain Legume Options in Rice-Wheat System

Lathyrus, lentil, chickpea, black gram, mungbean, pigeonpea, and soybean are often included in rice-wheat rotations of South Asia as substitutes for rice or wheat, or as relay or catch crops between the cereal crops. Winter legumes such as lathyrus, lentil, and chickpea are substituted for wheat or are intercropped with wheat followed by summer rice; while black gram, mungbean, and soybean are cultivated in early or mid-summer, followed by winter wheat. Use of short-duration pigeonpea has made it possible to grow pigeonpea as a summer substitute for rice or as a winter crop in rice-fallow cropping systems.

- Would increased animal productivity change the quantity or quality of manures applied to fields for maintenance of soil fertility?
- What effects would increased production of rice or wheat after forage legumes or green manure crops have on residue supply? Would more residues be available for soil incorporation and soil fertility improvement?
- How would increased income from better animal productivity or fewer purchased inputs (fertilizers) influence farmers' decisions?

Increased cultivation of grain, forage and green manure legumes is critical for regenerating degraded soils, and for providing essential proteins, minerals, and vitamins for humans and livestock. It is essential to understand the benefits from a systems perspective to encourage adoption of legumes. Government support is essential to promote legume cultivation.



Adapted from:

Lauren, J.G., R. Shrestha, M.A. Sattar and R.L. Yadav. 2001. Legumes and Diversification of the Rice-Wheat Cropping System. pages 67–102. *In:* Kataki, P.K. (ed). The Rice-Wheat Cropping System of South Asia: Trends, Constraints, Productivity and Policy. Food Products Press, New York, USA.

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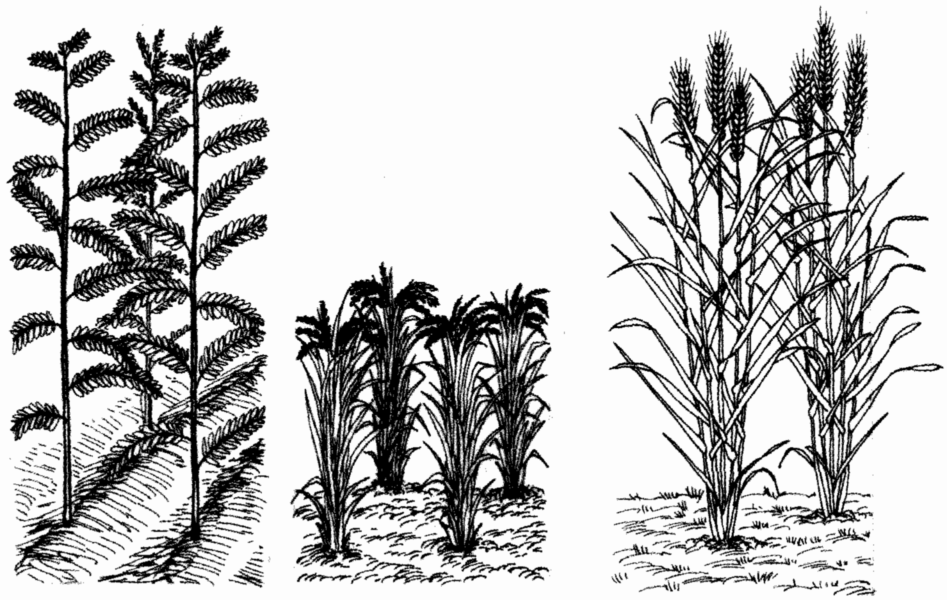
J. G. Lauren

Role of Legumes in Cropping Systems in the Indo-Gangetic Plains of India



Legumes have been known for their soil ameliorative effects since time immemorial. They trap atmospheric nitrogen (N) in their root nodules and add substantial amounts of protein-rich biomass to the soil surface and rhizosphere and thus keep the soil productive and healthy. By including legumes in cropping systems, the heavy N needs of modern intensive cereal-based cropping systems such as rice-rice, rice-wheat and maize-wheat can be at least partly met, and the physical and chemical characteristics of the soil are generally improved. Legumes in rotation with cereals not only improve cereal productivity but also economize on N use up to 40 kg N per ha. Chickpea performed better than lentil and pea, and increased yield of succeeding rice crop by 1 ton per ha when compared with wheat, without addition of N fertilizer as well as at 40 kg N per ha. At a higher level of N application (120 kg per ha), the effect was narrowed down and the increase in rice yield was 0.8 tons per ha.

Nutrient Recycling

Partial Recyling

Nutrient recycling in legumes cropping systems could be partial or complete. For partial recycling, short-duration legumes such as mungbean, black gram (urd bean), or cowpea can be either grown as a catch crop during spring or summer, or intercropped with cereals (e.g., maize, sorghum, and pearl millet), oilseeds (e.g., sunflower), and commercial crops (e.g., cotton and sugarcane). This system not only provides a bonus yield of legumes but also benefits the succeeding or companion crop. Cultivation of cowpea during summer enhanced yield of succeeding rice by 0.33 tons per ha. Intercropping black gram and mungbean with spring-planted sugarcane had synergistic effects on cane yield but soybean and cowpea adversely affected cane production. Incorporation of loppings of leguminous trees such as *Gliricidia* sp. and *Leucaena* sp. in rice fields also helps in partial recycling of plant nutrients. Incorporation of *Leucaena* loppings over a period of three years increased yield of rice by 0.48 tons per ha and that of wheat by 0.73 tons per ha.

Intercropping of Legumes with Sugarcane at Lucknow, India

Cropping system	Yield (t/ha)	
	Sugarcane	Legume
Sugarcane	109.4	-
Sugarcane + black gram	128.8	0.5
Sugarcane + mungbean	113.3	0.4
Sugarcane + cowpea	106.3	0.5
Sugarcane + soybean	102.5	1.2

Utilization of Rice-Fallows

Vast areas in the eastern Indo-Gangetic Plains (IGP) are monocropped under medium- and long-duration rice. Double cropping is not feasible in these areas due to non-availability of irrigation water and delay in vacating the field after rice. The top soil layer dries up at the time of rice harvest and thus planting of a postrainy season crop is not possible. Under such conditions, these monocropped areas can be used for double cropping by relay planting small-seeded lentil or low toxin (BOAA) containing lathyrus genotypes (e.g., Bio L 212). Lentil or lathyrus seeds are broadcast in the standing rice crop, seven to 10 days before harvest when there is adequate moisture for germination in the top layer of soil. Thus, legumes production can be increased and the productivity of the rice-based system can be sustained. Genotypes of lentil and lathyrus that are specially suited for relay cropping and appropriate production technologies are essential for the expansion of this cropping system.

In some parts of northeastern Bihar and West Bengal where temperatures are moderate during winter, black gram (urd bean) and mungbean can be grown in rice fallows. Thus, the area under legumes can be increased and the residual moisture in rice fallows can be utilized. High-yielding, cold-tolerant, powdery mildew resistant varieties are ideal for this system.

Complete Recyling

For complete recyling of N, green manuring with *Sesbania* sp., sunn hemp, or cowpea in rice-wheat rotation can be practiced. Green manuring with *Sesbania* over a period of three to four years improved productivity of rice-wheat system by 3 tons per ha on light-textured, sandy loam soils in Ludhiana, Punjab. On medium-textured, sandy loam to loam soils in Kanpur, Uttar Pradesh, the increase in productivity was only 0.6 tons per ha. Green manuring with *Sesbania* also improved the productivity of pearl millet-wheat system in Uttar Pradesh.

Green manuring with *Sesbania* sp. in rice-wheat system increased organic carbon (OC) of soil from 0.29% to 0.45% over a period of six years at Ludhiana. Similarly, on sandy loam in Pantnagar, OC, total N, and available P increased by 0.01%, 15 kg per ha, and 13.8 kg per ha respectively. The OC content and available P also increased under rice-lentil and pigeonpea-wheat sequential cropping. The effect of increased fertility status was also reflected on grain yields of rice and wheat.

Legumes Production Systems in the IGP

There is great potential for enhancing legumes production both under irrigated and rainfed conditions in the eastern and western regions of the Indian IGP.

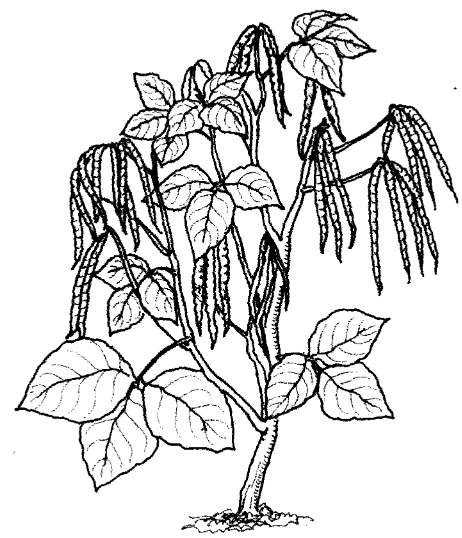
The Western IGP

Mungbean as a Catch Crop

Mungbean can be included as a catch crop between wheat and rice by using short-duration (60 to 65 days), high-yielding, and yellow mosaic resistant genotypes such as PDM 54, ML 267, Pusa Vishal, Samrat, and SML 668. However, the success of the system will depend upon the choice of appropriate genotypes of rice and wheat and their timely planting so as to vacate fields with wheat by the end of March or first week of April, assured irrigation, and a community approach to halt the predations of blue bulls and stray cattle. This cropping system can be popularized further by introducing extra-early-maturing (50 to 55 days) varieties of mungbean.

Mungbean and Black Gram in Spring

Mungbean or black gram can be successfully grown during spring (March-May) after harvest of short-duration post-rainy season crops such as mustard, potato, pea, or sugarcane. Spring cultivation of these legumes is increasing rapidly with the availability of yellow mosaic resistant and high-yielding (0.8 to 1.0 ton per ha) black gram varieties such as Pant U 19, PDU 1, Shekhar, and Narendra Urd 1, which mature in 70 to 75 days. Similarly, release of mungbean varieties such as PDM 11, Pant Mung 2, and MH 81-1-1 has encouraged spring cultivation. About 200,000 ha in the states of Punjab, Haryana, and western Uttar Pradesh are currently occupied by spring black gram and mungbean and the area can be substantially increased.



Chickpea-Cotton Sequential Cropping

Chickpea-cotton system is more remunerative than wheat-cotton system. With the availability of genotypes amenable for late planting, chickpea can be successfully introduced in the uplands of Punjab and western Uttar Pradesh, where cotton is grown as a commercial crop.

Pigeonpea-Wheat Sequential Cropping

Western IGP is a non-traditional area for pigeonpea. But with the introduction of short-duration (140 to 160 days) pigeonpea genotypes such as UPAS 120, AL 15, AL 201, Manak, Pusa 992, Pusa 84, and ICPL 151, pigeonpea-wheat sequential cropping has become popular and the area under this system is increasing progressively. About 150,000 ha under western IGP is under short-duration pigeonpea.

Most of the available short-duration pigeonpea varieties are susceptible to sterility mosaic, fusarium wilt, and phytophthora blight, and have a tendency to prolong maturity with late monsoon rains. Therefore, it is imperative to develop genotypes having a yield potential exceeding 2 tons that will mature by early November (e.g., ICPL 88039 and Pusa 992), to facilitate sowing of winter crops.

Groundnut-Wheat Sequential Cropping

On uplands having light-textured soils, groundnut cultivation is more profitable than pearl millet, maize or sorghum. Wheat in sequence with groundnut is greatly beneficial due to improvement of physical and chemical properties of soils. Government support is needed to popularize this system.

The Eastern IGP

Short-duration Pigeonpea in Sequence with Wheat

As in western IGP, on uplands of eastern Uttar Pradesh, short-duration pigeonpea can be successfully grown. As this region receives more precipitation, pigeonpea planting should be done in ridges in the first fortnight of June with pre-planting irrigation so that by the time monsoon rains start, the seedlings are strong enough to tolerate adverse effects of excess moisture. Short-duration pigeonpea can be popularized with the availability of disease-resistant genotypes having tolerance to excess soil moisture.

Spring and Summer Cultivation of Black Gram and Mungbean

As in western IGP, the eastern region also offers good scope for cultivation of spring black gram and mungbean as well as summer mungbean. Over 200,000 ha of land is presently under mungbean. Both mungbean and black gram are cultivated after harvest of mustard, potato, pea, wheat, and sugarcane. They can also be intercropped with spring-planted sugarcane and sunflower.

Popular Varieties	
Black gram	Pant U 19, Shekhar, Narendra Urd 1, and PDU 1
Mungbean	PDM 11, Narendra Mung 1, Pusa Vishal, and Pant M2

Rice-Chickpea/Lentil Sequential Cropping

Chickpea varities (e.g., KPG 59 and Pusa 372) amenable for late planting in mid-December are cultivated after rice. Under resource constraints, rice-chickpea is more remunerative than rice-wheat. The system has more potential in eastern Uttar Pradesh and Bihar.

In lowland areas with excessive moisture, lentil is a more assured crop than chickpea. Hence, the rice-lentil system is popular in the lowlands of eastern Uttar Pradesh, Bihar and West Bengal. The adoption of the high-yielding, bold-seeded, wilt-resistant vatieties such as DPL 62 and Noori, and small-seeded, rust-resistant varieties such as DPL 15, PL 406, and PL 639 may encourage expansion of lentil.

Post-Rainy Season Pigeonpea

Eastern IGP receives heavy rains and experiences frequent floods during July-August, which cause considerable or complete loss of July-planted pigeonpea. Under such situations, post-rainy season pigeonpea can be grown succesfully. Varieties (e.g., Sharad and Pusa 9) that are resistant to Alternaria blight with yield of 2 tons per ha and suitable for September planting have proved a boon for extension of post-rainy season pigeonpea on uplands of eastern Uttar Pradesh, Bihar and West Bengal. As these varieties are highly thermo-sensitive, their planting period is restricted up to mid-September. Delayed planting causes considerable yield loss. Hence, varieties which can be successfully planted until early October will provide greater opportunities to expand pigeonpea cultivation under sequential cropping with short-duration upland crops such as maize, sorghum, and pearl millet.

Post-Rainy Season Common Bean

Common bean has been recently introduced in the IGP. High-yielding genotypes (e.g., Udai, Amber, HUR 15, and HUR 137) that yield 2.5 to 3.0 tons per ha and suitable for planting in October-November have been adopted. Common bean is a high-value and short-duration (115 to 125 days) crop with few problems of insect pests and diseases. This legume has the potential to cover large areas under irrigated conditions. It can be intercropped with potato.

Adapted from:

Ali, M., P.K. Joshi, S. Pande, M. Asokan, S.M. Virmani, R. Kumar and B.K. Kandpal. 2000. Legumes in the Indo-Gangetic Plains of India. pages 35–70. *In*: Johansen, C., J.M. Duxbury, S.M. Virmani, C.L. L. Gowda, S. Pande and P.K. Joshi (eds). Legumes in Rice and Wheat Cropping Systems of the Indo-Gangetic Plain: Constraints and Opportunities. ICRISAT, Patancheru, India; and Cornell University, New York, USA.

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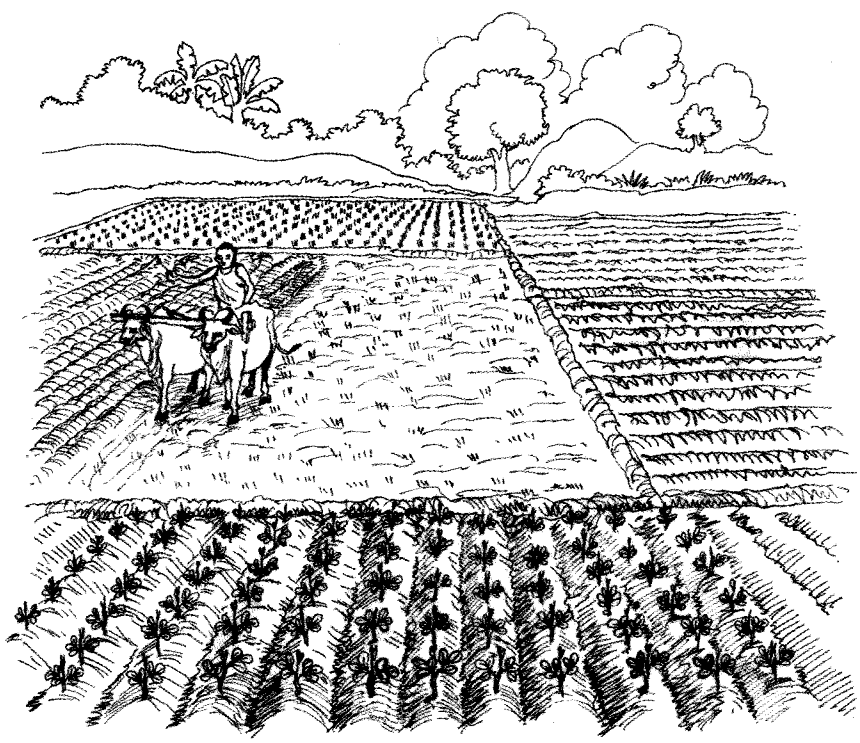
Masood Ali

Role of Legumes in Different Cropping Systems in Bangladesh

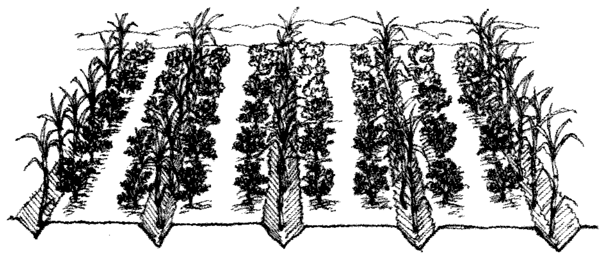


Food legumes have traditionally been cultivated under rainfed conditions in Bangladesh, usually without any monetary inputs. The productivity of these crops is low compared to wheat and rice as legumes, unlike cereals, do not respond to high inputs of irrigation and fertilizer. As irrigation facilities become available, farmers shift to predominantly rice-rice or rice-wheat cropping systems. Thus, legumes are being relegated to marginal lands. It is undesirable to continue rice-wheat systems indefinitely. Legumes are ameliorative crops that can break continuous cropping with cereals and can add 20 to 60 kg per ha residual nitrogen to the succeeding crop. Soil aggregation, structure, permeability, fertility and infiltration rate improve with the inclusion of legumes in the cropping system. Legumes are grown in different cropping systems in Bangladesh and play a vital role in the sustainability of agroecosystems.

Lathyrus: The Hardy Crop

Lathyrus is cultivated as a relay crop with the main season (*a m a n*) rice in the lowlands and medium lowlands. It is broadcast on the saturated soils about 15 to 20 days before rice harvest. It can thrive under both excess moisture and extreme drought conditions and has no major insect pest or disease problems. The yields are stable and input cost is negligible. Therefore, it is difficult to replace lathyrus by any other crop as it is well established in the rice-fallow areas. However, when lathyrus seed is consumed as staple food (i.e., one-third of the daily calorie intake) continuously for two to three months, the neurotoxin present in the seed causes lathyrism, a paralytic disease of the limbs of humans. Genotypes with low neurotoxin levels should be made available to farmers.

Chickpea: The Multicuisine Food Crop



About 60% chickpea area is under the *a u s* rice/jute-fallow-chickpea cropping pattern, where it is sown in November. About 35%-40% chickpea is grown in the *a m a n* rice-chickpea cropping pattern, where it is sown in December as a late-sown crop. Besides these cropping patterns, chickpea is cultivated as a mixed crop with linseed, barley and mustard, and as an intercrop with sugarcane.

Lentil: The Main Crop

Lentil is mostly grown in upland (*a u s*) rice areas and is usually sown in mid-November. It is also grown as a late-sown crop after *a m a n* rice and is sown in late November. Lentil is commonly cultivated as a sole crop but often as a mixed crop with mustard or as an intercrop with sugarcane in northern Bangladesh and is sown in early November.

Black Gram: The Rainy Season Pulse Crop

Black gram is generally sown in August to September on well-drained highlands or medium highlands after rice harvest in the *a u s* rice-black gram-fallow cropping pattern. Short-duration, small-seeded black gram is cultivated in the *a u s* rice-black gram-rabi cropping pattern where sowing is completed in August. The Bangladesh Agricultural Research Institute (BARI) has released three varieties for this cropping pattern.

Groundnut: The Oilseed Crop

Groundnut is mostly grown in the *a u s* rice-groundnut cropping pattern or as a monocrop in the riverbed areas. It is sown in November and harvested in April. Some groundnut is sown in April/May for seed and harvested in August/September in the groundnut-winter crop cropping pattern.

Mungbean: A Green Manure Potential Crop

About 65%-70% of the mungbean crop is grown in the *a u s* rice-*a m a n* rice-mungbean cropping pattern in southern Bangladesh, where the crop is sown in January and harvested in April. About 5% of the crop is grown in the winter crops-mungbean-*a m a n* rice cropping pattern. This crop is sown in March and harvested in June. The remaining 20%-25% of mung bean crop is cultivated in the central part of the country in the *a u s* rice/jute-mungbean cropping pattern. Varieties grown under this pattern are photoperiod-sensitive and golden seeded; these are planted in August and harvested in December. This pattern, however, is being replaced by rabi crops such as wheat, mustard and potato.

Important Cropping Patterns with Legumes in Rice-Based Systems in Bangladesh

Cropping pattern (Apr May Jun Jul Aug Sep Oct Nov Dec Jan Mar Apr)	Land Type
Broadcast *aman* rice / Lathyrus	Medium lowland, clay loam, clay soil
Aus rice/jute / Fallow / Lentil	Highlands, loamu soil
Aus rice/jute / Fallow / Chickpea	Highlands, clay loam soil
Aus rice + Broadcast aman rice / Chickpea	Medium highlands, clay loam to clay soils
Transplanted *aman* rice / Chickpea	Medium lowlands, clay soil
Aus rice/jute / Black gram	Highlands and medium highlands, river basin (after flood), sandy loam, silty soil
Aus rice / Black gram / Mustard/wheat/ sugercane/lentil	Highlands, sandy loam to clay loam
Aus rice / Transplanted *aman* rice / Mungbean	Silty loam to clay loam
Aus rice/jute / Mungbean / Fallow	High-medim highlands, sandy loam to clay loam
Aus rice/jute / Fallow / Groundnut	High-medium highlands, sandy loam to silty loam

Adapted from:

Rahman, M.M., M.A. Bakr, M.F. Mia, K.M. Idris, C.L.L. Gowda, J. Kumar, U.K. Deb, M.A. Malek and A. Sobhan. 2000. Legumes in Bangladesh. pages 5–34. *In:* Johansen, C., J.M. Duxbury, S.M. Virmani, C.L.L. Gowda, S. Pande and P.K. Joshi (eds). Legumes in Rice and Wheat Cropping Systems of the Indo-Gangetic Plain: Constraints and Opportunities. ICRISAT, Patancheru, India; and Cornell University, New York, USA.

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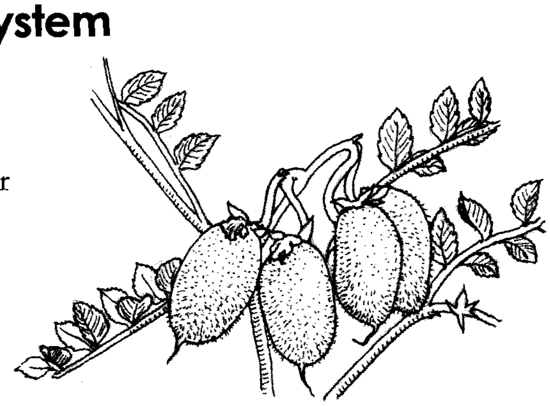
M. Matiur Rahman

Importance of Legumes in the Cropping Systems in Pakistan

Wheat and rice are the main staples of Pakistan, yet the food legumes are of strategic importance for the economy and for human nutrition. Grain legumes are referred as "gold from the fields" as they are the cheapest source of high-quality protein that can help the poor in combating malnutrition. They are also vital in restoring and building soil health, particularly in rice-wheat areas as the productivity of this system is declining. The beneficial effects of including legumes in cereal-based cropping systems, whether on succeeding or companion crops, depend on the legume species, the purpose for which they are grown (seed, fodder, green manure), and the management practices followed. Short-duration legumes can fit well into the existing cropping systems such as rice-wheat, as they are drought-tolerant and adapted to low-input situations. In Pakistan, both winter legumes and summer legumes are included in the rice-wheat cropping system.

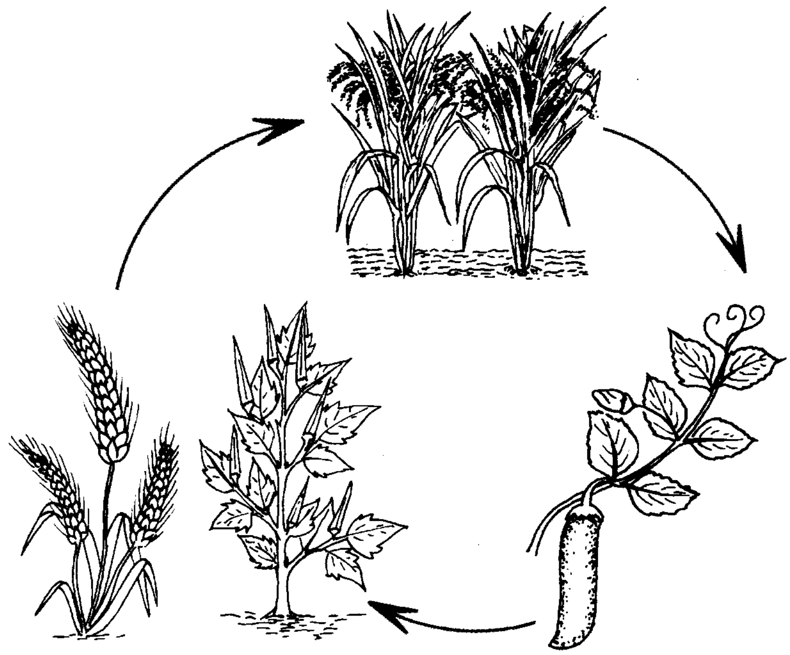
Winter Legumes in Rice-Wheat System

In Sind and Baluchistan in Pakistan, chickpea, lentil and lathyrus (on large scale) and in Punjab and North-West Frontier Province (NWFP), chickpea and lentil (on small scale) are grown after rice on residual moisture and fit very well into the rice-wheat systems as alternatives to wheat. Chickpea is generally grown as a relay crop in the standing rice crop in Sind and Baluchistan. Rice-chickpea rotation gives maximum monetary



return, followed by rice-lentil and rice-lathyrus rotations. However, for the rice-chickpea system in the traditional rice belt in Punjab, high-yielding, early-maturing, ascochyta blight resistant chickpea varieties and better management options with effective pod borer control are needed.

With the availability of irrigation facilities, lentil has been replaced by wheat in some districts (e.g., Sialkot) of Punjab. Lentil can be reintroduced by using rust-resistant, early-maturing cultivars along with appropriate weed control measures. Short-duration varieties of lentil may give better return than wheat planted in December. Lentil can also be intercropped with wheat or September-planted sugarcane.



The rice-pea-okra + wheat cropping pattern is practiced in Sheikhupura district. Farmers grow short-duration, non-aromatic rice from June to September and pea from end of September to early December.

Lathyrus and berseem are important winter fodder legumes of the rice-wheat systems and are commonly rotated with rice. Small landholders in Sind prefer to grow lathyrus as it is hardy and tolerant to drought, waterlogging and salinity, and the cost of production is low. Lathyrus seeds can be broadcast even in standing water of ricefields whereas some other crops can be planted only very late after rice harvest when land becomes available for succeeding crops. This relay-cropped lathyrus can also be used as an effective green manure for the succeeding wheat crop.

Berseem serves dual-purpose when intercropped with sugarcane planted in September. One or two cuttings of berseem are first harvested as green fodder for livestock and later plowed in as green manure for the standing sugarcane crop.

The rice-berseem-rice rotation is important in the rice belt of Punjab and NWFP because of its multipurpose nature. Besides being a valuable fodder, berseem also improves soil fertility and suppresses weeds and thus acts as an excellent means of weed control for subsequent rice and wheat crops.

Summer Legumes in Rice-Wheat System

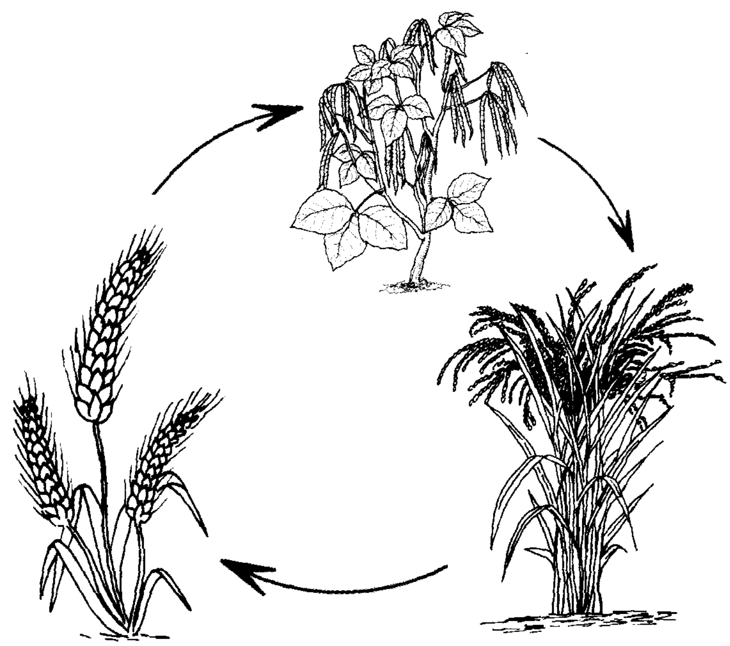
Mungbean and black gram are important summer and rainy season legumes of Pakistan. Cowpea is also cultivated on a very small area primarily for fodder. These crops are mainly grown on marginally fertile soils of rainfed areas. But in irrigated areas, short-duration and photoperiod-insensitive cultivars of these crops have good potential.

Scope for Mungbean Expansion

Mungbean area can be further expanded in Pakistan through the potential cropping systems: mungbean-rice-wheat and cotton-sunflower-mungbean-wheat. In Bahawalpur area, sunflower is planted during January after cotton and harvested in May/June. There is a fallow period from July to October and wheat is planted in October/November. Mungbean can be successfully grown in this cropping system during the fallow period.

New Cowpea Varieties Needed

Cowpea offers very little scope for inclusion in rice-wheat system but it has a large scope as pre-rice crop especilly in the rice-growing areas of Punjab. For this cropping pattern, short-duration (60 to 65 days), photoperiod-insensitive cowpea varieties having high grain or fodder yield and resistance to yellow mosaic and other diseases are needed so that these can be sown after wheat. No such cowpea variety that could fit in the rice-cowpea-wheat cropping pattern is available at present in Pakistan. Collection and evaluation of cowpea germplasm and a strong hybridization program to develop such varieties are needed at both federal and provincial levels.



Short-duration Mungbean

Mungbean cultivation in the rice-wheat system is practiced in a small area. Limited availability of short-duration (60 to 70 days), photoperiod-insensitive, and heat-tolerant mungbean cultivars to grow in the short period between harvest of wheat and planting of rice limits the adoption of this practice. Shortage of irrigation water is a common constraint as mungbean requires at least two irrigations during this hot period for good yield. However, few disease and insect problems occur in summer or pre-rice mungbean.

Short-duration Black Gram

Black gram cultivation is carried out in those areas of the rice-wheat system where water supply is scanty or which depend on rains. Its cultivation is impeded due to non-availability of high-yielding, photoperiod-insensitive, and short-duration cultivars. Short-duration black gram cultivars can be intercropped with maize or sorghum, particularly in rainfed areas where it serves as a cover crop to conserve moisture.

Green Manure Legumes in Fallows

The fallow period of 60 to 70 days between wheat and rice crops can be effectively used for cultivation of fast-growing, green manure legumes. But growing a green manure crop before wheat is not possible as there is only a very short turn-around period for land preparation after rice harvest. *Sesbania aculeata* is a potential green manure legume for the rice-wheat system in Pakistan. It is raised for eight to nine weeks as pre-rice crop and incorporated into the soil during the puddling operation of rice transplanting in July. *Sesbania* green manure increases yields of succeeding crop, but the increase is more in rice than in wheat. *Sesbania rostrata* produces more biomass and accumulates more nitrogen than *Sesbania aculeata.*

Sunnhemp and cluster bean are also grown occasionally for green manure. However, green manure crops are not grown at present due to high labor cost and shortage of irrigation water. Also, it is difficult to fit these crops into prevailing cropping systems without disturbing a remunerative spring crop (e.g., spring maize and fodder crops). A good plant stand establishment of these crops at low cost is essential for the economic viability of such cropping systems.

Adapted from:

Haqqani, A.M., M.A. Zahid and M.R. Malik. 2000. Legumes in Pakistan. pages 98–128. *In:* Johansen, C., J.M. Duxbury, S.M. Virmani, C.L.L. Gowda, S. Pande and P.K. Joshi (eds). Legumes in Rice and Wheat Cropping Systems of the Indo-Gangetic Plain: Constraints and Opportunities. ICRISAT, Patancheru, India; and Cornell University, New York, USA.

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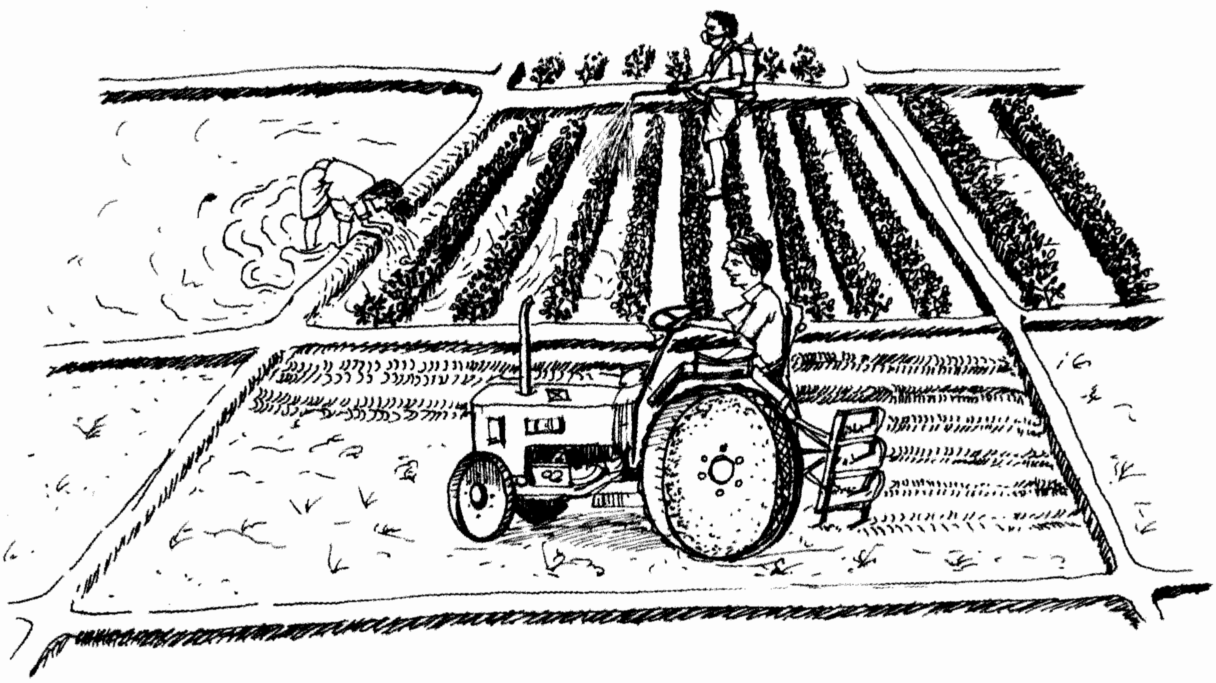
A. M. Haqqani

Management Factors Affecting Legumes Production in the Indo-Gangetic Plains



Grain legumes are important in the Indo-Gangetic Plains (IGP) as food crops for human consumption and animal feed, as components of cropping systems, and as restorers of soil fertility. Legumes are included in the rice-rice or rice-wheat systems that predominate in the IGP. The area under legumes in rice-based cropping systems is substantial.

Some common cropping systems practiced in the region are: *aus* rice-jute-fallow-legume in Bangladesh; pigeonpea-wheat and rice-chickpea in India; rice-wheat-mungbean in Nepal; and mungbean + groundnut-wheat in Pakistan. The choice of legume to be grown depends on various factors such as crop season, rainfall pattern, temperature, soil texture, irrigation water supply, available growing period, and pests and diseases. Although yields of legumes have remained low due to several production constraints, they are still cultivated because they produce reasonable yields with low inputs under harsh climatic and edaphic conditions. When grown before or after rice, legumes encounter some formidable difficulties because the optimum soil physical conditions for these crops differ substantially. Cropping sequences that include rice and legumes, therefore, require special management to improve the total system productivity.

Area (thousand ha) Under Legumes in the IGP

Country	Total area under legumes	Legumes area in rice-based systems
Bangladesh	785	750
India	18790	1990
Nepal	253	197
Pakistan	1576	262

Grooming the Land

Legumes are cultivated on a wide range of soils, from loamy sand in western IGP to heavy clay in the eastern region. After rice harvest, use of low-energy tillage methods confines cultivation to a shallow depth forming a compacted layer which impedes root growth. While tillage of wet puddled clay soil produces a cloddy surface soil, tillage of dry soil produces small aggregates. Both conditions are unsuitable for good crop stand of legumes. Poor germination in a cloddy seedbed is due to less seed-soil contact and reduced water transmission to seeds while the fine aggregates after wetting and drying form a compact seedbed with high soil strength, which impedes emergence.

Simple management techniques should be adopted for optimum land preparation to facilitate good seed germination, seedling emergence and plant growth. The most common practice for cultivation of mungbean, black gram, cowpea, lathyrus and lentil in rice-fallows is zero tillage. This method reduces the cost of land preparation, facilitates timely sowing and reduces the risk of crop failures caused by early season drought. Although zero tillage is profitable, yet yields are low. Therefore, minimum tillage is required in medium- and heavy-textured soils, in both lowland and upland rice fields in the IGP. Seedbed preparation, especially after rice, should be good in heavy-textured soils. Deep tillage breaks the strong compaction layers preferably along parallel strips at 30 to 50 cm spacing. Legumes are sown on the strips for deep rooting and access to the subsoil water.

Tillage Practices for Some Legumes

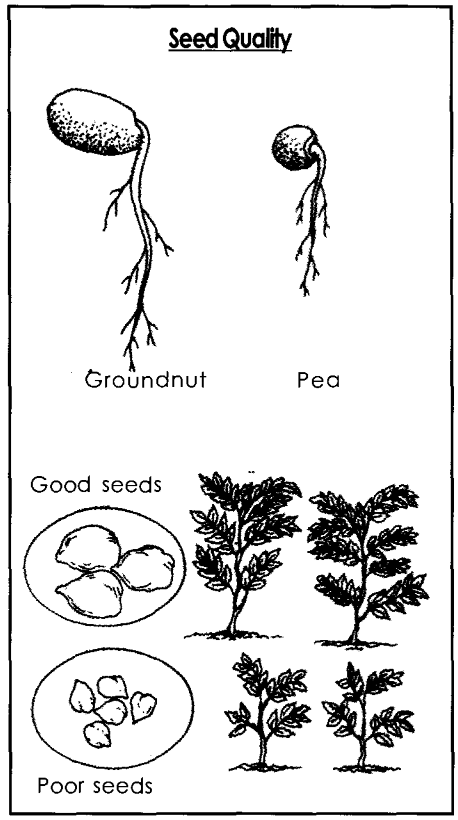
- Mungbean: The crop is grown successfully after lowland rice by using a single tine to disrupt the compact soil zone and by sowing along the tilled strip without fertilizer or irrigation.
- Soybean: Draining the field a day before rice harvest followed by one tillage with a rotavator produces good soybean yields when the soil moisture is optimum.
- Groundnut: In light-textured soils, light tillage with a rotavator ensures optimum moisture availability in the seeding zone and improves germination, crop growth and yield of groundnut after rice.

Selection of Crops and Genotypes

For good crop establishment in the rice-wheat systems in the IGP, legumes that are capable of penetrating hard soil should be selected. Groundnut has higher root elongation rate than pigeonpea and pea because it has better ability to overcome soil mechanical resistance. In areas receiving rainfall with gradual onset and termination, several legumes perform well: mungbean, black gram and cowpea before rice; and chickpea, lentil, lathyrus, pea, soybean and cowpea after rice.

Seedling emergence and plant vigor depend on seed quality and genotype. Large seeds have more vigorous growth than small seeds. Therefore, selection of appropriate crop and genotype, and use of good quality seed are important criteria for enhancing yield of legumes.

Time of Sowing



Legumes are generally sown when the opportunity exists in the rice-wheat systems and not necessarily at the optimal time. Better management of turn-around time between rice harvest and sowing of the following legume crop can avoid surface soil drying. Sowing date depends on various factors such as duration of rice or wheat crop, cropping sequence and the lag time from harvest of the rice or wheat crop until the field is prepared for legume cultivation. However, some adjustments within the available window can be made to improve timeliness of sowing. Land preparation and sowing practices can be modified so that sowing coincides with appropriate soil moisture condition for good crop establishment.

Sometimes the variety or sowing date of the preceding crop can be changed so that sowing date of the legume crop could be advanced to avoid drought stress during the later growth stages. Short-duration rice or wheat varieties can be used to optimize sowing time of legumes. Sowing date adjustments can also be made by mechanization of various operations to reduce the turn-around time and speed up sowing. In areas with double cropping systems, duration of the two component crops normally covers most of the growing season, leaving little opportunity for adjusting sowing dates to grow legumes. In such areas, short-duration legumes can fit into the narrow summer window of the rice-wheat rotation without sacrificing a rice or wheat crop during the year.

Better Crop Stand for Good Yield

Low crop stand reduces the productivity of legumes. Yields can be improved by increasing the plant density. Under late-sown conditions, plant growth is often restricted. Therefore, a higher plant population is required to compensate the yield loss per plant. However, dense crop stand attracts foliar diseases if appropriate plant protection measures are not adopted.

Appropriate sowing methods should be used to improve germination and establish an optimum plant population of legumes. In rice-wheat systems, seed of legumes can be dibbled at the base of rice stubble. Higher yields can be obtained by tillage and seeding in rows rather than broadcasting. In residual soil moisture conditions, deep sowing reduces the adverse effect of dry topsoil.

In rainy season legumes such as pigeonpea, groundnut, and soybean, crop stand is often vitiated due to water stagnation or poor drainage. In such situations, sowing on raised beds instead of flat beds, or ridges in a ridge-furrow bed system will ensure optimum plant stand. Seedling emergence can be increased and hastened by seed priming, use of bold seeds, and seed pelleting.

Soil Amelioration

Mulching, green manuring, stubble incorporation, and relay cropping of short-duration legumes improve soil organic matter content and the structural stability of the soil. Mungbean or black gram can be grown in the rice-wheat rotation to improve soil fertility in the IGP.

Sources of calcium such as gypsum or slaked lime improve the establishment and early root development of legume crop in puddled soils. As puddling results in soil dispersion, the application of gypsum improves the physical conditions of the soil following rice.

In some areas, waterlogging is a serious constraint for legume production. In areas where water is excess during the early part of crop growth, calcium ameliorants can improve the soil structure and drainage, particularly in soils dominated by exchangeable sodium and/or magnesium. Legumes (e.g., soybean, mungbean and black gram) that can better adapt to waterlogging conditions and are better suited to high moisture conditions early in the season, compared to other legumes such as chickpea, pea and lentil should be used.

Nutrient Management

Legumes respond to both macro- and micronutrients. Balanced supply of plant nutrients is essential for their high productivity. Legumes improve soil physical conditions and derive a large proportion of their nitrogen (N) requirement through biological nitrogen fixation (BNF). However, a starter dose of 10 to 15 kg N per ha is often recommended. In fields where the rhizobial population is low, late-sown legumes respond to applications of up to 40 kg N per ha. The application of N may not only be directly beneficial to the legume but also benefit the succeding cereal crops.

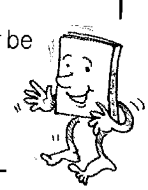
The soils of the IGP are generally low to medium in available phosphorus (P) content and therefore application of 17 to 26 kg P per ha increases seed yield of legumes. Sulfur (S) deficiency has been observed in rice-wheat areas due to increased cropping intensity and use of S-free fertilizers (urea and diammonium phosphate). It is more pronounced in legumes than cereals due to comparatively higher S requirement.

Legumes fix atmospheric N in their nodules through *Rhizobium*. But the quantum of N fixed is influenced by several physical, environmental, and biological factors. Lack of native rhizobial population causes poor nodulation. Use of efficient rhizobial inoculants enhances productivity of legumes by 10%-15%. Legume species and cultivars that have high nodulation capacity must be selected.

Increased use of organic manures is essential because of greater incidence of multiple nutrient deficiences, soil degradation, and decline in productivity. About 25%-50% of the N requirements of wet season rice can be substituted through farmyard manure, crop residues, or green manure. The short window of six to eight weeks between the harvest of wheat and transplanting of rice allows cultivation of a legume (e.g., mungbean, black gram, cowpea, *Sesbania*) for seed, fodder, or green manure. Incorporation of legume biomass into the soil can save 30 to 60 kg N per ha. Mungbean biomass buried after picking pods and before transplanting rice could save as much as 60 kg N per ha.

Micronutrient Deficiencies

Lentils are highly suseptible to zinc (Zn) deficiency. Soil application of 12.5 to 15 kg zinc sulfate ($ZnSO_4$) per ha improves yields. Foliar sprays of $ZnSO_4$ with lime is effective in correcting Zn deficiency in chickpea and lentil. In chickpea, application of 25 kg $ZnSO_4$ per ha improves nodulation, root growth, and yield and increases uptake of Zn, iron (Fe), and phosphorus (P). Boron (B) deficiency causes poor podding. Application of 0.5 to 1.0 kg B per ha improves chickpea and lentil yields; also, application of 0.5 kg ferrous sulfate per ha improves yield by 450 kg per ha over control. Cultivars that are tolerant to micronutrient deficiencies must be selected.



Water Management

Legumes require limited irrigation, particularly during drought. Common bean is more responsive to irrigation followed by pea. The success of mungbean as a catch crop during summer in the rice-wheat system is solely dependent upon adequate supply of irrigation. Late-sown chickpea after rice crop also needs irrigation compared to the normal-sown crop, probably due to restricted root growth.

Although pod initiation is the most critical stage in most legumes, the intial soil profile moisture and soil types determine the requirement of irrigation. Similarly, excess soil moisture or waterlogging reduces oxygen in the rhizosphere and thus affects BNF activity and nutrient availability resulting in yield reduction. Therefore, fields should have good drainage, especially in low-lying areas.

Weed Management

In early stages of crop growth, legumes are poor competitors to weeds. The nature and magnitude of crop-weed competition is influenced by several factors such as crop species, cropping system, sowing time, plant population, moisture availability, and fertility conditions. Weed competition affects crop yield and BNF. Yield losses due to weeds in the IGP were 44% in pigeonpea, 50% in black gram, and 42% in chickpea.

Short-statured and early-maturing legumes (e.g., black gram, mungbean, cowpea, and soybean) can be intercropped in wide-spaced crops (e.g., pigeonpea) to reduce weed menace. Cowpea, mungbean, and soybean are efficient in smothering weeds. Fast-growing legumes, both as sole crops and intercrops, suppress weeds and improve physical and biological conditions of the soil. Various chemical (herbicides), cultural (hand weeding), and mechanical (interrow cultivation) options are effective and economical for weed management.

Adapted from:

Ramakrishna, A., C.L.L. Gowda and C. Johansen. 2000. Management Factors Affecting Legumes Production in the Indo-Gangetic Plains. pages 156–165. *In:* Johansen, C., J.M. Duxbury, S.M. Virmani, C.L.L. Gowda, S. Pande and P.K. Joshi (eds). Legumes in Rice and Wheat Cropping Systems of the Indo-Gangetic Plain: Constraints and Opportunities. ICRISAT, Patancheru, India; and Cornell University, New York, USA.

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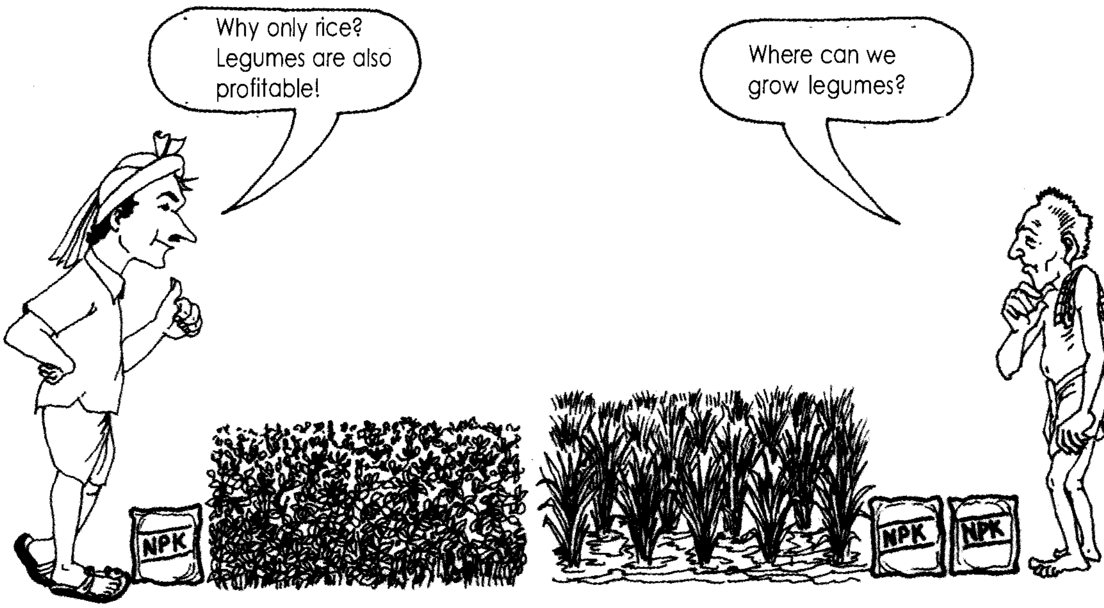
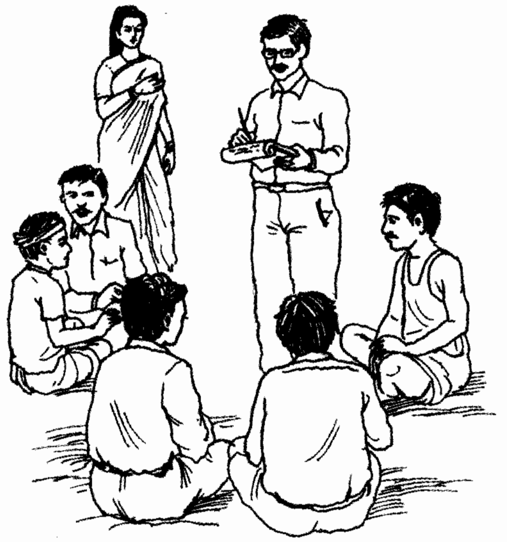
Socioeconomic Constraints to Legumes Production in Rice-Wheat Cropping Systems of India



The major problem of the rice-wheat system in the Indo-Gangetic Plain (IGP) of India is the stagnating or declining yields of rice and wheat. Also, the soil nutrient status and groundwater level are deteriorating. Crop diversification through legumes can address these problems as legumes complement cereals in both production and consumption. In the production process, legumes improve soil fertility status, require less water than cereals, and their rotation with cereals helps control diseases and pests. On the consumption side, legumes are the cheapest source of protein in the vegetarian diet and supplement mineral and vitamin requirements. Despite their value in production and consumption, area under legumes in the rice-wheat system has declined after the introduction of improved technologies during the mid-1960s. Several socioeconomic factors constrain legumes production in the rice-wheat system, and these issues are examined.

Reasons for Decline in Legumes Area

- Government's focus of support onto other cereals
- Lack of superior technology for legumes
- Biotic constraints (diseases and pests) in legumes
- Abiotic constraints (soil salinity, waterlogging and frost)
- Low productivity of cultivars



Data Collection and Analysis

The analysis is based on both secondary and primary data. The secondary data were collected from published sources on area, production, yield, and prices of legumes, rice, and wheat. To collect primary data, Karnal district in Haryana was selected as rice-wheat is the predominant system. Conclusions derived from this district may be relevant for other regions in Punjab and Uttar Pradesh, which practice intensive rice-wheat system and have similar agroclimatic features.

Legumes in the Existing Cropping System

The cropping pattern followed by the selected sample farmers in 1996/97 indicated that rice and wheat were the major crops of the study area and occupied 81% of the total cropped area. Although legumes area in this predominantly rice-wheat system was less than 10%, it was much higher than the area of other crops. Thus, legumes were preferred besides rice and wheat.

Crops Grown in Selected Villages of Karnal District in Haryana, India, 1996/97

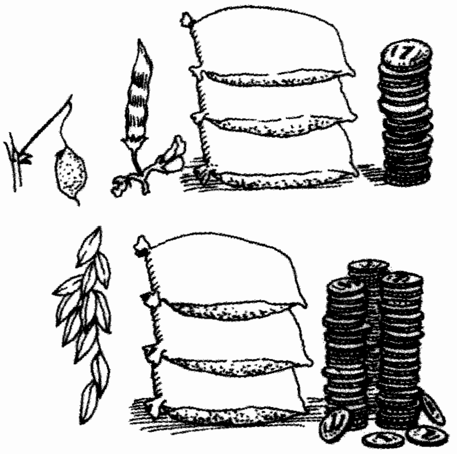
Crop group	Crop	Area (%)
Cereals (grain)	Rice Wheat Others (maize)	43.0 38.0 0.2
Cereals (fodder crops	Sorghum, maize during rainy season)	3.4
Legumes (grain)	Pigeonpea, chickpea, lentil, mung bean, black gram	3.1
Legumes (fodder crops	Berseem, lucerne during winter)	3.5
Legumes (summer)	*Sesbania* spp.	2.2
Oilseeds	Mustard, toria, and sunflower	2.8
Commercial crops	Sugarcane	3.2
Others	Others	0.6

Profitability of Legumes

Profitability was the most important criterion for allocating area to alternative crop choices and this was largely influenced by cost of production, crop yields and output prices. Despite low cost of cultivation of legumes, the profitability of different legumes did not consistently match that of rice and wheat. However, berseem was more profitable than wheat but it was solely grown for fodder and its area expansion was restricted due to lack of market demand.

Lower net profit of legumes when compared with that of rice and wheat was mainly due to their poor yield performance. However, output prices of all legumes were much higher than those of rice and wheat. Yields of legumes were so low that higher output prices could not make them more profitable than rice and wheat. The output price of pigeonpea was double that of rice whereas the yield of rice was four times higher than that of pigeonpea. Similarly, the output price of chickpea was double that of wheat, but wheat yield was 60% higher than chickpea yield.

Historical trends in the prices of legumes, rice and wheat indicated that the minimum procurement prices of all legumes announced by the government were always kept higher than those of rice and wheat. During the past three decades, yields of legumes were always substantially lower than those of rice and wheat in the states of Haryana, Punjab and Uttar Pradesh. Yields of rice and wheat increased much faster than legumes in these states. A yield breakthrough in legumes was not realized as in rice and wheat. Although several improved cultivars of various legumes were developed, they were not widely disseminated due to lack of knowledge of the farmers.



Legumes Cultivation: A Risk to Farmers?

Farmers considered production of legumes as relatively more risky than rice or wheat. The price and yield risks of legumes were much higher than those of rice and wheat. The coefficients of variation in yields of chickpea and pigeonpea were greater than wheat and rice in most districts in the Indian states of IGP. This suggests that legumes were more prone to risk due to crop failure (low yields) when compared with rice and wheat. Similarly, price fluctuations (post- and preharvest) in chickpea and pigeonpea were higher than rice and wheat. Thus yield and price risks were hindering adoption of legumes in the rice-wheat system.

Profitability of Alternative Cropping Sequences

The profitability of the rice-wheat cropping sequence was compared with other alternative cropping sequences under three options: (1) existing prices of fertilizers and electricity charges paid by the farmers for irrigation; (2) without electricity subsidy for extraction of groundwater for irrigation; and (3) without fertilizer and electricity subsidy for irrigation. The most profitable crop sequence was rice-wheat-black gram followed by rice-berseem and rice-wheat-mungbean. The adoption of these three crop sequences was limited in the study area due to resources and market constraints.

Cultivation of black gram and mungbean requires much water after the harvest of wheat, whereas berseem area expansion was restricted due to limited market determined by livestock population. Profitability of rice-wheat, the most popular cropping sequence in the study area, was higher than that of rice-chickpea and pigeonpea-wheat. Even if the existing subsidies on fertilizer and electricity for irrigation were withdrawn, the rice-wheat rotation was still the most profitable crop sequence. Therefore, farmers allocated area for rice-wheat sequence. Substitution of legumes for rice or wheat means loss in earnings of farmers. To introduce legumes in the rice-wheat system, profitability of legumes needs to be raised subtantially. This is possible through a substantial increase in their yield levels, which could be attained through dissemination of appropriate technologies to farmers.

Trade-off Between Legumes and Competing Crops

Five criteria were assessed to examine the trade-off due to inclusion of legumes in the rice-wheat cropping systems. These were:

1. profit;
2. food grain production;
3. fixed assets (farm implements and machinery);
4. groundwater; and
5. soil nutrients (nitrogen).

Most farmers maximize profit, food grain production and utilize fixed resources.

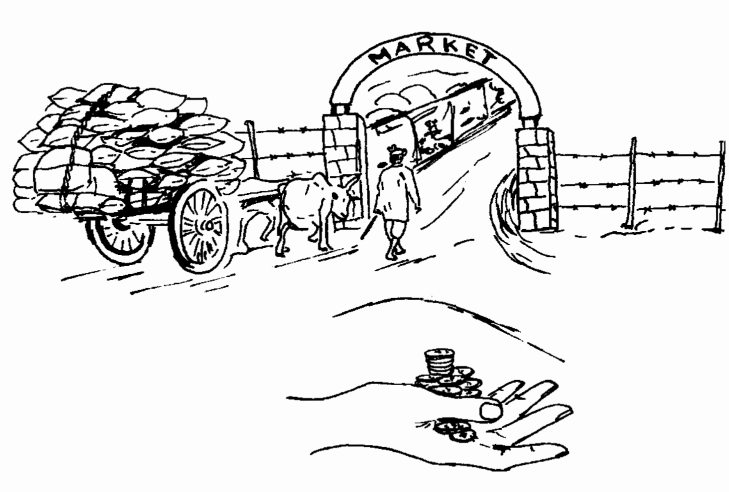
Trade-off (percentage change) in Replacing Rice or Wheat with Legumes in Karnal District, 1996/97*				
Indicator	**Pigeonpea**	**Chickpea**	**Lentil**	**Berseem**
Profit	-49	-19	-41	+2
Food grain	-76	-64	-76	
Fixed resources	-57	-49	-61	-43
Groundwater	+95	+85	+83	-125
Soil nutrients	+65	+73	+75	+56

*In rice-wheat system, rice was substituted by pigeonpea and wheat by chickpea, lentil, or berseem

The trade-off values for replacing rice by pigeonpea indicated that farmers would lose 49% profit. The region would need to sacrifice 76% food grain production and 57% of the fixed resources would remain unutilized. However, the region would save about 95% of the groundwater and 65% of the nitrogenous fertilizer. Similarly, trade-off was also observed when wheat was substituted by chickpea or lentil. But the trade-off between wheat and berseem (a fodder legume) indicated negligible loss in profit, despite more groundwater being used for berseem than wheat. Thus substitution of wheat by this fodder legume would mean further over-exploitation of groundwater. When food grain legumes substituted rice and wheat, there was a loss in profit, food grain production, and use of fixed resources. However, there were substantial gains in conserving groundwater and nitrogenous fertilizers.

Lack of Adequate Markets

Markets for legumes were thin and fragmented in comparison with rice and wheat, which have assured markets. Government procurement system for legumes was ineffective. Often, farmers were not able to get the minimum prices announced by the government.



The price spread (or the market margin) for legumes was much higher than for rice and wheat due to higher post-harvest costs. The share of farmer's returns in consumer price was much lower for legumes than for rice and wheat. The price spread for pigeonpea dal was Rs 15 per kg, while it was less than Rs 1 per kg for rice. For chickpea, it was Rs 3.20 per kg whereas it was only Rs 1.20 per kg for wheat. Farmers' share in consumer rupee was 40% for pigeonpea and 85% for rice; for chickpea, it was 35% and for wheat it was high at 91%. These estimates indicated that farmers were not really benefited by higher market prices of legumes. To encourage legumes production in rice-wheat system, similar mechanisms for their procurement as for rice and wheat need to be evolved.

The Prime Needs

The existing low yield levels of legumes will displace them from the rice-wheat system. Therefore, more resources should be allocated for research to break yield barriers, and design innovative policies on risk and resource management. If pigeonpea should compete with rice, its yield must be increased from 1 to 2 tons per ha. Similarly, lentil yields must be raised from less than 1 to 1.4 tons per ha and chickpea yields from 1.5 to 1.6 tons per ha to compete with wheat. Although chickpea is now competetive with wheat with respect to yield, the risk factor due to diseases and insect pests in chickpea remains high and needs due attention.

Strategies to Reduce Legumes Production Risk

- Develop high-yielding varieties
- Create assured output markets
- Reduce post-harvest losses and costs
- Develop appropriate crop production technologies

Adapted from:

Joshi, P.K., M. Asokan, K.K. Datta and P. Kumar. 2000. Socioeconomic Constraints to Legumes Production in Rice-Wheat Cropping Systems of India. pages 176-184. *In:* Johansen, C., J.M. Duxbury, S.M. Virmani, C.L.L. Gowda, S. Pande and P.K. Joshi (eds). Legumes in Rice and Wheat Cropping Systems of the Indo-Gangetic Plain: Constraints and Opportunities. ICRISAT, Patancheru, India; and Cornell University, New York, USA.

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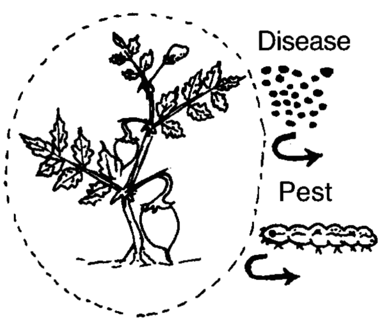
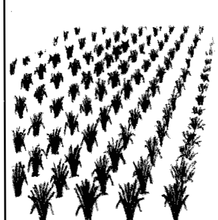
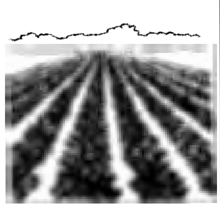
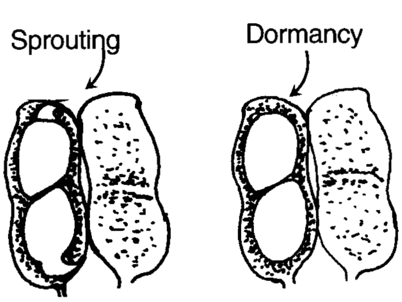
P. K. Joshi

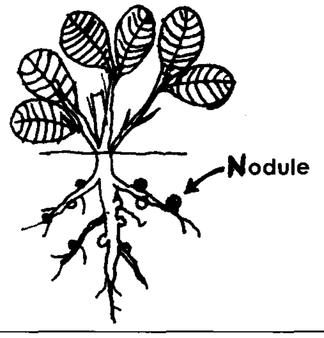
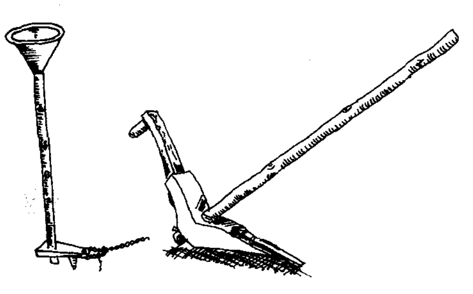
Strategies for Increasing Legumes Production in the Indo-Gangetic Plains

Legumes enhance fertility restoration, break pest and disease cycles, and improve rhizosphere conditions in rice-wheat systems of the Indo-Gangetic Plain (IGP). But legumes are cultivated primarily for seed, for human consumption and sometimes for fodder. Good growing conditions are required for optimal crop yields. Under conditions of unfavorable soil moisture, soil texture, nutrients and weather, introduction of legumes in rice-wheat systems would be an opportunity cropping.

Optimum land preparation is essential to facilitate seed germination, seedling emergence and subsequent growth of legumes. Efficient crop management practices should be developed to overcome constraints and reduce cost of production.

Strategies for Enhancing Legumes Production in the IGP

	Delineate agroecological zones based on length of growing season and soil types to identify legume crops and cultivars that can be grown in a given region.
	Identify crops and genotypes having high seedling vigor for good crop establishment and plant stand.
	Select early-maturing genotypes with tolerance to drought, cold, salinity and resistance to insect pests and diseases for a given production system or ecoregion.
 	Select genotypes suitable for late sowing and relay sowing, and tolerant to excess moisture for areas having waterlogging or flooding problems.
	Incorporate seed dormancy trait in some crops, e.g., groundnut. Seed dormancy is also found in lentil and lathyrus.

Strategies for Enhancing Legumes Production in the IGP (contd.)	
	Identify efficient *Rhizobium* strains and genotypes to enhance symbiotic nitrogen fixation. Assess fertilizer requirements and application methods for crop sequences and mixed cropping systems rather than for single crops.
	Introduce early-maturing, high-yielding rice and wheat varieties to increase turn-around time for land preparation so as to ensure proper establishment of legume crops.
	Ensure production and distribution of quality seed of adapted high-yielding legume varieties.
	Develop and market low-cost farm implements to facilitate timely sowing and harvesting of legumes.

Adapted from:

Ramakrishna, A., C.L.L. Gowda and C. Johansen. 2000. Management Factors Affecting Legumes Production in the Indo-Gangetic Plains. pages 156–165. *In:* Johansen, C., J.M. Duxbury, S.M. Virmani, C.L.L. Gowda, S. Pande and P.K. Joshi (eds). Legumes in Rice and Wheat Cropping Systems of the Indo-Gangetic Plain: Constraints and Opportunities. ICRISAT, Patancheru, India; and Cornell University, New York, USA.

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A. Ramakrishna

Abiotic and Socioeconomic Constraints Limiting Productivity of Legumes in Bangladesh

Although food legumes are important crops in Bangladesh, they occupy only 5% of the total cropped area in the country. Several legumes are grown, e.g., lathyrus, lentil, chickpea, black gram, mungbean and groundnut. These crops are grown without monetary inputs. Hence, the productivity is low compared to cereals (rice and wheat). Besides biotic stresses (diseases, pests and weeds), several abiotic and socioeconomic constraints cause severe reduction in legume yields.

Abiotic Constraints

Food legumes are mainly grown in the Ganges Floodplain Region of Bangladesh, in areas with moderately to poorly drained soils. These areas receive moderate annual rainfall. Thus, several climatic and edaphic factors limit the productivity of legumes.

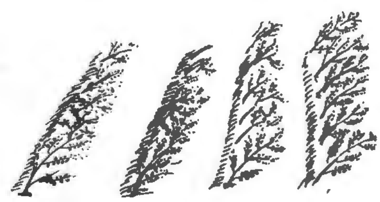
Drought

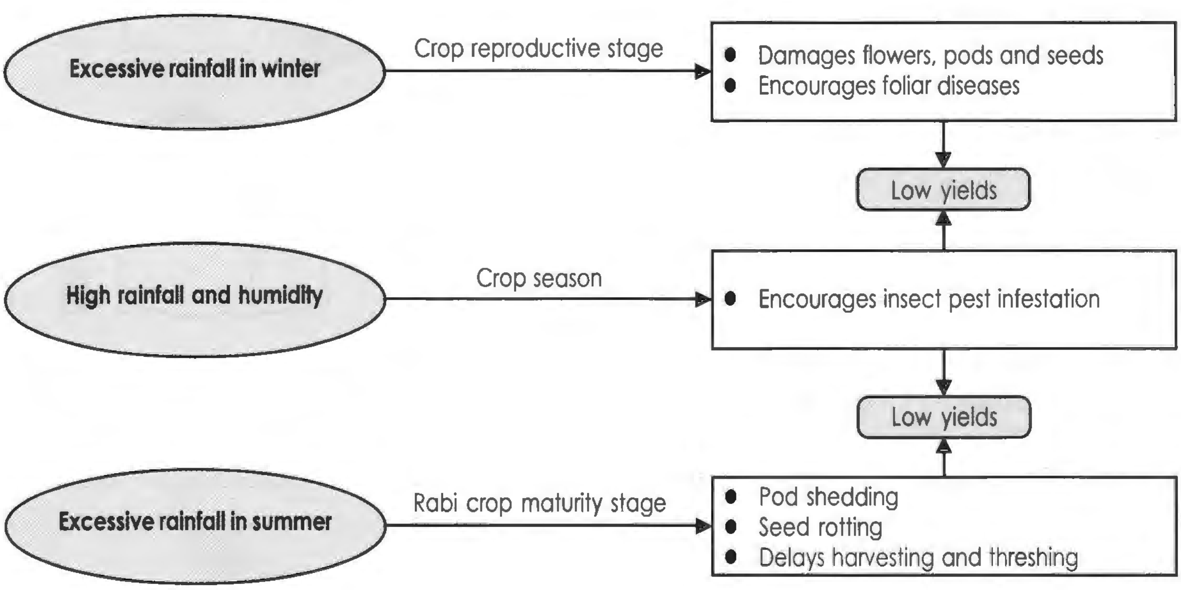
The climatic conditions in Bangladesh are variable, particularly during the post-rainy season (winter). In some years, very little rainfall occurs during winter and the major legumes (lentil, lathyrus, chickpea and groundnut) that are grown on conserved soil moisture suffer from drought stress. The dry surface soil hampers germination and emergence, especially in late-sown lentil and chickpea. Consequently, optimum plant stand cannot be established and thus yields are low. The water-holding capacity of the soil during winter is a major factor that determines the onset of drought. The crops can suffer from drought stress during both vegetative and reproductive phases. Abortion of flowers and young pods occurs and seed filling is prevented.

Excess Soil Moisture and Humidity

During winter, when excessive rainfall occurs at early crop growth stage, it encourages vegetative growth leading to lodging, and also encourages development of various leaf and root diseases. At reproductive stage, rainfall favors development of foliar diseases such as botrytis gray mold in chickpea, rust and stemphylium blight in lentil, downy mildew in lathyrus, and late leaf spot in groundnut.

Black gram and mungbean are sown in the late rainy season (August/September) when rainfall is high. Hence land preparation is difficult during this period and heavy infestation of weeds occurs. Crops may be seriously damaged due to waterlogging, and infestation of insect pests which cannot be controlled effectively through insecticide sprays applied during the rainy season.





Extreme Temperatures

In some areas, low temperatures encountered during January/February reduce podding in chickpea. A sudden rise in temperature in late February reduces vegetative growth period and causes forced maturity of rabi crops, especially of late-sown lentil and chickpea.

Soil Factors

> **Low Soil Nutrient**
> The soil organic matter content is low. Some macro- and micronutrient deficiencies do not reduce yields of legumes. However, boron deficiency is increasing and limiting yields of lentil and chickpea.

Legumes have been traditionally grown in the Ganges Floodplain. But chickpea cultivation is now increasing in the Barind tract, and mungbean in the young Meghna Estuarine Floodplain. The Ganges Floodplain soils are calcareous and alkaline. Moderately-well to poorly-drained, loamy to clayey soils occur on raised areas. Basin areas have poorly drained, loamy to clayey soils. The surface soil is acidic. Young Meghna Estuarine Floodplain soils are loamy on the raised areas and loamy to clayey in the basin areas. Soils here are neutral to slightly acidic. In soils of higher clay content, plow pan formation impedes root development of crops following rice, and thus the ability of those crops to access soil moisture and nutrients is reduced.

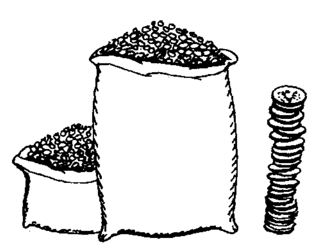
Socioeconomic Constraints

In Bangladesh, farmers and the government give priority to the production of cereals such as rice and wheat, or to cash crops. Farmers consider legumes as sensitive to microclimatic variation and to diseases and pests and thus high and stable yields cannot be ensured. Therefore, they consider legumes as risky crops, even if they are potentially remunerative, and give low priority to their optimum husbandry.

Use of Inputs

Use of irrigation and fertilizers often encourages excessive vegetative growth of legumes, which ultimately results in poor pod set and low yield. Therefore, farmers do not use inputs such as fertilizers, pesticides and fungicides. The prices of these inputs are high and increasing, which also discourage their use for risky crops like legumes.

Low Profit and High Risk



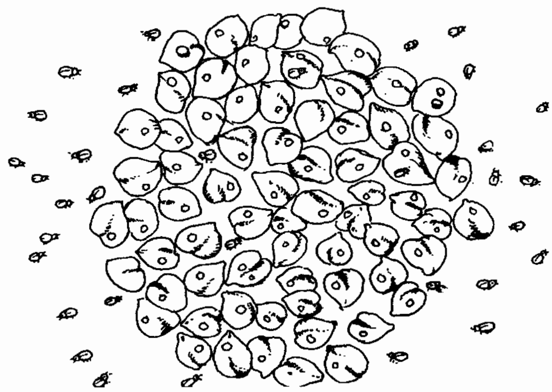
Farmers continue to use traditional landraces of legumes and thus yields have not increased over time. High-yielding varieties are not available to farmers. Although market price of legumes is increasing relative to other grains, the benefit-cost ratio is low (1.03 to 3.38).

Lack of Cash and Credit

Most farmers do not have enough cash to buy quality seeds or inputs. Credit facilities are not available for legumes as they are for other crops such as rice, cotton and sugarcane.

Traditional Cultivation Practices

Farmers follow traditional practices for legumes production in Bangladesh because improved methods of cultivation (such as line sowing and use of inputs) cannot assure high yields. Although prices of legumes are much higher than other competing crops, profitability seems to have little influence on production options/decisions. Improved technologies should be developed and disseminated to farmers to encourage them to include legumes in their cropping systems.

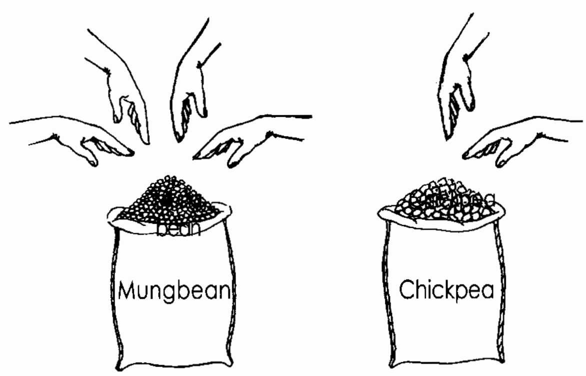


Lack of Support Price and Marketing

Legumes are more susceptible than other crops to stored grain pests. Therefore, farmers cannot store their produce for long so they have to sell it immediately after harvest. There is neither a definite marketing channel nor government support price for legumes. Traders buy the seed from farmers at a low price. About 74% share of the profit goes to traders and only 26% to farmers.

Consumer Preference

Consumers prefer various legumes in Bangladesh. The prices of legumes depend on consumer preference and total production. Most commonly, consumers prefer lentil followed by chickpea, mungbean, black gram, and lathyrus. Some legumes are regionally-preferred, for example, black gram is preferred by most people of north-western Bangladesh. Hence, it is not widely grown in other parts of the country.



Adapted from:

Rahman, M.M., M.A. Bakr, M.F. Mia, K.M. Idris, C.L.L. Gowda, J. Kumar, U.K. Deb, M.A. Malek and A. Sobhan. 2000. Legumes in Bangladesh. pages 5–34. *In:* Johansen, C., J.M. Duxbury, S.M. Virmani, C.L.L. Gowda, S. Pande and P.K. Joshi (eds). Legumes in Rice and Wheat Cropping Systems of the Indo-Gangetic Plain: Constraints and Opportunities. ICRISAT, Patancheru, India; and Cornell University, New York, USA.

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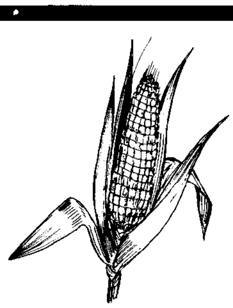
M. Matiur Rahman

Quality Protein Maize in Zero-tillage

Environmental and climatic changes have affected the rice-wheat areas in the Indo-Gangetic Plain (IGP). Due to deforestation, this region does not receive adequate rainfall resulting in receding watertable. Therefore, rice cannot always be grown successfully in these areas. Also, global warming has caused increase in temperatures. Hence, wheat too cannot always be grown successfully in the region. Consequently, maize is becoming an increasingly important crop in the marginal sector of the resource-challenged farmers of the IGP, particularly in the rice-wheat system.

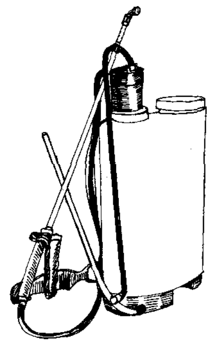
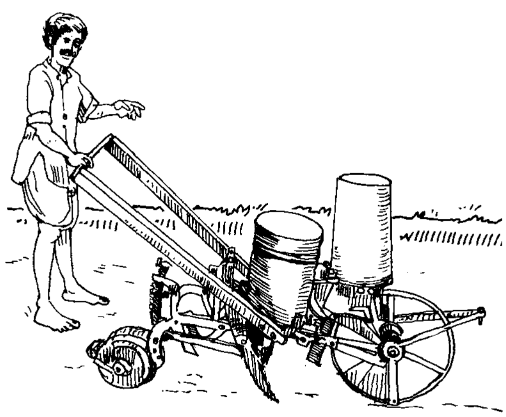
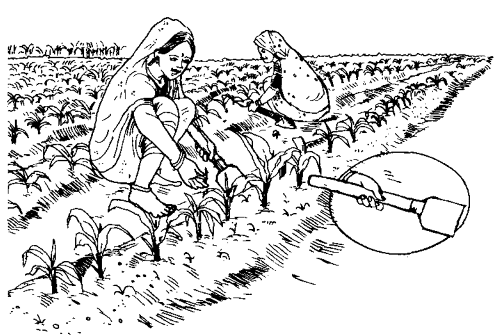
Maize does not require as much water as rice and does not require as cool temperatures as wheat for successful grain production. The Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) is promoting quality protein maize (QPM) because it is higher in usable protein than common maize. The protein in QPM is better absorbed by humans and animals and thus it is more beneficial than common maize.



"For the people who lack the resources to purchase milk or eggs, use of quality protein maize grain in tortillas or other maize based foods will provide more protein at no additional cost."

– Norman E Borlaug
(Nobel Peace Laureate
& Father of Green Revolution)

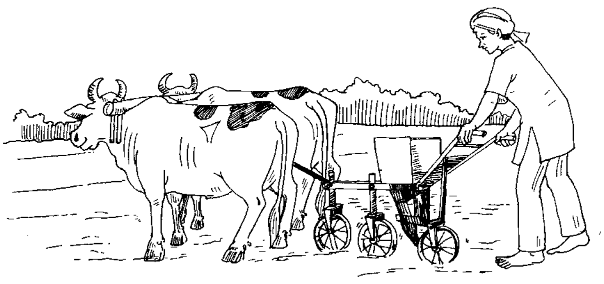
Guidelines for Planting and Other Operations for Maize Production in Zero-tillage

Management of existing vegetation without soil preparation 	**Commercial farmer** Spray herbicide (Glyphosate, 2,4-D, or Dicamba) one to two weeks before chopping vegetation. **Subsistence farmer** Chop vegetation at the base with a cutlass and spread it over the entire field as mulch. Allow it to sun-dry for a few days to facilitate planting operation.
Planting  One-row zero-tillage "chiquita" planter	**General** Place treated seed 5 to 10cm deep in moist soil. In hand planted zero-tillage situations, open up the mulch a bit on the top of the planting hole, just enough to facilitate seedling emergence. Mulch prevents crusting and reduces soil moisture loss caused by high temperature that affects seed germination. **Commercial farmer** Plant with a zero-tillage commercial planter, with fertilizer attachment. **Subsistence farmer** Hand plant with a planting stick or hand planting machine, or with a one row direct drill animal-driven planter.
Weed control 	**General** The maize field should be weed-free for at least the first three weeks after emergence, especially in dry areas under low nitrogen. For better results, the field should be weed-free until the canopy shades the inter-row (knee-high stage). **Commercial farmer:** Apply herbicide (Atrazine or Simazine) as pre-emergence application. **Subsistence farmer:** In mulched fields, weed population is low. Use a hand hoe to remove the weeds.
Fertilization 	**General** Apply about 50 kg nitrogen for every extra ton of maize above the yield normally obtained without nitrogen but with good management; follow split method in two or three applications. Also, apply phosphorus and potassium as recommended for the area. In mulched fields, broadcast all phosphorus fertilizers.

Source: Paliwal *et al.*, 2000

Advantages of Zero-tillage for Maize Production

Mechanized zero-tillage
- Planting in unprepared soil
- Requires low fuel and labor costs
- Requires little draft power
- Suitable for coarse soils
- Improves soil structure
- Maximum erosion control
- Less soil moisture loss
- Better rainwater use



Zero-tillage single planter

Matraca planter (dibbling machine)

Zero-tillage with planting stick
- Planting in unprepared soil
- Requires no machinery
- Low cost
- Suitable for soils of any texture
- Improves soil structure
- Maximum erosion control
- Less soil moisture loss
- Better rainwater use

Implications

As the zero-tillage system is established, use of herbicides is reduced due to decrease in weed population. Also, there is a substantial saving in time, irrigation, and monetary costs. Zero-tillage is the most conservative and suitable system for common maize and QPM production. QPM can be utilized in diversified ways in India through various products such as infant food, health food, convenience foods, and specialty food. Replacement of common maize by QPM is the most effective and attractive measure to meet quality protein needs and to raise the human and nutritional status. QPM production in zero-tillage would help India become both "food secure" and "nutrition secure".

Reference

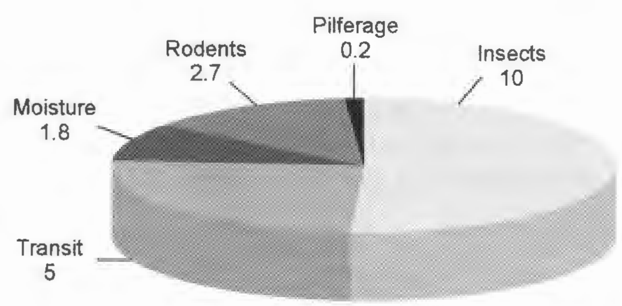
Paliwal, R.L., G. Granados, H.R. Lafitte and A.D. Violic. 2000. Tropical Maize Improvement and Production. FAO Plant Production and Protection Series No. 28. FAO, Rome, Italy.

Contributed by:
Sarvesh Paliwal

Seed Drying and Storage

Quality seed is important for good plant stand and high yield. Care is needed not only in selecting a suitable variety but also in using seeds having high levels of purity, germination and sanitation. In Bangladesh, about 20% loss of grain occurs during commercial storage of rice due to various factors. In Pakistan, losses due to improper storage, mishandling and rats are estimated at 8%, 2%, and 4% respectively.

Being self-pollinated, maintenance of genetic purity is simple in rice and wheat seeds. Hence, the farmer can use the farmer-saved seed of a good variety for two to three years, without replacing with certified seed, if care is taken from harvest to next sowing in maintaining seed quality.



Commercial storage loss (%) of paddy in Bangladesh

Harvesting

A part of the crop, which has a uniform, true-to-type plant stand and is free from weeds, off-types, and diseased plants, is selected for seed purpose. Harvesting at full maturity, threshing, drying, and cleaning of seed are the activities undertaken prior to sowing of the main crop to avoid any physical admixture and to ensure good seed quality. In the hilly region of Nepal, harvesting is sometimes delayed by about one month, thus coinciding with the onset of rains. In such situations, harvesting of wheat is done by picking the earheads only. Moisture content of early paddy at harvest is normally about 20% to 22% but sometimes it is more than 24%.

Seed Moisture

High moisture in seeds is the major single factor for loss of seed viability during storage. The moisture content of seed at harvest is normally 15% to18% in winter season crop and around 20% or more in rainy season crop, which is far too high for safe storage. To minimize the metabolic degradation and to control mold growth, moisture content should ideally be less than 12% in rice and wheat seeds, whereas to control insect infestation, it should be less than 9%. Moisture level of 12% or below is permissible for storage of rice and wheat seeds in moisture-pervious containers (jute canvas sacks or cloth bags). As the storage conditions at farmer's level are generally less favorable, seed should be dried to ~10% moisture before storage. Moisture content depends on the initial seed quality and should not be less than 8% or more than 12%.

Estimated Storage Life of Cereal Seeds at Temperatures Not Exceeding 32°C

Seed moisture (%)	Storage life (years)
≥13	<1
10-12	1
9-10	2
8-9	4

Seed Drying

As wheat is grown in winter (rabi), it matures in April-May when the ambient relative humidity (RH) is low and temperature is rising, particularly in the northern part of the Indo-Gangetic Plain (IGP). These conditions are very conducive for seed drying to a moisture level of 10% or below. But if rains occur at pre-harvest, harvest, or pre-threshing time, then seed drying and thus seed quality is affected. Consequently, germination and yield are reduced.

Germination Test

Assessment of seed germination helps in planning its storage and use. Shallow pots (about 12" diameter or 15" square) are filled with soil/sand and watered well. Hundred seeds are sown in each pot. As wheat is harvested in summer, the test pots should be kept in a cool place. The number of healthy and vigorous seedlings are counted after one week. A count of 85% or more is ideal.

Rice is primarily grown in the wet/rainy season (kharif) and matures in October-November, when the ambient RH is high and wind velocity is low. These conditions are not favorable for seed drying particularly in eastern IGP, where the monsoon retreats late. Hence, more care is needed for drying rice seed.

A pre-threshing drying of crop harvest reduces seed moisture below 15% and minimizes seed damage. After threshing, the seed is spread evenly over a canvas sheet (or other similar material) on a clean and preferably *pucca* (concrete) floor for drying. Occasional turning and moving of seed layer helps in uniform seed drying and also in maintaining a safe temperature range, particularly in northern IGP.

Exposure to high temperature (35 to 40°C or more) causes serious damage to seed having high moisture, which results in poor germination as well as discoloration. As seed moisture is generally high (15% to 18%), drying temperature should not exceed 35°C. Hence, the seed is partially dried under shade and later under sun. A good air-flow by using a domestic fan helps faster and full drying of seed. The seed is cooled after sun-drying prior to storage.

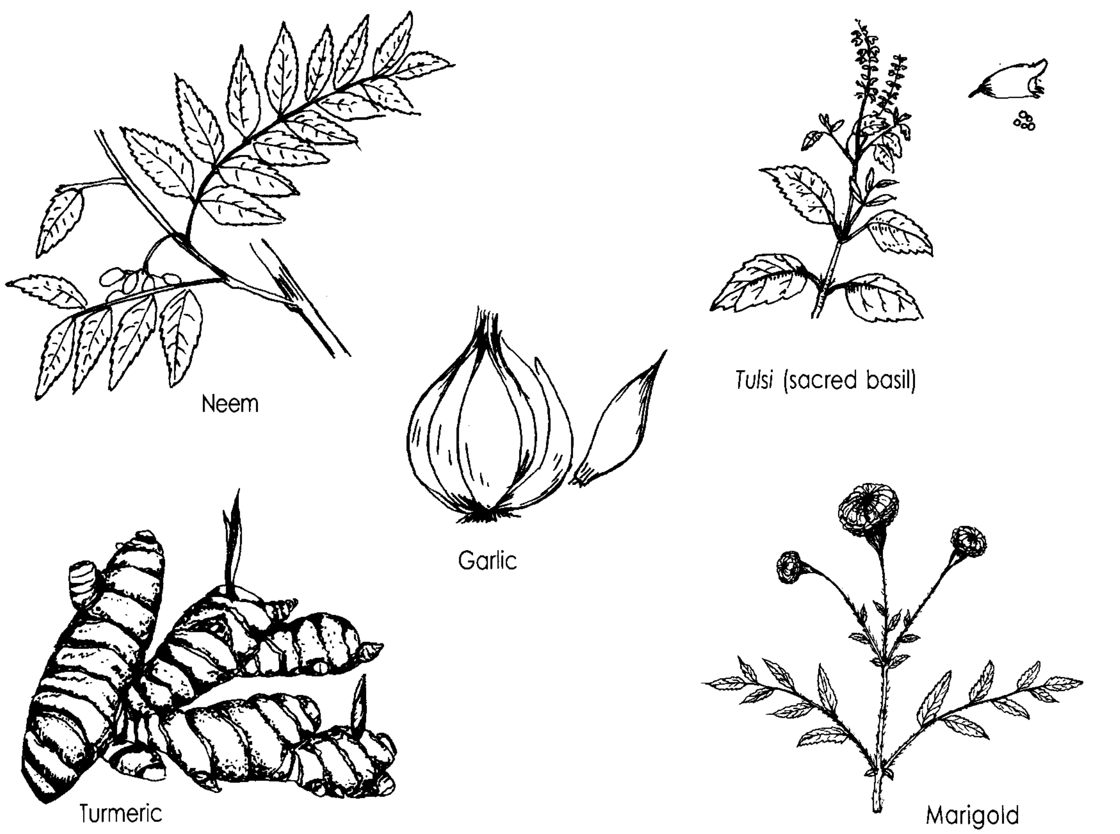
Pre-storage Pest Management

Storage losses due to insect damage is estimated at 10% to 15% in cereals. These losses can be reduced significantly by effective pre-harvest and post-harvest pest management. Proper seed drying helps in controlling many storage pests. For further protection, fumigation of seeds with aluminum phosphide at 1-2 tablets (2 g each) per ton seed for seven days inside a leak proof cover/ container is effective against major storage grain pests. In Pakistan, three tablets of aluminum phosphide per ton seed are used.

> **Caution**
> Seed moisture should not exceed 12% at fumigation.

Sacks, bins, and silos used for seed storage are cleaned thoroughly and sprayed with Malathion 50% EC at 2%. Mixing ash or edible oils (at 1% to 2% v/w) with grains is also effective in controlling insect pests. Seed health test is also important before storage. Visual examination is performed on 1kg sample per 20-ton seed lot (maximum). From each sample of 1kg, 400 seeds are tested for microorganisms.

Indigenous Plants for Effective Control of Storage Grain Pests



Seed Storage Environment

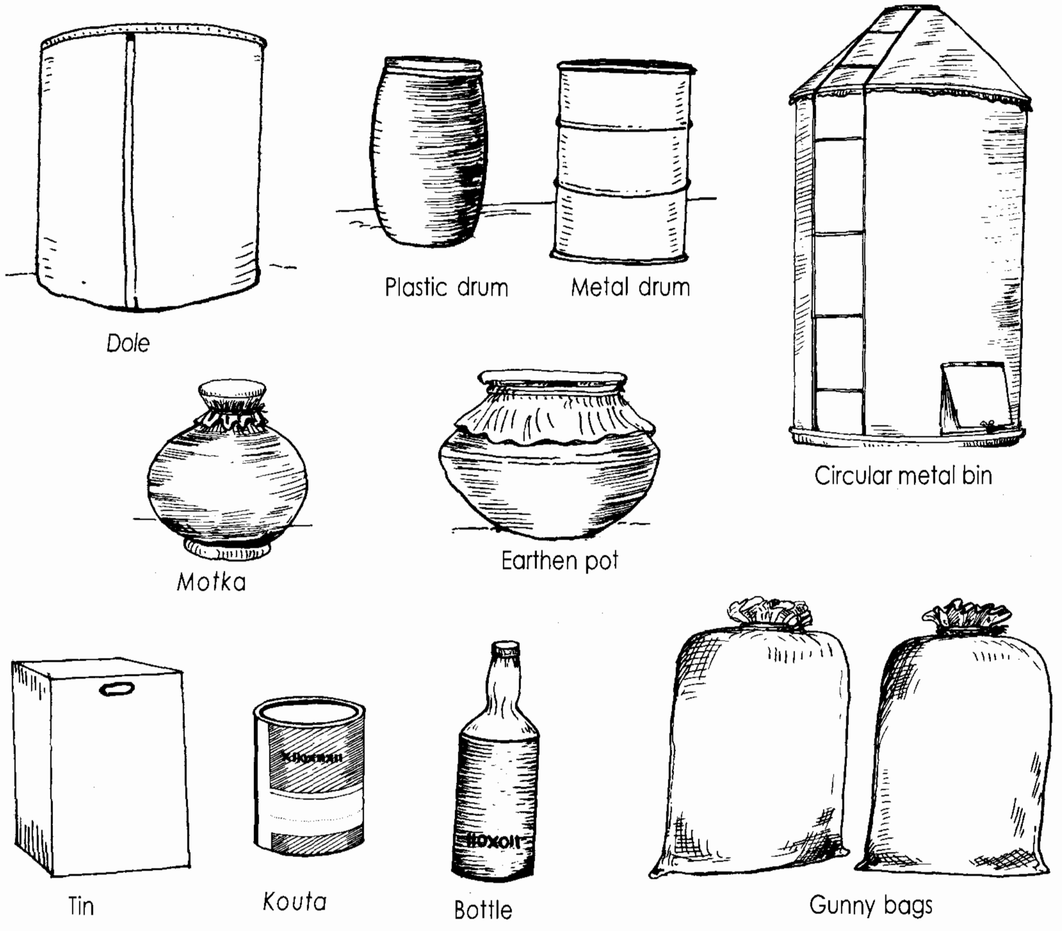
For maintaining high germination and vigor, seed is stored under dry but cool conditions. Storage life of seed doubles with the reduction of moisture content by 1% and storage temperature by 5°C, independently. Proper insulation during storage helps in minimizing the harmful impact of fluctuation in the ambient relative humidity and temperature.

Seed Storage in Bangladesh and Pakistan

Traditional storage structures used by farmers in Bangladesh are made of indigenous materials readily available in rural areas at low cost. The size and use of these structures vary in different parts of the country. Cereals (rice, wheat, and other crops) and pulses (lentil, chickpea, etc.) are generally stored in *dole*, metal and plastic drums, *motka*, earthen pots, and tins. Vegetable seeds are stored in small tins (*kouta*) and bottles.

General cleanliness and pest control is important in seed public stores. In farms, gunny bags and large metal bins are primarily used for storing field and vegetable crop seeds. Storage structures are also made of mud, bamboo, bricks, or metal. Hay is commonly used to pack seed bags inside these structures for protection against moisture and temperature.

Seed Storage Structures in Bangladesh



Alternatively, the coolest and driest corner of the farm dwelling is selected for seed storage. Seed sacks are stacked over a wooden plank, a little away on the walls. The stack is fully covered from all sides by a canvas or polythene sheet. Improved structures such as house-type sheds, binnishels, silos, Italian bins, and Australian bins are now used for storing cereals. Some wheat and rice seeds are also stored in the open and covered with tarpaulin or polythene sheet.

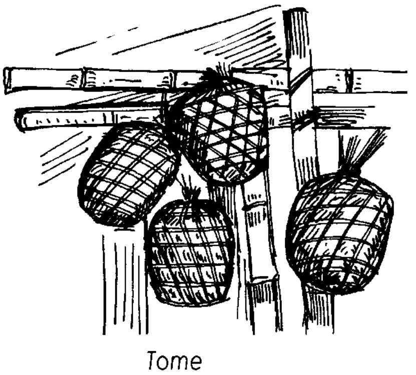
About 70% seed is stored in house-typed godowns by the Pakistan Agricultural Supply and Services Corporation (PASSCO) and other government agencies. Small farmers store seed in new bags dipped in neem leaf extract. Seed is also stored in mud or metal bins. Farmers ensure proper cleaning and drying of seed. The seed moisture content is 8% to 12%.

In Nepal, seed storage structures made of mud, bamboo or brick are common. Being a hilly country, stone is also used in mud structures.

Indigenous Storage Structures in Northeastern India

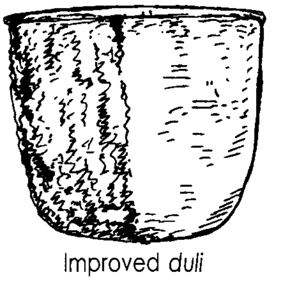
Tome, a unique seed storage structure, is commonly used for rice storage in Assam. It is made of a rope sack lined with thick layers of rice straw of the same variety as seed stored. This helps in maintaining purity of seed. After placing seed in the *tome,* it is tied at the upper end. The *tome* is then hung from the ceiling in the driest corner. Seed stored keeps well with high germination for one planting season. Seed germination is high, about 90% to 95%. The capacity of each *tome* is about 5 to 10 kg.

Duli is an indoor storage structure made of bamboo strips and mud plastered on inner and outer sides. Plastering on both sides strengthens the structure. Various insect-repellent plants such as neem, *tulsi,* and marigold are dried and mixed with cowdung and mud (preferably silt from ponds). Some farmers place a layer of straw at the bottom of *duli.* A lid with a handle is used for closing the container and often sealed with mud. The *duli* has now been improved. The outer surface is coated with tar to control insects, minimize moisture absorption, and toughen the container. Also, a pout is fixed at the base to draw seed as and when required, without opening the lid. The capacity of *duli* is 1 to 2 tons. Similar structures with minor variations are also used in other parts of eastern India.



Tome

Duli

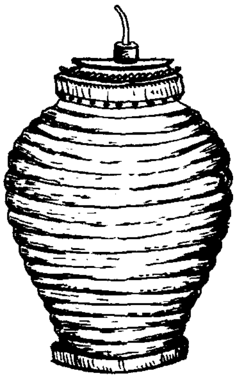


Improved *duli*
(with tar coating)

Use of polythene-lined jute canvas or cloth bags prolongs the longevity of wheat or rice seed by four to six months than when the grain is stored in similar bags without polythene lining. However, for storing in polythene-lined bags, seeds must be dried well to 10% (or less) moisture. Polypropyline/polyethylene interwoven bags are also used. *Pusa Kothar,* a structure made of unbaked bricks and mud plaster with polythene lining, is effective for seed storage. Polythene lining is used to cut-off gaseous exchange.

Hermetic Storage of Rice Grain: Options for Small Farmers

Hermetic or sealed storage has gained importance in Asia to combat insect damage during medium-and long-term storage of paddy grain. The technique reduces reliance on chemical pest control during seed storage. At the International Rice Research Institute (IRRI), Philippines, research is underway to provide rice farmers with low-cost sealed storage devices for farm-level seed preservation. Some of these devices (e.g., recyled oil containers, recyled PVC containers, and modified clay pots) that hold 25 to 250 kg seed are being evaluated. Storing grain in recyled containers or modified clay pots results in similar conditions as commercial hermetic storage units. In collaboration with the private sector, sealed storage devices that can hold 200 kg to 5 tons seed are being evaluated. A crucial requirement for succcessful hermetic storage is sufficiently low seed moisture content. A low-cost seed dryer for 100 to 250 kg paddy seed has been developed and is being tested and demonstrated in several countries.



Modified clay storage pot

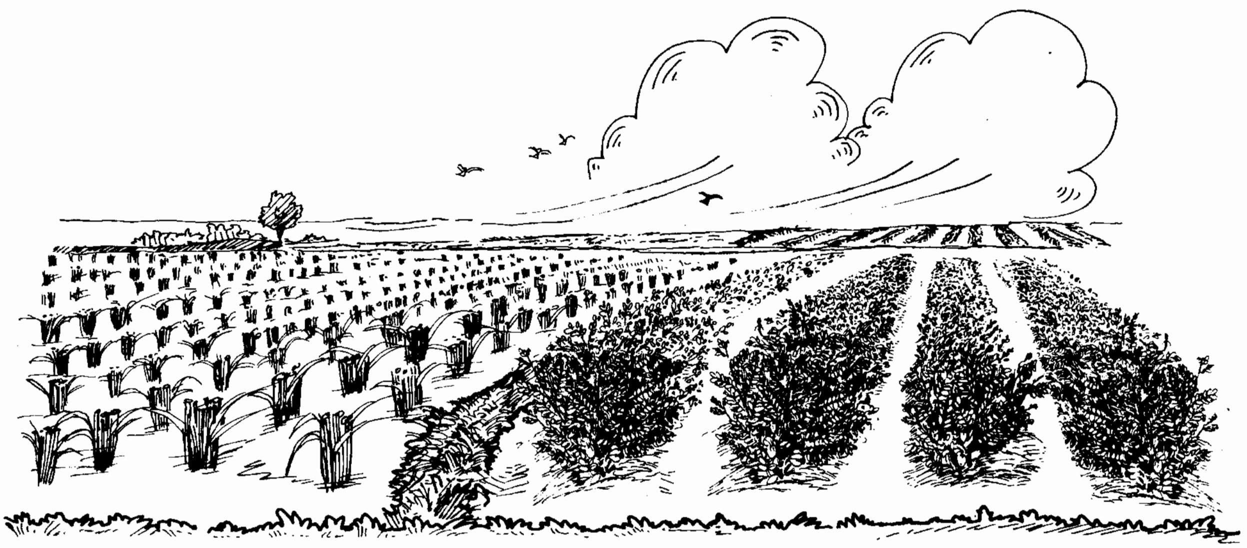
(Contributed by: Joseph F. Rickman, IRRI, Phillipines. Email: J.Rickman@cgiar.org)

Mid-storage and Invigoration Treatments

When seed is stored for more than one season, it should be sun-dried with or without prior hydration after the monsoon. The moisture gained by the seed is thus lowered and pests and pathogens are controlled. At this time, the seed can also be re-fumigated before storage. Seed treatment with fungicides (Thiram, Captan, Captof) at 2.5 g per kg seed, prior to sowing helps in controlling soil-borne pathogens resulting in better plant stand. In Pakistan, Baytan, Benlate, and TopsinM at 1 to 1.5 g per kg seed, prior to sowing is practiced for certified seed. A short hydration treatment of wetting seed for 3-4 hours, followed by drying back to a safe moisture level, improves subsequent storability of seed.

Contributed by:
Malavika Dadalani, Md. Syedul Islam,
Iftikhar Ahmad and **Gautam Buddha Manandhar**

Utilizing Rice-Fallows in South Asia:
A Potential for Legumes



South Asia is one of the major rice producing regions of the world, with around 50 million ha planted with rice. A substantial proportion of this area is under only a single crop, usually kharif (rainy) season rice, with the land being left fallow during the following rabi (post-rainy) season. This situation largely occurs for rainfed rice, where irrigation facilities for either rice or a post-rice crop are not available. Nevertheless, residual soil moisture, derived from the previously-flooded ricefields that could support growth of a short-duration (legume) crop after rice, is available even in the rabi season.

Large areas of land lying fallow for a long period after kharif rice during the year are particularly a cause of concern in South Asia, for two main reasons. Firstly, the large and growing population of the region requires ever-increasing quantities of locally-available food grains, and fallow lands on which crops could potentially be grown represent under-utilization of agricultural land resources. Secondly, continuous cereal cropping is unsustainable over a period of time and some form of crop rotation or diversification is desirable for sustaining the agricultural production system.

Precise estimates of rice-fallows and their spatial distribution were not available. Rice-fallows in South Asia have been quantified by using satellite image analysis and their spatial distribution documented. Using geographical information system (GIS) tools, spatial distribution of the rice-fallow was overlaid on to the climatic and soil information data to understand the soil types and climatic conditions of these areas. This information is critical for developing strategies to utilize

Potential Legumes for Rice-Fallows

- Chickpea
- Lathyrus
- Lentil
- Mungbean
- Black gram

these lands for short-season crops (e.g., legumes) that are suitable to the climatic and soil conditions of this region. Legumes may not require supplemental irrigation and they enrich the fertility status of the soils by fixing atmospheric nitrogen and adding organic matter. They help in sustaining the rice-based cropping systems by breaking pest and disease cycles associated with sole rice systems. They also enhance the microbiological activity and thereby increasing the nutrient availability in the soils following rice.

Satellite image analysis estimated that rice area during 1999 kharif season was about 50.4 million ha. Rice fallows during 1999/2000 rabi season were estimated at 14.29 million ha. This amounts to nearly 30% of the rice-growing area. These rice-fallows offer a huge potential niche for legumes production in this region. Nearly 82% of the rice-fallows are located in the Indian states of Bihar, Madhya Pradesh, West Bengal, Orissa and Assam.

Estimates of Rice Areas and Rice-fallows Based on Satellite Image Analysis

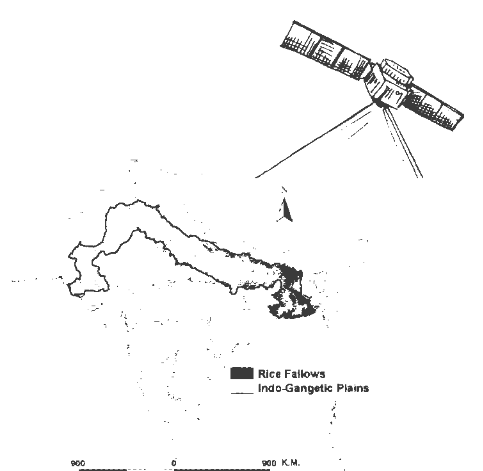
Country	Rice area* (million ha)	Rice-fallow** (million ha)	Rice-fallow as % of rice area	% total rice-fallow in South Asia
Nepal	1.45	0.39	26.9	2.7
Bangladesh	6.36	2.11	33.2	14.8
Pakistan	2.45	0.14	5.7	1.0
India	40.18	11.65	29.0	81.5
Total	**50.44**	**14.29**		

* During 1999 kharif season
** During 1999-2000 rabi season

The GIS analysis of these fallow lands has indicated that they represent diverse soil types and climatic conditions; thus a variety of both warm season legumes (such as soybean, mungbean, black gram, pigeonpea, and groundnut) and cool season legumes (such as chickpea, lentil, lathyrus, faba bean, and pea) can be grown in this region. Available soil water-holding capacity (1 m soil profile) for most of these lands ranges from 150mm to 200mm. If it is assumed that the soils in these lands are fully saturated during most of the rice-growing season, the residual moisture left in the soil at the time of rice harvest will be sufficient to raise a short-season legume crop.

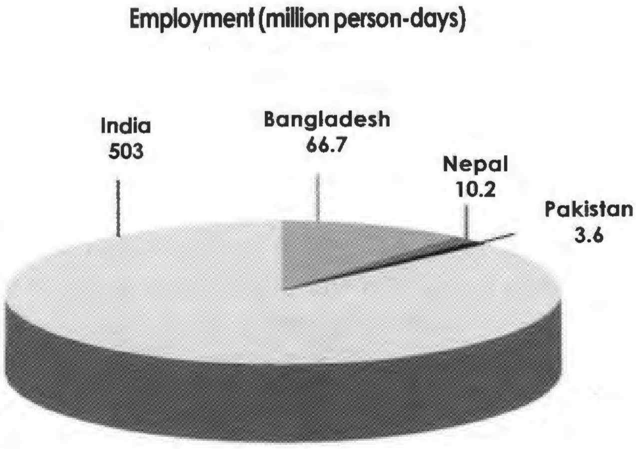
Methodology for Estimating Rice-Fallow Area Using Satellite Image Analysis

Satellite remote sensing is an appropriate tool for deriving information on spatial and temporal domains by providing multi-spectral reflectance data at regular intervals in a synoptic mode. Also, satellite data are amenable to geo-referencing, thus making it compatible for analysis by GIS. The rice acreage and production at district, state, and national levels are being routinely generated with the techniques developed and tested under Crop Acreage and Production Estimation (CAPE) project using single date Linear Imaging Self Scanning Sensor (LISS-I/II) data of Indian Remote Sensing Satellite (IRS 1A/1B).



A number of abiotic (soil acidity, salinity, alkalinity, and terminal drought), biotic (diseases and insect pests) and socioeconomic (social unrest, lack of awareness of legume technologies among farmers, and lack of effective policy initiatives to promote legumes) constraints contribute to the lack of cropping during this period in this region. These will have to be addressed by appropriate research and policy initiatives in addition to developing suitable legume varieties that have targeted adaptation to these rice-fallows.

A review of existing technologies indicates that it is possible to productively cultivate legumes in most of these identified rice-fallows. An economic analysis has shown that growing legumes in rice-fallows is profitable for the farmers with a benefit-cost ratio exceeding 3.0 for many legumes. Also, utilizing rice-fallows for legume production could result in the generation of 584 million person-days employment for South Asia. Thus, introducing legumes into these rice-fallows will have a multi-faceted impact on the economy through employment generation, poverty alleviation, food security, quality of nutrition to human and animal population and contribution to the sustainability of these production systems in South Asia.



Adapted from:

Subbarao, G.V., J.V.D.K. Kumar Rao, J. Kumar, C. Johansen, U.K. Deb, I. Ahmed, M.V. Krishna Rao, L. Venkataratnam, K.R. Hebbar, M.V.R.S. Sai and D. Harris. 2001. Spatial Distribution and Quantification of Rice-Fallows in South Asia: Potential for Legumes. ICRISAT, Patancheru, India. 316 pp.

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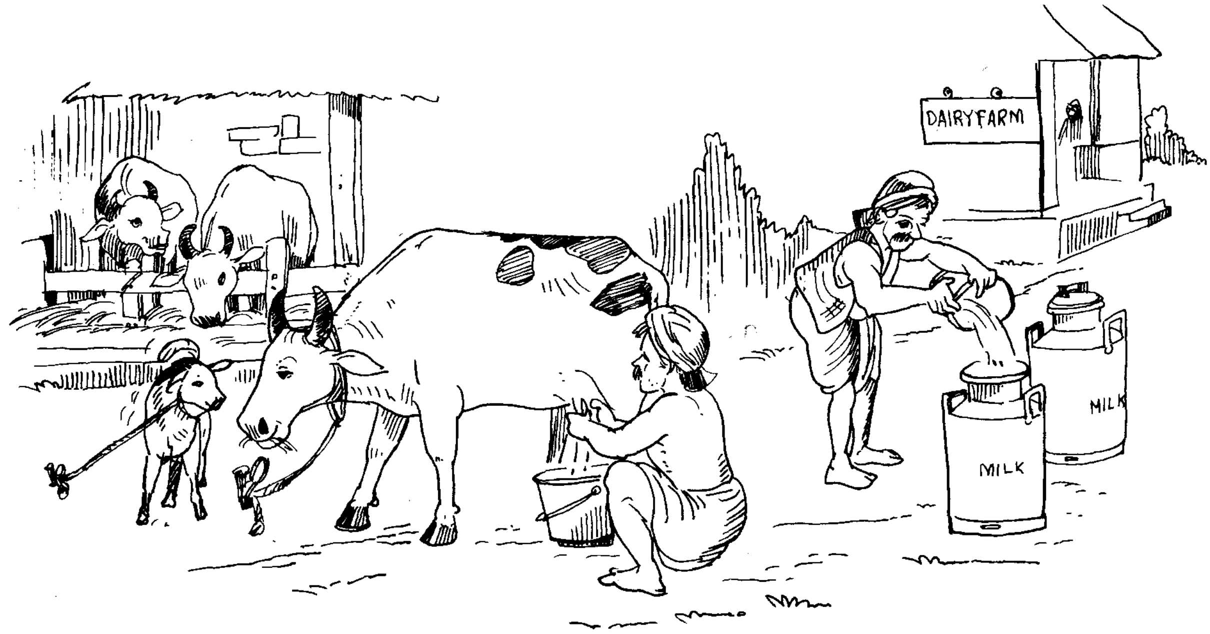
J.V.D.K. Kumar Rao

Role of Livestock in Sustaining the Farming Systems in the Indo-Gangetic Plains of India



The mixed crop-livestock farming system in the Indo-Gangetic Plain (IGP) stretching across India from Punjab in the Northwest to West Bengal in the southeast, account for 53% of all food grains supply in 1995. Nearly two-thirds of the cropped area in this system is under rice and wheat rotation. The total crop residue thrown up by the system is 241 million tons; it includes 85 million tons of wheat straw, and 21 million tons of sorghum/pearl millet/maize straw.

Over 70% of the landholdings in the IGP are made up of traditional mixed farms, owned by small and marginal farmers. Recyling of crop residues as ruminant fodder and farmyard manure for soil enrichment has been a traditional practice for natural resources management and continues to be crucial to their survival and progressive viability. Progressive mechanization of farm operations and replacement of draught animals by farm machines have not resulted in overall reduction in the livestock population in the IGP.

Livestock Population

Among livestock, cattle and buffalo are the preponderant and the most interactive species, subsisting on crop residues (exept in the intensive production areas of Punjab and to some extent in Haryana) and contributing milk, meat, farm power, and farmyard manure. The five states forming the IGP in India accounted for 44% of the total milk output in the country in 1995. The ruminant population in the region includes 69.86 million (34%) cattle, 36.72 million (44%) buffalo, 46 million (40%) goat, and 6.80 million (13%) sheep according to the 1992 Livestock Census.

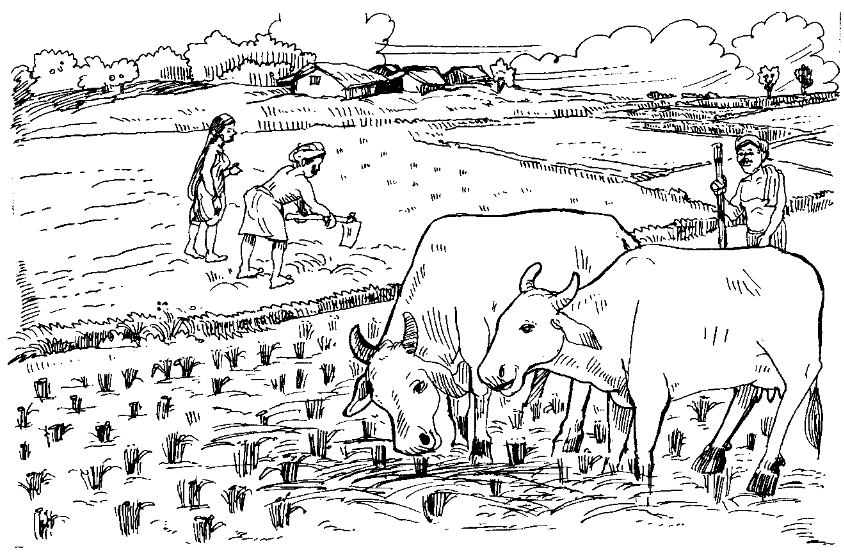
Changes that affect the crop-livestock farming system in the IGP most are those related to the large ruminants (cattle and buffalo). Overall cattle and buffalo population in the IGP states increased substantially, even though the quantum of increase varied widely between states and between categories within species. In 1972, the male:female ratio in the IGP (excluding Bihar) was 1:0.75 among cattle and 1:2.94 among buffalo while in 1992 the ratio was 1:1.38 among cattle and 1:3.55 among buffalo, clearly indicating a shift in favor of milch animals over draught animals even among cattle. The trend is common in all states, the change being most pronounced in Punjab.

Change (%) in the Composition of Bovine Population in IGP, 1972-92

State	Cattle			Buffalo		
	Male	Female	Total	Male	Female	Total
Punjab*	-62.94	+33.46	-22.14	-1.92	+78.92	62.58
Haryana	-39.40	+17.91	+12.98	+105.11	+67.34	73.67
Uttar Pradesh	-12.31	+15.47	-2.23	+49.88	+62.85	59.50
West Bengal	+19.42	+72.94	+44.50	+13.97	+32.03	19.63

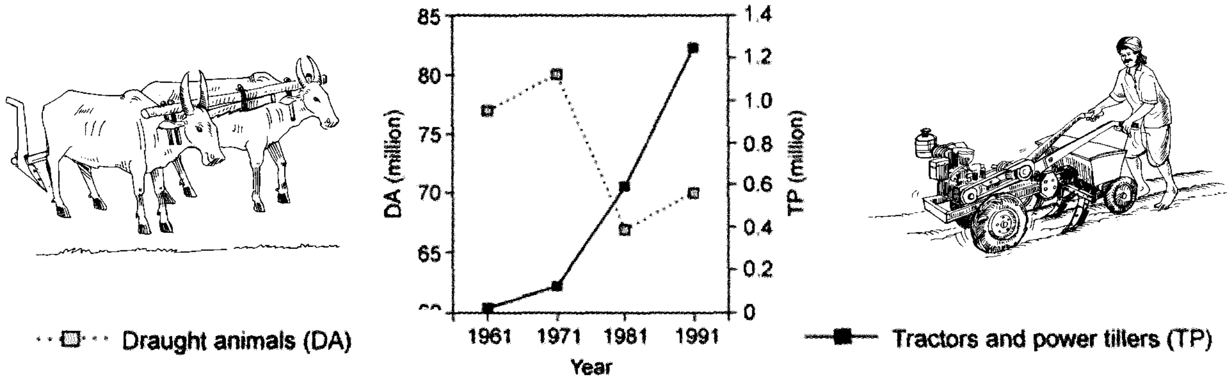
*Analysis is based on 1997 Livestock Census

Livestock farming is intensive in Punjab with high inputs of feed and cultivated fodder. But it is less intensive in Haryana and western Uttar Pradesh with diminishing dependence on crop residues. In the rest of the IGP, ruminants subsist largely on grazing and crop residues. The productivity of cattle and buffalo in Punjab is high; more than 70% of the cows are high-yielding cross breeds and the milch buffaloes are high-yielding Murrah and Nili-Ravi.



Declining Crop-Livestock Interaction

Progressive replacement of draught animals by electrical and mechanical sources of power, diminishing reliance on crop residues as ruminant fodder, large-scale burning of straw, and progressive decline in recyling of farmyard manure for enriching soils have all upset the traditional symbiotic interactions between crops and livestock in the small holder, mixed farming systems in the IGP. Use of draught animals for farm power varies widely in the different regions of the IGP: very low in the trans-Gangetic area, medium to high in upper Gangetic area, and high in the middle and lower Gangetic plains.



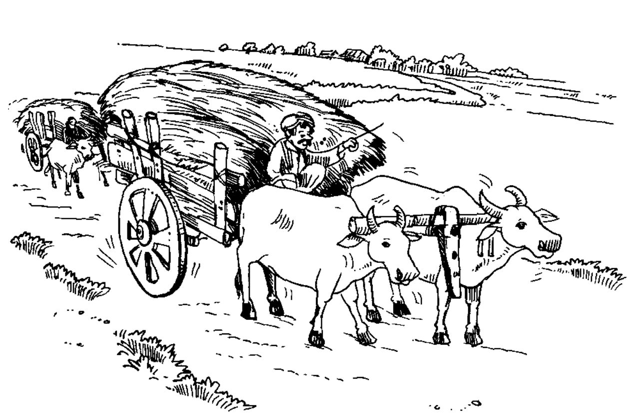
Draught Animals and Tractors in India

Areas Needing Emphasis for Sustainability of Crop-Livestock System

Crop residue use for ruminant fodder can be optimized by processing and value addition to increase nutrient content and to improve their storage and transport properties. Traditionally, farmers do not use rice straw for ruminant feeding or for improving soil health and texture. Wheat straw is fed to livestock and is not associated with any adverse effects in animals. More than 70% of the rice straw and about 50% of wheat straw produced is routinely burned *in situ* in the trans- and upper Gangetic area. Almost the entire quantity of millet straw is utilized by the farmers for ruminant feeding, especially for feeding buffaloes.

Straw Production and End Use in Punjab, India

Description	Rice straw	Wheat straw
Production ('000 t)	9852	18972
End use (% to total)		
Fodder	6.5	42.6
Manure	0.9	0.2
Burned	81.4	48.2
Sold	4.8	8.1
Miscellaneous	5.8	1.0

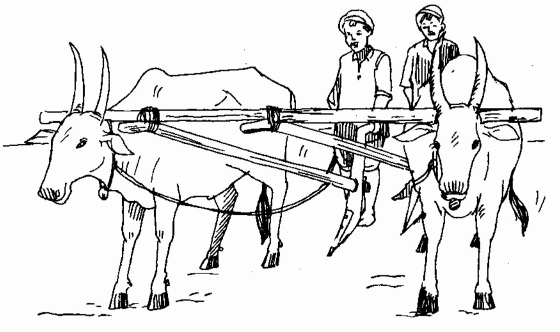


Interventions for efficient recycling of farmyard manure, enabling its dual use as a source of household fuel at the same time conserving its manure qualities, will enhance crop-livestock interaction and will be a crucial factor in assuring the sustainability of the farming systems in the IGP. Using the accumulated manure for biogas production saves it from burning and makes it available for meeting the fuel requirement of the farm household, while making it still available for recyling as manure and enriching the soil and improving its texture. Development of appropriate technologies for the efficient utilization of the slurry need to be developed.

Strategic interventions for germplasm enhancement among livestock, particularly cattle and buffaloes, are the most critical factor for improving the sustainablilty of the livestock subsystem in the IGP. Institutional change and policy support are prerequisites for improving AI (artificial insemination) services for quality genetic inputs and for quality assurance.

Effects of Rationalization of Draught Animal Use for Farm Power

- More efficient use of draught animals.
- Increase in their output while reducing their numbers.
- Progressive reduction in bovine population size.
- Reduction in livestock load on land.
- Freeing feed and fodder for optimal feeding practices in the livestock production system.



Adapted from:

Rao, P.P. 2002. Role of Livestock Subsystem in Sustaining the Mixed Crop-Livestock Farming Systems in the Indo-Gangetic Plains in India. Paper Presented at the Rice-Wheat Consortium Regional Technical Coordination Committee Meeting. 10-13 February 2002. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

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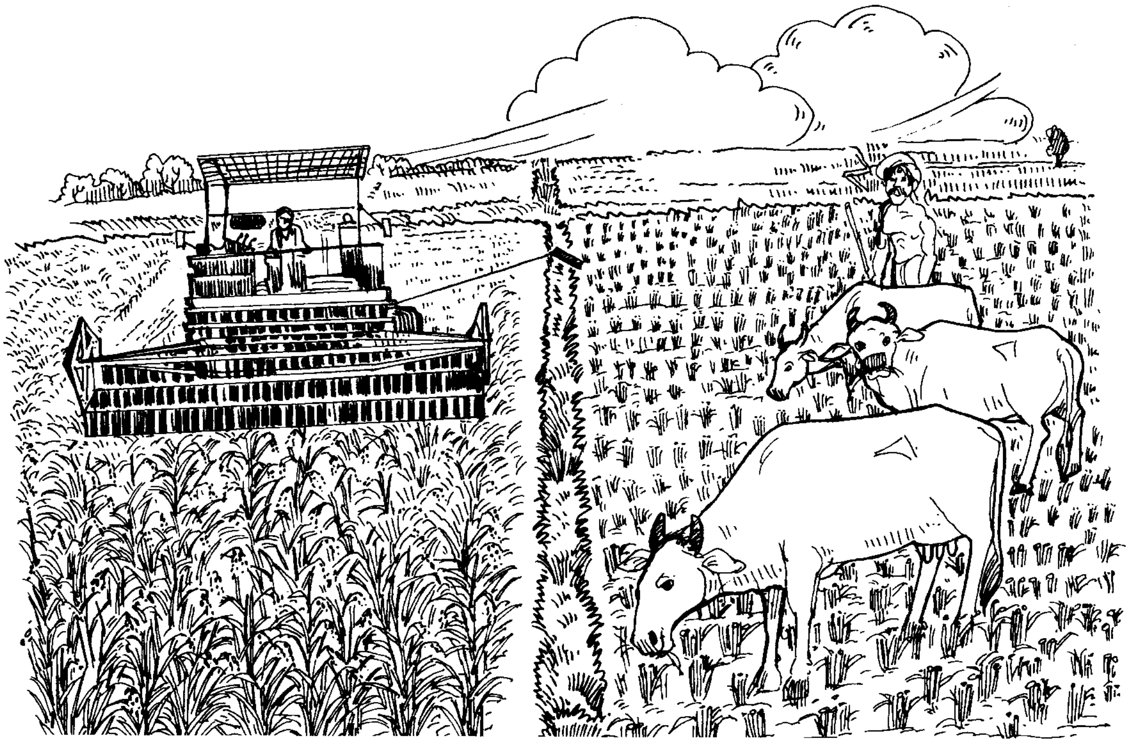
Crop Residues as Animal Feed



Rice and wheat are the most important crops in India and have enabled the country to attain food and fodder security during the past three decades. These two crops produce a large amount of straw. Due to increased mechanization of harvesting cereal crops, large amounts of straw are left in the fields. Combine harvesting of rice and wheat is increasing rapidly in India. In the northern states of Punjab, Haryana, Uttar Pradesh and Uttaranchal, the traditional harvesting using sickle has been replaced largely by combine harvesting. The large amount of 'header trash' left by combine harvesters must be removed from the fields for agronomic or management reasons. Farmers using combine harvesters normally burn straw in their fields. The practice of burning reduces the availability of straw to livestock which is already in short supply by more than 40%. Burning also results in loss of valuable organic carbon necessary to maintain soil health and it also increases environmental pollution.

Crop Residues in Plenty for Disposal

For every 4 tons of rice or wheat grain, about 6 tons of straw is produced. In 2000, the total agricultural residue production in India was 347 million tons of which rice and wheat straw amounted to more than 200 million tons.

Straw Collection System

The huge amount of straw which is wasted either by burning in the fields or due to poor utilization could contribute to the income of Indian farmers. Conservation of rice and wheat straw as a livestock feed and/or its utilization as industrial raw material requires a series of on-farm and off-farm operations including collection, packaging, handling, transportation, storage and pre-feeding processing.

Because of the low bulk characteristics and low market value per unit weight of crop residue, handling and transportation is generally uneconomical. Hence, farmers opt for open field burning as a perfect solution although it results in great economic losses. Appropriate straw recovery systems for collection and utilization of straw as livestock feed or as industrial raw material are essential.

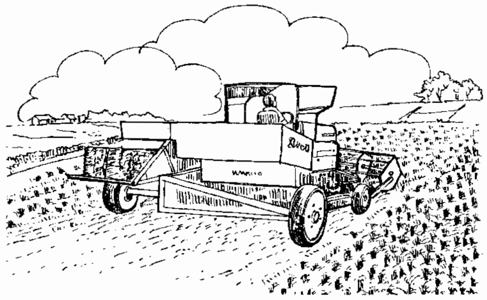
Increasing labor wages and labor shortage prevents timely manual harvest in major rice-wheat growing areas of India. Self-propelled and tractor mounted combinations are being used; though these incur high capital cost, they remain economical when compared to other options available. Combines with *bhusa* (straw) making attachment were introduced but these are not popular as the combine capacity gets reduced to half.

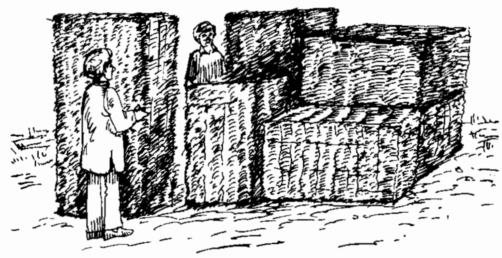
Straw Combines

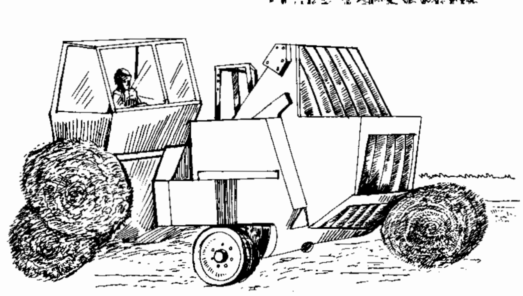
Straw combines harvest the wheat crop residues after combining and convert them into bruised straw called *bhusa*. These combines are economical for farm size of 100 ha and up to a distance of 15 km, as 45% of the total cost is for transporting and unloading. Cost of straw recovery is Rs 600 per ton.

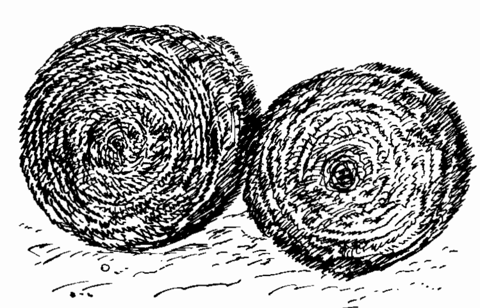
For collection of straw after combining, imported conventional field balers have been introduced by three firms. These balers, however, recover only about 25% to 30% of potential straw yield after combining depending upon height of plant cut by combines. Baling cost is Rs 800 per ha. The total cost of operation including baling, collection, transportation up to 5km distance, and stacking is Rs 1300 per ha or Rs 650 per ton of straw. Cost could be further reduced by exempting the present custom duty of Rs 100,000 on import of baler, reducing height of plant cut up to permissible limit, and improving collection system for bales by using specialized trolleys. Baling of straw is done either by conventional field balers that produce rectangular bales or by balers that produce round (big roll) bales. In India, conventional field balers that produce bales of 36 x 46 x 110 cm size are presently available.

The field balers should be operated over 400 ha annually (1:2 rice and wheat) to break-even with existing harvest prices and price of straw. For long distance transportation of straw, further densification of bales by 2-3 times (bulk density of 250 to 300 kg/m^3) would be necessary for economical transport. Imported bales compactor with retying arrangement would be useful.









Utilization of Straw for Livestock Production

The straw collected from the fields is of great economic value as livestock feed, fuel and industrial raw material. Cereal straws are, however, low quality feeds with low nutritional value. Leaves are more nutritive than nodes and internodes. Also, the upper portion of the plant has higher nutrition than the lower portion. Preference for rice or wheat straw depends on the availability and customs of farmers. In North India, wheat straw is preferred while in South India rice straw is fed to livestock.

Agricultural residues are low quality fodder with low nitrogen and high lignin contents. These two factors are responsible for their poor digestibility and low intake and consequently low productivity of livestock. Several chemicals such as sodium hydroxide and ammonia in anhydrous or aqueous forms have been used to improve the nutritive value of straw. However, urea as a source of ammonia is the best for treatment of straw in India because of its ready availability, and conversance of farmers with its transport, storage, and application. Ammonia (urea)-treated straw is superior to untreated straw in terms of digestibility, intake of nutrients, growth of animals, and milk production. Livestock on-farm feeding trials of ammonia (urea) treated baled wheat straw with 2 kg green fodder + 30 g salt to meet the full energy need of heifers of 15 to 20 months age have shown a saving of more than 25% in concentrate mixture for the same growth rate. Similarly, milk production increased by more than 30%.

New Method for Treatment of Baled Straw

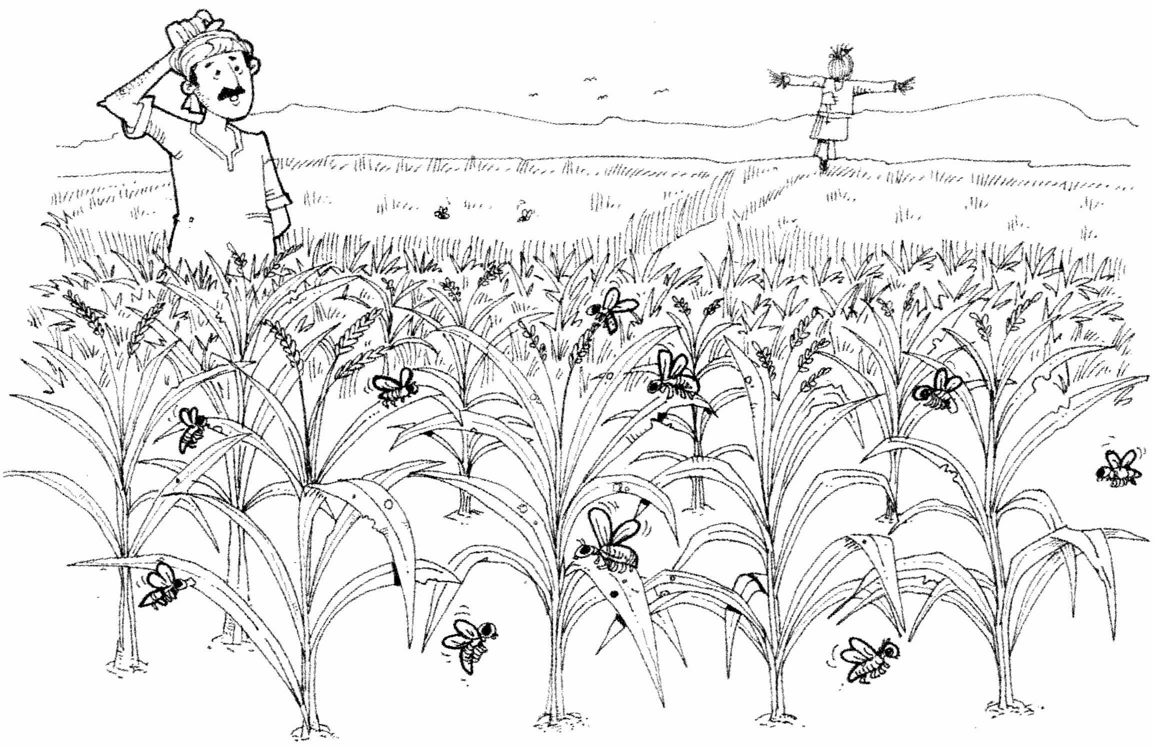
On-farm treatment of loose straw with urea is well-established. Recently, "Dripping Method" for ammonia (urea) treatment of 4 to 5 tons of stacked bale straw (i.e., 216 bales of 36 x 46 x 90 cm size placed in 6 layers up to 2 m height) has been succesfully developed at Pantnagar and is being commercialized. The cost of treatment is Rs 350 per ton.

Adapted from:

Thakur, T.C. 2002. Mechanized Systems for Rice-Wheat Straw Recovery after Combining and Utilization of Straw as Livestock Feed. Paper Presented at the Rice-Wheat Consortium Regional Technical Coordination Committee Meeting. 10-13 February 2002. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

Corresponding author:
T. C. Thakur

Integrated Pest Management of Rice in Rice-Wheat Cropping Systems



The dynamics and severity of pest attack has shifted with the adoption and spread of rice-wheat crop rotation in the Indo-Gangetic Plains during the last three decades. Excessive use of chemicals for pest control in agriculture is known to degrade the environment. Integrated Pest Management (IPM) involves a proper choice and blend of compatible tactics (cultural, mechanical, biological and chemical) so that the components complement each other to keep the pest population at manageable levels.

Implementation of IPM in Rice

Although Integrated Pest Management (IPM) is accepted in principle as the most attractive option for the protection of agricultural crops from the ravages of pests, its implementation at the farmers' level is rather limited. Pesticides still remain as the means of intervention and as an essential component of IPM strategies.

It may not be possible to avoid chemical pesticides altogether but integrating non-chemical methods in pest management can reduce dependence on chemical control. This would reduce the costs considerably besides offering protection in an ecologically sound manner. In rice, the cost of average pesticide application is Rs. 163.50 and Rs. 447.90 per hectare respectively for IPM trained and untrained farmers.

Components of Integrated Pest Management (IPM)

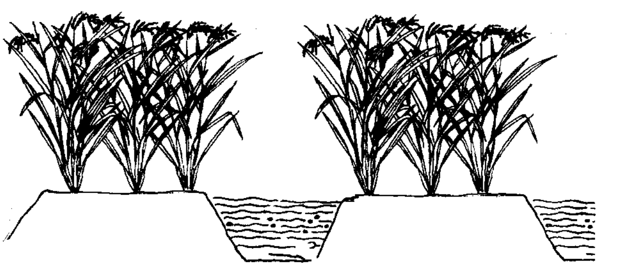
Pest-Resistant Crop Varieties

This is the easiest, effective, compatible, economical and practical method among all the pest management practices. Such crop varieties are extensively used in pest-prone areas as a principal method of IPM or as a supplement to other pest management strategies. It can counter the pest problems and is free from all adverse effects of pesticide use. A number of resistant varieties, with single or multiple resistance to insect pests, mites and nematodes, are commercially available. These varieties have high yield potential and possess desired agronomical characteristics.

Cultural Methods

These refer to good agronomic practices that enhance the crop productivity and also suppress the pest population. The cultural practices which are commonly used for rice in rice-wheat systems are:

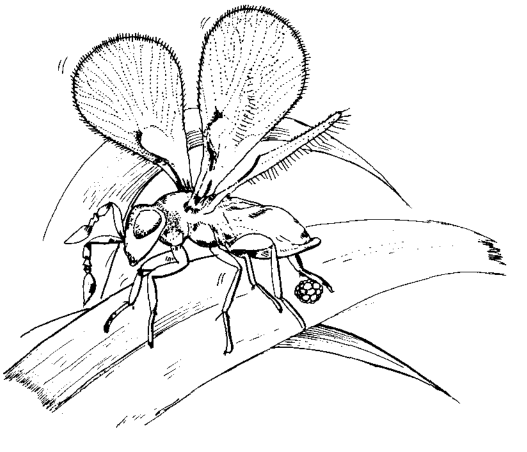
- **Proper Sanitation** – Timely removal of weeds to reduce the pest survival and reduce the chance of any carryover of the pest.
- **Proper Water Management** – Timely irrigation and good drainage system is required to control plant hoppers.
- **Proper Spacing** – Provision of alley ways of 30cm. width after 2-3m or bed planting particularly in the White backed plant hopper and Brown plant hopper prone area, proves helpful.



- **Timely Planting** – Timely and synchronous planting can reduce the occurrence of insect pests like Yellow stem borer, Gall midge, Brown plant hopper, White backed plant hopper and Green leaf hopper.
- **Balanced Fertilizer** – Judicious and optimum dose of nitrogen and other fertilizers based on soil testing is essential. Split dosage of nitrogen can also reduce the risk of Gall midge, Leaf hopper, Brown plant hopper, White backed plant hopper and Green leaf hopper.

Biological Control

Biological control is the mainstay of the IPM strategy. Out of 100 phytophagus insects having potential of becoming pests, only a few attain the pest status while the rest are kept under check by their natural enemies. Even those which attain the pest status have biological agents like predators, parasites and pathogens which decrease their population in the rice ecosystem. It is very important to conserve the natural enemies of pests in the field. Avoid the use of broad spectrum pesticides when natural enemies are abundant.



However, it is observed that inundative release of egg parasite, *Trichogramma japonicum* that *T. chilonis* is really an effective approach to decrease the Yellow stem borer or Leaf folder incidence. It is also observed that a very high count of *Trichoderma viridae* and a few bacterial antagonists are effective against fungal pests.

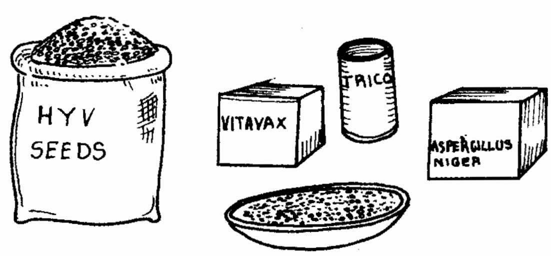
Chemical Control

Application of pesticides is no doubt one of the quickest and, sometimes, the only solution for the sudden outbreak of pests, specially insect pests. Their application draws the farmer to quick and visible action. However, their prophylactic usage is not economically and environmentally sound.

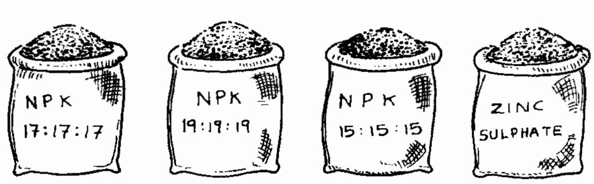
The IPM Approach

IPM is a knowledge-based technology and it is now an in-built component of crop improvement research and its various disciplines. Several technologies are available for implementation of IPM. Many of them are outcome or consequence of the failures of those technologies that had been in practice and/or a refinement of a successful practice. Presently, the available technologies aim to provide an ecologically-sound pest management program with sustainable use of renewable natural resources and comprise the following practices for rice in rice-wheat systems.

1. Use of the improved crop variety which is recommended for the area.
2. Sowing of seed at the proper time and at recommended rate.
3. Soil solarization in the nursery bed.
4. Seed treatment with Vitavax @ 2.5gm/kg seed, *Trichoderma sp.* @ 4gm/kg seed and *Aspergillus niger* @ 8gm/kg seed.



5. Use of balanced fertilizers, preferably as NPK granules and zinc sulphate.
6. Hand weeding/application of herbicide Butachlor @ 1.5kg/ha or Anilophos @ 0.4 kg/ha within 2-3 days of transplanting.



7. Release of egg parasite *Trichogramma japonicum* @ 150,000/ha at days interval for 2-3 times.
8. Selective application of chemicals as a last resort depending upon the pest attack.

Availability of IPM technology alone is no guarantee that it will be highly effective and economical. There is a strong need for farmer participation. The research and extension agencies have to ensure that quality inputs needed for IPM are easily and economically accessible to the farmers. Awareness must be created among farmers for community level IPM that will save their resources, manpower and environment. There is a strong need to develop forecasting and forewarning models on the basis of climatic variability.

Success Story of IPM in Basmati Rice

Many insect pests attack basmati rice in the predominantly basmati rice growing areas in the states of Haryana, Uttar Pradesh and Punjab in India. Leaf folders, *Cnaphalocrocis medinalis* and yellow stem borer, *Scirpophaga incertulas*, are the major insect pests in Haryana. Among diseases, blast is the most important one followed by bacterial leaf blight. For controlling these pests, farmers follow chemical control methods which are quite expensive and often lead to pesticide residue problems.

Pesticide residues adversely affect the export potential of Basmati rice. To overcome these problems, an IPM module was developed. The module was field tested from 1994 to 1996 by the National Center for Integrated Pest Management, New Delhi, in collaboration with Rice Research Station, Kaul, in the Haryana State of India. A popular basmati rice variety in the area, Taraori, was chosen for experimentation and raised according to normal agronomic practices followed in the region. The IPM strategy consisted of the release of *Trichogramma japonicum*, spraying of neem-based pesticide, and use of insecticidal spray only as the last resort. For blast, application of burnt rice husk, which induces resistance to the disease, and need-based application of fungicide were the main components. The IPM treatment was compared with sole pesticide treatment and untreated control. The results showed that the IPM approach reduced the infestation of leaf folder and stem borer effectively and it was almost at par with the insecticidal application during all the three years. The chemical control gave the highest yields of 31.51, 34.33 and 28.25 q/ha, compared to the 29.89, 31.96 and 28.55 q/ha in IPM treated fields during 1994, 1995 and 1996, respectively. However, economic analysis indicated that the IPM method was superior to the chemical control method, as the mean cost benefit ratio of IPM over untreated control was 1:5.70 as compared to 1:5.03 of the chemical control method.

On-farm trial of this IPM technology was carried out during the monsoon season of 1997 at Baraut, which is emerging as a potential Basmati-producing area in Uttar Pradesh State of India. The continuous monitoring of pests showed moderate to high incidence of leaf folder and low incidence of stem borer in this area. The incidence of sheath blight was also noticed but did not warrant fungicidal application. However, timely field release of *Trichogramma japonicum* in IPM fields suppressed the incidence of leaf folder and stem borer to a bare minimum. Overall, results showed the superiority of IPM over chemical method or farmers' own practices as indicated by the yield data and economic analysis.

Important Pests of Rice in Rice-Wheat Cropping System

Common name	Scientific Name	Symptoms	Intensity	Change
Insects				
Leaf folder	*Cnaphalocrosis medinalis*	Folds leaves and remains inside, scraping the green tissues between the veins making the leaves white and papery and can give scorched appearance on drying up.	*****	+
Brown plant hopper	*Nilaparvata lugens*	Plants become yellow and die. Insects congregate in large numbers, causing hopper burn in circular patches.	***	↑↑↑
White backed plant hopper	*Sogatella furcifera*	Hopperburn frequently appears uniformly over large areas. Insects suck sap causing reduced vigor, stunting, yellowing of leaves, delayed tillering and grain formation.	*****	↑↑↑

Common name	Scientific Name	Symptoms	Intensity	Change
Insects				
Green leaf hopper	*Nephotettix virescens*	Important vector of viruses that cause rice dwarf, transitory and yellowing, tungro and yellow dwarf disease.	****	↑↑↑
Rice hispa	*Dicladispa armigera*	Linear patches along the veins. The yellowish grubs mine into the leaves presenting blister spots. Feeds on the chlorophyll. As a result, irregular/longitudinal white patches/blotches are produced.	**	↓↓
Diseases				
Bacterial blight	*Xanthomonas oryzae*	Typical vascular wilt disease. The partial or total blighting of leaves or complete wilting of affected tillers leads to unfilled grains.	*****	↑↑↑
Blast	*Pyricularia oryzae*	Reduces the number of mature panicles, grain and straw weight. Main attack is between seedling and maximum tillering stages and often plants die.	*****	↑↑↑
Sheath blight	*Rhizoctonia solani*	Seedling may be infected in the nursery. Infection starts at the base of plant and death of the seedling is observed. Seedling often observed only in patches.	****	↑↑
Brown spot	*Helminthosporium oryzae*	Innumerable dark brown elliptical spots are comon on leaves, stem and glumes. At maturity, these lesions/spots may exhibit a dark or reddish brown margin with light brown or grey centre.	***	↑
Falsesmut	*Ustilaginoides virens*	The affected grains are transformed into greenish black masses and in general only a few grains in a panicle are infected.	***	↑
Rice tungro virus	*RTV*	Stunting of the plant and discoloration of leaves characterize the infection. It reduces tillering, number and length of panicles and number of spikelets and also delays maturation.	**	↑
Nematode		Sedentary endoparasites of roots.		
Root-knot nematode	*Meloidegyne graminicola* *M. triticoryzae* *Rarely,* *M. javanica,* *M. incognita*	Hyperplasia of root protophloem and abnormal xylem proliferation causing swollen knots in stele; disruption and hypertrophy of root cortex; small galls with many females, curly or club shaped galls on root tips; stunted plants with chlorotic leaves; curling of leaves along midribs; poor tillering; shorter earheads with fewer poorly filled grains. Damage more in nursery, upland direct seeded rice and transplanted rice in well drained soils	**	+

* Very low to ***** very high intensity
\+ minor pest, becoming a major problem
↑↑↑ major pest increasing in economic importance
↓↓ major pest declining in economic importance
↑ increasing trend

Adapted from:

Sehgal, M., M.D. Jeswani and N. Kalra. 2001. Management of Insect, Disease and Nematode Pests of Rice-Wheat in the Indo-Gangetic Plains. Journal of Crop Production 4(1): 167-226.

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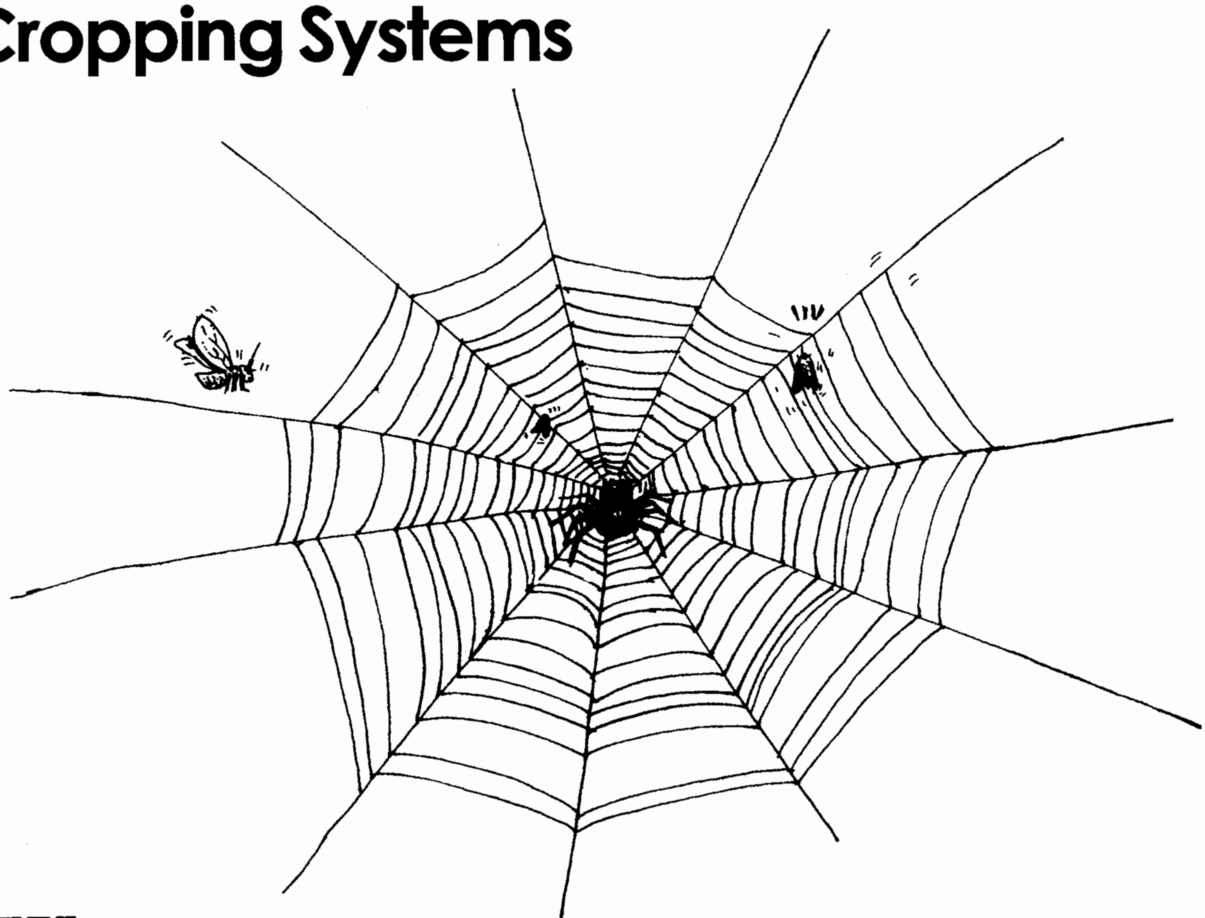
Integrated Pest Management of Wheat in Rice-Wheat Cropping Systems



Wheat sown immediately after harvesting rice is more susceptible to attack by diseases and pests due to the conducive micro-climate in crop profile and soil physical conditions developed by rice crop in the rice-wheat cropping sequence. Several insect species, hitherto having none or minor economic importance, are now serious pests of the wheat and/or rice in the rice-wheat sequence. The past decade is a witness to a number of outbreaks of sporadic pests like armyworm and cutworm. However, certain pests like shoot fly and aphids have become regular in occurrence. Termites continue to be serious pests in drier areas whereas Gujhia weevil, a serious sporadic pests of yesteryears, has assumed a non-pest status.

Pest-Resistant Varieties

The use of crop varieties resistant to endemic insect pests and diseases is one of the most effective, economical, practical and easiest means of countering the pest problems and keeping the environment free from adverse effects of pesticides. In recent years, breeders, with the help of pest managers, are developing wheat varieties which are specifically bred for resistance to a single or multiple diseases or pests. A number of resistant/moderately resistant varieties of wheat are available for reducing the damage by insect pests and diseases.

Control Methods for Insect Pests and Diseases

Cultural Methods

1. Destroy of above-ground termitaria located in and around cropped areas.
2. Hand pick borer-infested tillers and destroy them to reduce infestation by pink stem borer.
3. Remove and burn rice stubbles after harvesting in borer-infested fields.
4. Sow the crop early to reduce the shoot fly infestation.
5. Avoid irrigation at flowering stage to reduce the Karnal bunt disease.
6. Replace crop variety every of four to five years.
7. Do solarization, specially on hot and non-windy days during the summer months to manage the loose smut disease.

Biological Control

Biological control is a component of IPM which is potentially self-renewing and available to all farmers, rich or poor. A number of biological agents are available. Application of *Trichoderma pseudokonigii* and *T. lignorum* can reduce the build up of primary inoculum of Karnal bunt disease. A special strain of *Aspergillus niger* has proved very effective against soil-borne pathogens. Kalisena SD seed dressing reduces seed rotting, improves germination and enhances the yield.

Among insects, the Brown wheat mite is predated upon by another mite *Lasioseius terrestris* and lady bird beetle. Aphids are also predated on by Lady bird beetles.

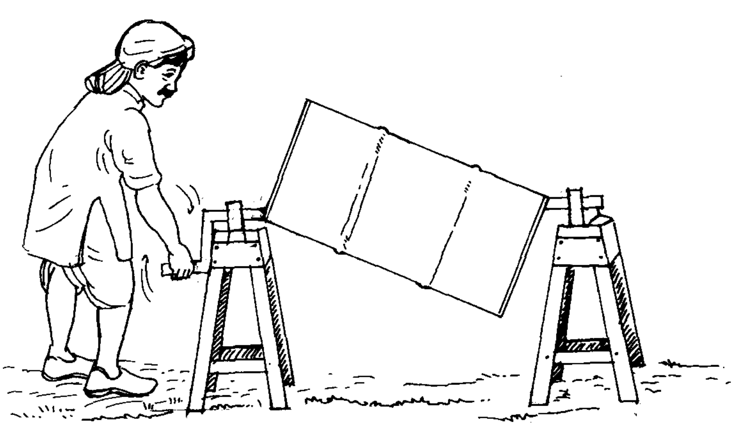
Chemical Control

Application of plant protection chemicals is done only as a last resort to prevent crop loss. Prophyllactic spraying is to be avoided.

Seed Treatment

- Treat the seeds with Chloropyriphos or Endosulfan 1-2 day before sowing in dry regions to control termites.

- Dress the seed with Carboxin or Carbendazim or rovl @ 2.5 gm/kg seed to help reduce Loose smut or Flag smut.

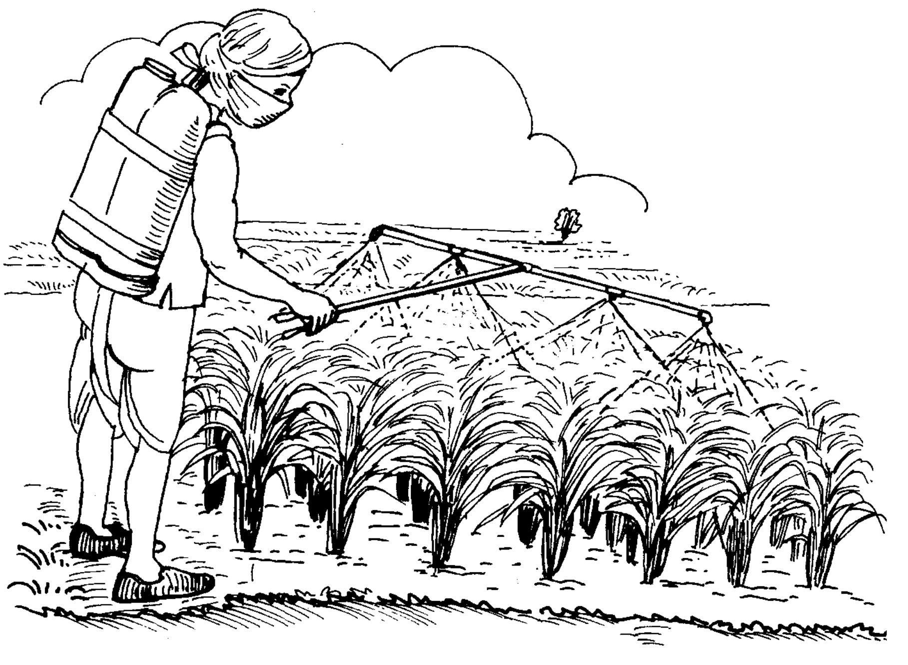


Soil Treatment

Broadcast Chloropyriphos @ 800 gm a.i. diluted in 5 liters of water and mixed with 50kg of loose soil per hectare to control termites.

Foliar Sprays

- Spray with Karathane 0.05% to control Powdery mildew.
- Spray Fenitrothion @ 500 ml a.i./ha or Fenitrothion or Carbaryl 1 kg/ha to control armyworms and cutworms.
- Spray Dimethoate or Oxydemetan methyl @ 375 ml/ha to control aphids.
- Apply Carbofuran @ 1.0 kg a.i./ha or spray Cypermethrin @ 50 gm a.i./ha to control shootfly.
- Dust with Carbaryl @ 25 kg/ha or spray with Malathion @ 25 kg/ha to reduce Gujhia weevil.
- Spray Phosphamidon @ 250 ml a.i./ha or spray Monocrotophos 200 ml. a.i../ha to help manage Brown wheat mite infestation.
- Spray Tilt 25 EC @ 500 ml/ha using 400 liters of water at ear emergence stage to control Karnal bunt.



Strategies for Intergrated Pest Management

- Remove stubbles and burn them to suppress the borer attack in endemic or infested areas.
- Use zinc phosphide to prevent rodent damage after earhead emergence.
- Destroy termitaria in the vicinity of field.
- Reduce the termite population by spot application of Lindane or Chlorpyriphos spray. For prevention of termite damage, treat seeds with Endosulfan or Chloropyriphos, 1-2 days before sowing.
- Use available biocontrol agents.
- Use only well decomposed manure.
- Avoid late sowing to reduce shootfly and aphid.

Important Pests of Wheat in Rice-Wheat Based Cropping System

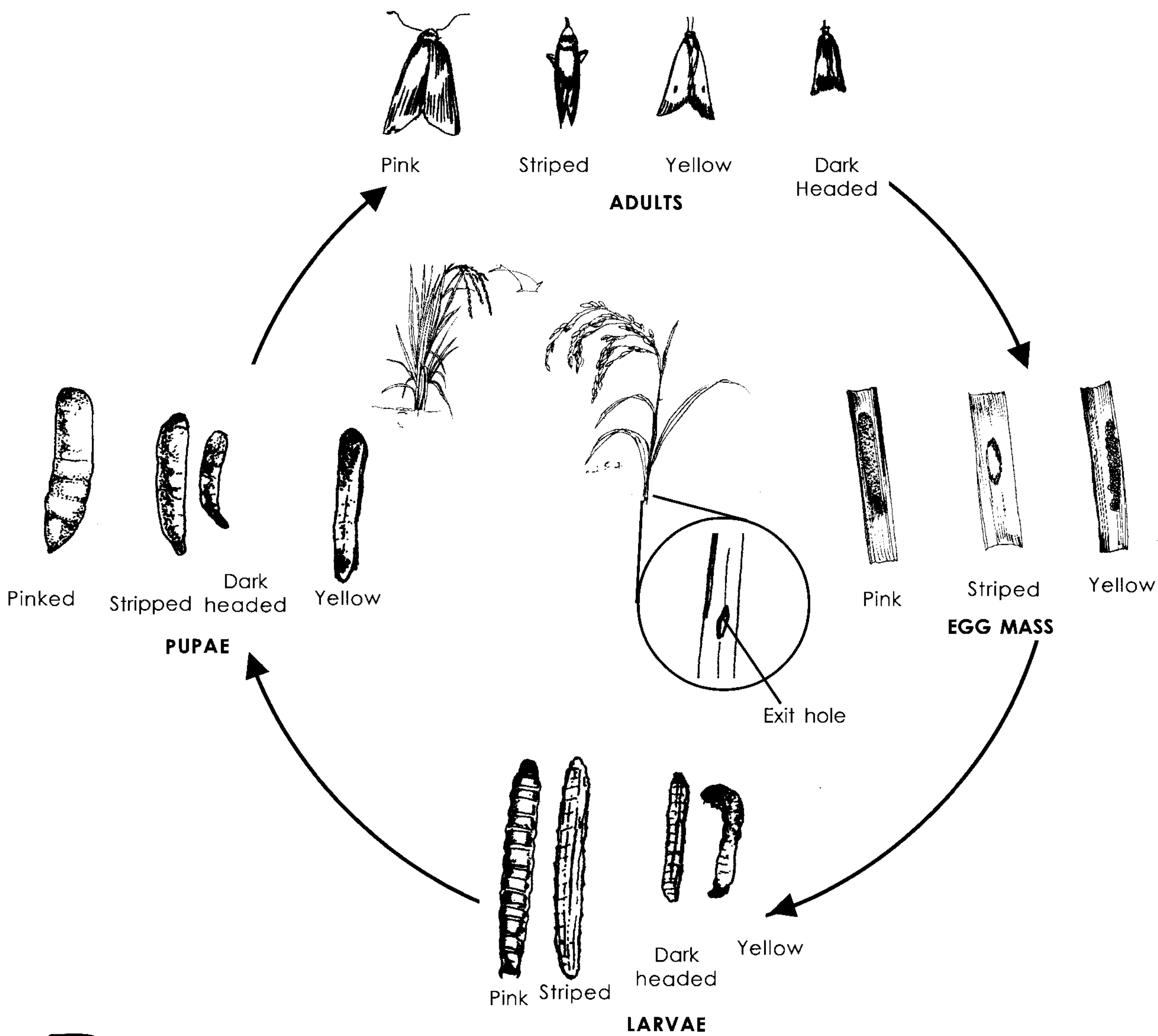
Common name	Scientific name	Disease / Symptoms	Intensity
Insects			
Termite	*Odontotermes obesus*	Worker termites feed on roots and underground parts of stem and result in drying up of plants and tillers.	***
Aphid	*Macrosiphum avenae*	Damage to the developing grain is serious, reduces the yield.	* *
Pink stem Borer	*Sesamia inferens*	Larva feeds within the stem resulting in empty white heads at crop maturity.	* *
Armyworm	*Mythimna separata*	Larvae that thrive and feed on the leaves may reduce the leaf number and sometime defoliate the leaves during night. It can also damage the earheads.	* *
Diseases			
Loose smut	*Ustilago tritici*	Symptoms of the disease appear only at the time of ear emergence. The diseased ears emerge from the boot leaf slightly earlier than healthy ears and form black powdery mass. A smooth silvery membrane covers this powdery mass of spores. The spores are released with the rupture of the membrane. The infected plants have reduced numbers and heights of tillers.	* *
Karnal bunt	*Neovossia indica*	Disease first visible only when the grains are formed. The grains are partially or wholly converted into a black powdery mass enclosed by the pericarp. All the grains in an ear may not be uniformly infected.	* * *
Leaf blight	*Alternaria triticana* *Helminthosporium sp.*	Disease starts as a small, discolored, irregular lesion, brown to grey in color and varies in size. The lesions can attain a size of 1cm or more and be surrounded by a light yellow zone. They may coalesce to cover lateral areas of leaf. In severe infection, the whole leaf may die.	*
Leaf rust	*Puccinia recondita*	Attacks leaves almost exclusively but rarely the leaf sheath, stem, awns, glumes, pendtuncles and internodes. The uredopostule which develops on the leaf sheath and stalk, bursts on the upper surface.	* *

Common name	Scientific name	Disease / Symptoms	Intensity
Stripe rust	*Puccinia striiformis*	Pustules appear as stripes on leaves, stalk and glumes. The color of the leaves fades.	* *
Stem rust	*Puccinia graminis*	Stem is most severely attacked followed by the leaf sheath, leaves, ears, glumes and awns.	* *
Powdery mildew	*Erysiphe graminis tritici*	Greyish white powdery growth appears on the leaf, leaf sheath and floral parts, as superficial colonies of pathogens develop on them. As a result, there is reduction in the number of leaves.	* *
Nematode			
Root-knot nematode	*Meloidogyne, triticoryzae, M. incognita*	Sedentary parasites of roots which cause swollen knots, curly or club shaped galls on root tips; stunted plants with yellowed leaves; curling of leaves along midribs; poor tillering; shorter earheads with fewer, poorly filled grains. Damage is more in nursery.	* * *
Cereal cyst	*Heteodera avenae*	Patchy growth with stunted and yellowish plants. Infected plants exhibit fewer leaves, reduced tillering, delayed emergence of ears, and reduced number of spikelets and grains.	* *
Seed gall	*Anguina tritici*	The infected plants have more number of tillers with a comparatively faster growth rate than the healthy plants. The affected ears are short and broad with very short or no awns on the glumes. In such cases, the nematode gall replaces either all or some of the grains. Each spikelet may contain 1 to 5 galls instead of grains of wheat.	* *

* Very low to ***** very high intensity

Contributed by:
Mukesh Sehgal

Managing Rice Stem Borers in Rice-Wheat Systems



Rice stem borers are serious pests and of regular occurence infest the crop at all stages of crop growth. The rice plants can compensate the damage caused by the borers during the vegetative phase up to the stage of maximum tillering. Infestation by stem borers during the reproductive phase, specially during panicle initiation and ear head emergence, causes loss in yield. All important stem borers which affect rice come under the Order Lepidoptera. Important stem borer species of Bangladesh, India, Nepal and Pakistan belong to genera *Scirpophaga* and *Chilo* of family Pyralidae, and genus *Sesmia* of family Noctuidae.

The life cycle is represented by complete metamorphosis in which the larva must find suitable food during its life of 16 to 56 days, pupa must be protected from enemies and adverse physical conditions for four to 11 days, and the adult, which lives for just two to six days, must again find food (generally different from that of larva). If it does not feed, it must at least find a suitable place to deposit its eggs to perpetuate itself.

Pupation in rice stem borers usually takes place in the stem, straw, or stubble. Sometimes *S. inferens* also pupates between leaf sheath and stem. Pupae of *Scirpophaga* are covered with whitish silken cocoon, while *C.suppressalis* pupae are without cocoon. Before pupating, the full-grown larva cuts an exit hole in the rice internode and plugs it with a fine web through which emerging moth escapes.

Name of Stem Borer Species	Common Name	Life Cycle Duration (days)	Feeding Habit
Chilo auricilius Dudgeon	Gold–Fringed Rice Borer, GFSB	42-52	Polyphagus
Chilo partellus (Swinh.)	Spotted Stem Borer, SSB	30-52	Polyphagus
Chilo polychrysus (Meyrick)	Dark-headed stem borer, DHSB	26-61	Polyphagus
Chilo suppressalis (Walker)	Rice striped Borer, RSB	41-70	Polyphagus
Scirpophaga incertulas (Walker)	Yellow Stem Borer, YSB	52-71	Monophagus
Scirpophaga innotata (Walker)	White stem Borer, WSB	30-51	Monophagus
Sesmila inferens (Walker)	Pink Stem Borer , PSB	46-83	Polyphagus

Egg laying sites on plants are: GFSB - mainly on foliage of underside of rice plants and occasionally on leaf sheaths: SSB - as overlapping rows on all parts of plants; DHSB - in longitudinal rows along shallow furrows on both surfaces at the basal portion of leaves; and RSB - on basal half of leaves. Occasionally on leaf sheaths along mid rib of either the upper or lower surfaces, YSB - near the tip of leaf blade; WSB - on underside of young leaves, and PSB between leaf sheaths and stems.

Larvae live gregariously during the first three instars. In gregarious phase if young larvae are isolated from each other, they suffer high mortality.

The newly emerged larvae show a strong tendency to disperse. They are negatively geotropic and crawl upward, reach leaf tip and aided by silken thread reach other plants. Those falling directly on water catch air layer and swim safely. Later instars cut leaf tips, wrap, form tubes and swim swiftly.

Larvae of *C.suppressalis*, which remain between four and 7 inches above the soil are thus removed in the straw at harvest. Larvae of *Scirpophaga* spp, which have a tendency to feed in the basal part of the plants, are usually left behind in the stubble. During dormancy or diapause the larvae in the stubble move down into the plant base and most stay 1-2 inches below the ground level. Overwintering *T.innotata* larvae move into the root and construct tunnel up to 4 inches deep. On the return of the optimum conditions, overwintering larvae of most species pupate in the stubble. Some larvae of *C.suppressalis* may also pupate in the harvested straw.

Survival and Carry-over

During period when there is no rice crop and the temperature is not optimal for larval development, mature larvae undergo dormancy or diapause in the stubble after moving down into the plant base to stay 1 to 2 inches below the ground level. However, larvae of *C. suppressalis* have a tendency to dispause between 4 inches and 7 inches above the soil and are thus removed with the straw and overwinter in the heaped straw. Larvae of *T. incertulas* cannot survive in the straw, so they go down into the stubble and also in the root zone to diapause; in the floating rice the diapause site is the mid-section of stem near a node. Overwintering *T. innotata* larvae move into the root and construct tunnels up to 4 inches deep.

The moths of these stem borers are strong fliers and, with the help of wind, may cover three miles (5 km) in a single flight. They thus have little difficulty in locating the early rice nursery or summer crop. Further, where two or more rice crops are grown in a year, larvae have adapted to undergo only a temporary diapaude or to discard diapause nature. Polyphagus species of borers have ample opportunities to remain active throughout the year under the diversified cropping system.

Factors of Abundance

Due to the availability of cheap irrigation water, cultivation of rice in summer is profitable. Use of high doses of nitrogen, closer spacing, indiscriminate use of pesticides (killing natural enemies), lack of attention to selection of resistant varieties, possible depletion of silica from soil, heaping of rice straw in the corner of plots, contribute to an increase borer population. Lack of follow up of practices to destroy diapause larvae in stubble and straw is also an important factor which is responsible for the increased infestation of these pests, particularly from 1980s.

Borers Disaster

In Pakistan, stem borers are a great threat to traditional basmati growing areas of Punjab province. Reduction in basmati yields has been estimated at 20%-25% by yellow and white stem borers. During an outbreak season, 70% to 90% of crop may be damaged and, in certain cases, crop is left unharvested in the field due to the cost of harvesting being higher than the yield obtained (Baloch, 1975). It is also reported that the attack of rice stem borers in late transplanted crop is as high as 80% in some parts of Lahore district. Recently, NARC, Pakistan has also expressed concern regarding the increased incidence of stem borer in wheat under rice-wheat cropping system.

Serious Pests

In India, *S.incertulas* is reported to cause 1% to 19% yield loss in early-planted and 38% to 80% in late transplanted rice crops. In the north India's hilly tracts, low infestation on rice occurs in early July, when larvae cause dead hearts in seedlings. Severe infestations occur in September, with maximum whiteheads reaching upto 50%-60% in the field. In the zonal workshop of Krishi Vigyan Kendra at Meerut, India, scientists who are responsible for transferring technologies on farmers' fields voiced grave concern that stem borer under rice-wheat cropping system have come under the category of 'one of the most important' pests. In some farmers' fields, losses were 40%-50%.

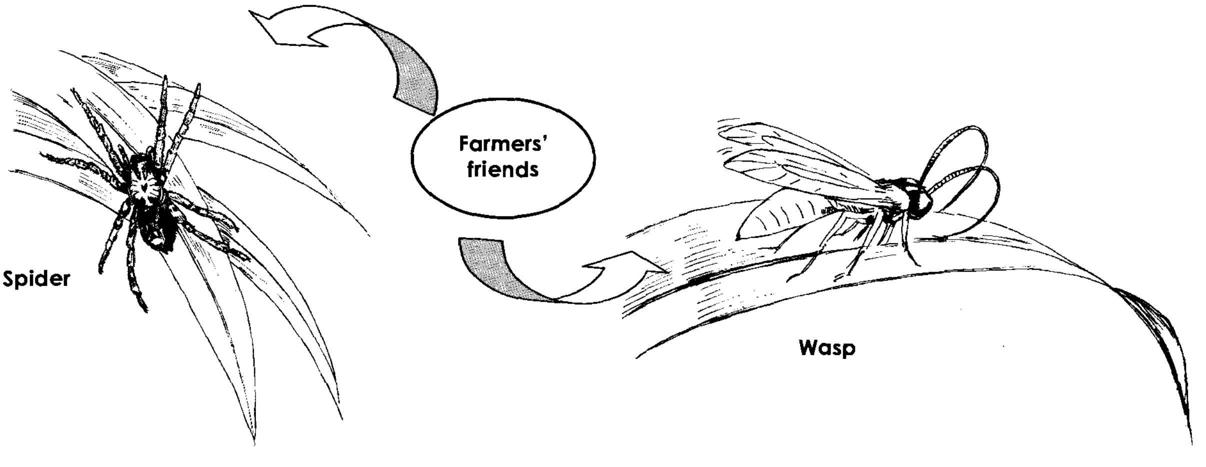
Management Strategies

Resistance Management

Use of pest-resistant rice varieties, maintenance of soil organic matter level at desired level, balanced use of nitrogen, phosphorous and potash by using both organic and inorganic sources of nutrients, amelioration of micronutrient deficiencies, and silicon enrichment of soil by incorporating straw, help plants to resist insect attack. Varieties containing more layers of lignified tissues, a greater area under sclerenchymatous tissues, and large number of silica cells have been found more reisistant to stem borers. Several rice varieties have now been transformed with toxic genes from *Bacillus thuringensis* (BT), and have been shown to have enhanced resistance to stem borers.

Conservation of Natural Enemies of Stem Borers

Recent collaborative studies by Rice-Wheat Consortium reveal that retention of rice stubble in no-till wheat fields immensely enhanced the diversity and population density of natural enemies of rice pests, particularly the predatory crickets, beetles, bugs, ants and spiders. The predators were seen in abundance in the rice stubble as also in or on the nearby grasses and weeds in the early stages of wheat crop. This fauna, however, was found almost absent in wheat fields sown with conventional tillage or on raised beds.



Habitat Diversification

Introduction of plant diversity, crop rotation, cover crop, etc. also improve biological control because diverse agroecosystems tend to enhance abundance of natural enemies due to availability of alternate prey, food and suitable microclimate. The population of predators was higher in rice nurseries and transplanted crops located near Egyptian clover, alfalfa and sorghum fields. Cutting these fodder crops in appropriate manner, i.e., cutting that begins at the farthest end and proceeds towards rice nurseries or the transplanted crop encourages biocontrol agents to gradually move from the harvested portion of the field to the standing crops. They concentrate on a small unharvested portion of fodder crops and then move to rice nurseries or the transplanted crop once this portion is also harvested.

Managing Sowing Periods

Studies show that timely sowing (November 10-25) of wheat reduces the infestation by borer, but in late sown conditions (>December 10) infestation was recorded up to April. Zero-tillage technology helps in early sowing of wheat crop.

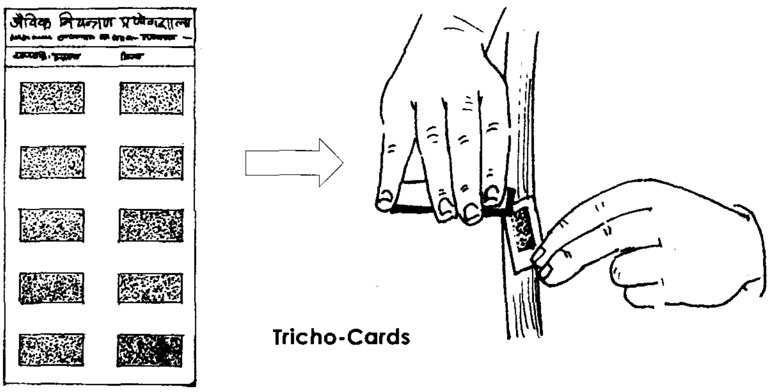
Direct Seeding of Rice

Direct seeded rice without standing water during the vegetative stage often grows less vigorously making it less attractive to Yellow stem borer.

Management of Rice Transplanting and Irrigation

Delayed transplanting at the beginning of the monsoon season using early maturing cultivars over a large area causes a suicidal flight at stem borers while still allowing a timely harvest. Seedling that are bundled for transplanting can be held back for two days to drive out stem borer larvae. Alternate flooding and draining of irrigation water enhances the degree of control of both stem borers and weeds.

Management of Egg Masses



Tricho-Cards

Around 40% of yield loss due to stem borers in rice can be avoided by removing egg masses. Removal of egg masses must be timed to coincide with the susceptible growth stages. Application of ovicides either cost effective strategy. However, YSB eggs are covered with heavy matrix that prevents insecticides penetration and hence the ovicidal action is nullified. In *C suppressalis* eggs, cholinesteerase activity starts at 60 hours after oviposition, and thus action of organic phosphate insecticides are nullified on freshly laid eggs. Among the natural enemies, egg parasitoids *Trichogramma spp* are mass produced and supplied as "Tricho-Cards" with each card containing over 20,000 parasitoids distributed in ten segments. Each segment is cut and stapled on the underside of the leaves. On hatching, the parasitoids emerge and disperse in search of host (stem borer) eggs. *Trichogramma* spp. can also be released as adults at the rate of 50,000 wasps per hectare. It is not effective against eggs of *S. inferens* as these are always concealed by the leaf sheath.

Use of Pheromone Traps

Pheromone lures are a cost-effective strategy to reduce the population of male insects and the subsequent generation of the pest. These lures are fixed in the field at a distance of 20m to 25m from each other. Application of insecticide is needed only when 5% dead hearts or one female insect or one egg mass per square meter is seen.

Formulation of Integrated Location-Specific Schedule

Proper level of soil to avoid low-lying patches and use of balanced dose of both organic and inorganic nutrient supplements reduces infestation by borers. Depending upon the nature and prevalence of stem borers along with other pests and diseases, a strategy needs to be formulated for selection of resistant varieties, selection of weed control strategy as weeds harbor both insect pests and their natural enemies, selection of cultural methods like flooding and raking to kill stem borer larvae, giving priority to biological methods like pheromone traps and use of Trichocards. It also needs to consider insecticide, keeping in view their safety against natural enemies, giving priority to pesticide application methods like seed treatment, seedling treatment and root zone application, which require least quantity of chemicals, and use of chemicals only on the basis of economic and environmental thresholds.

Adapted from:

Srivastava, S.K., M. Salim, A. Rehman, A. Singh, D.K. Garg, C.S. Prasad, B.K. Gyawali, S. Jaipal and N.Q. Kamal (eds). 2003. Stem Borer of Rice-Wheat Cropping System: Status, Diagnosis, Biology and Management. Rice-Wheat Consortium Bulletin Series. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India. (In print).

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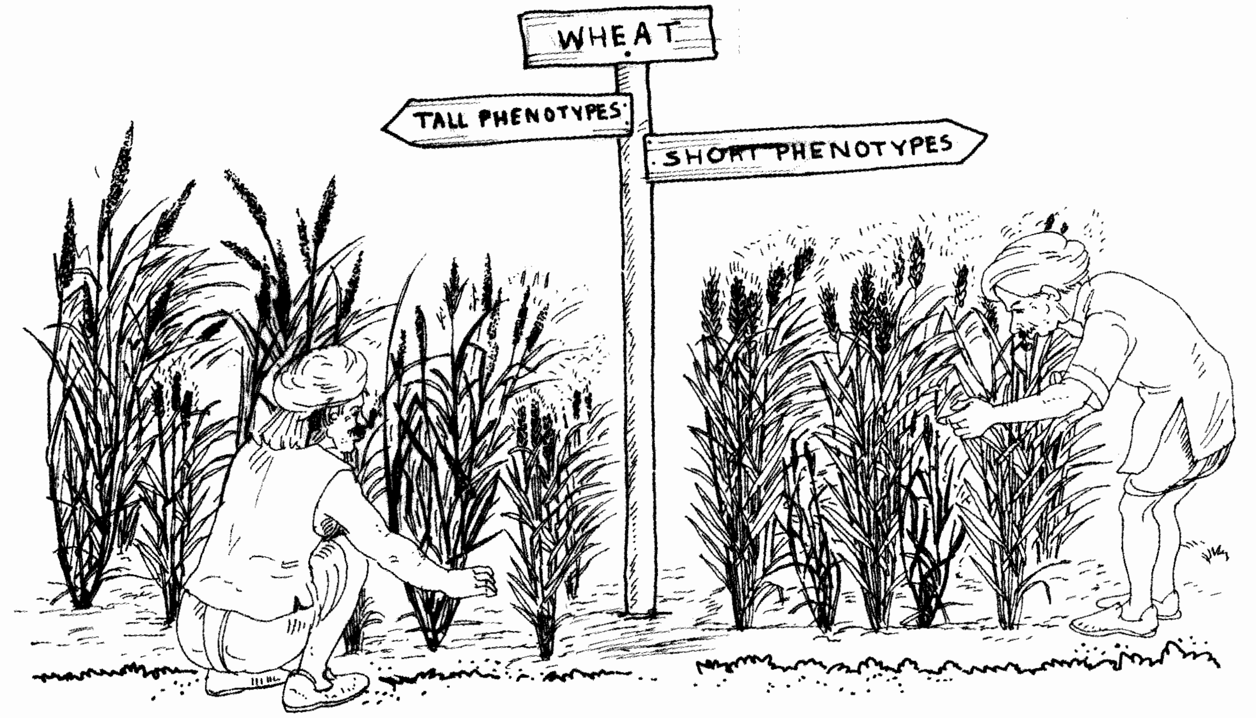
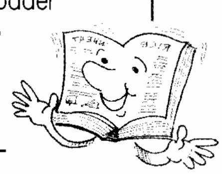
Herbicide Resistance in Littleseed Canary Grass



In South Asia's Indo-Gangetic Plains (IGP), wheat is grown on nearly 13.5 million ha in rotation with rice. Since the late 1980s, the rate of yield increase has slowed partly due to increasing incidence of weeds.

The herbicide, isoproturon (IPU) was widely used in the northwestern states of India to control littleseed canary grass (*Phalaris minor*), the most common weed in wheat. Over the years, this weed has developed resistance to IPU and reached menacing proportions. Repeated use of a single herbicide, IPU, has been the main cause for the weed to develop resistance.

Do you know that....
Many farmers believe that the seed of littleseed canary grass (*P. minor*) came to India with modern dwarf wheat varieties from Mexico and later became a serious weed pest of wheat. However, scientists have traced its presence in association with field oats (*Avena* sp.) in New Delhi (India) in 1948. At that time, it was locally known as "*Chidia bajra*". The association of *P. minor* with CIMMYT dwarf varieties may be due to their less competitiveness with the weed. *Phalaris* is an excellent fodder but can be poisonous to livestock in the early vegetative stage.



Littleseed Canary Grass

Nomenclature

English name: Small canary grass, littleseed canary grass, Mediterranean canary grass and canary grass

French name: Alpiste mineur

German name: Kleines Glanzgras

Spanish name: Pasto romano, Alpistillo, Alpiste, Alfarin

Botanical name: *Phalaris minor* Retz. (synonym: *Phalaris canariensis* L.)

Local name: *Chirya bajra, Kanki, Guli danda, Genhun ka mama, Sitti, Dumbi sitti, Bandri, Mandusi, Biluri* and *Khuni dandi*

Botanical Characteristics

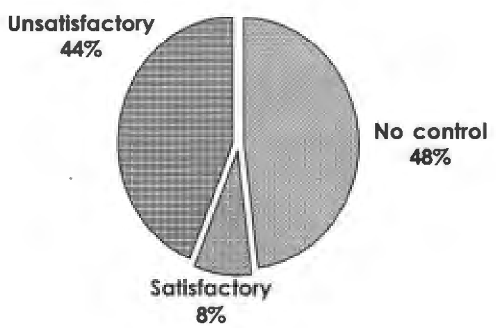
- *Phalaris* is a winter annual grass weed widely distributed and especially troublesome in wheat in the rice-wheat belt of northwest India. There are 8-10 species of *Phalaris*, but these are so closely related that it is difficult to distinguish one from the other.

Biology

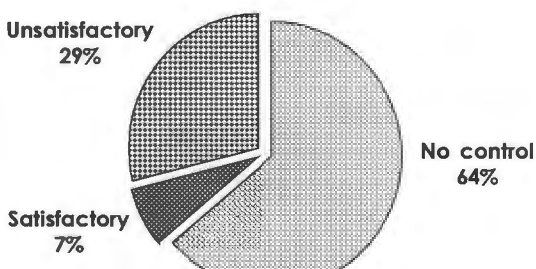
- The success of littleseed canary grass in the rice-wheat rotation appears to be related to high surface moisture for seedling emergence, high input levels and a phenology which is ideally suited to the climatic conditions.
- The weed tends to be surface rooting. *Phalaris* cannot emerge from depths greater than 4-5 cm.
- Temperatures during the crop-growth period are more favorable for *Phalaris* germination. The rate and extent of germination decrease with increase in temperature up to 30°C.
- Late sowings are common in the rice-wheat rotation which favor competitiveness of this weed against wheat.
- *Phalaris* seeds remain dormant for 3-4 months after maturity.
- Seeds of *Phalaris* are capable of tolerating anaerobic conditions by entering into secondary dormancy.
- Seeds shatter readily and usually well before harvest.

Reasons for Spread of Littleseed Canary Grass

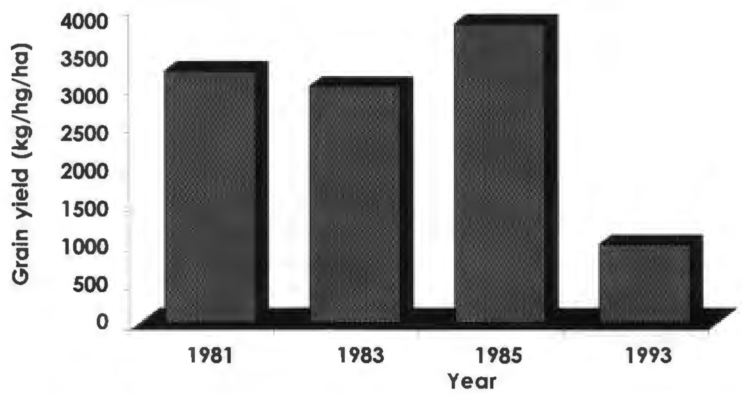
- Surfacing and equal distribution of *Phalaris* seeds burried at deeper soil depth due to soil cultivation under conventional tillage.
- Contaminated wheat seed, irrigation water and occasional flooding of infested areas.
- Inadequate cleaning of wheat seed by mechanical threshers used for sowing.
- Absence of serious competition from other weeds.
- Burning of rice stubbles, especially after combine harvesting, resulting in reduced herbicide efficacy possibly due to increased adsorption of IPU on the ash.



Rice-Wheat Rotation for 5-8 Years



Rice-Wheat Rotation for More Than 8 Years



Grain yield of wheat in isoproturon-treated demonstration plots against littleseed canary grass in rice-wheat zone of Haryana, India over a period of 12 years

- Continuous rotation of rice-wheat providing for adequate moisture availability throughout the year.
- Little focus on crop diversification, and alternative weed management after the success of Green Revolution.

Evidence of Herbicide Resistance in India

Experiments conducted in the rice-wheat sequence zone indicated that burning of straw was a reason for increase in the density of littleseed canary grass. Demonstrations for confirming resistance were, therefore, conducted in fields where straw was not burnt. Grain yield of wheat in these demonstration plots declined over time due to poor efficacy of IPU.

Effect of Burning Rice Straw on the Density (number/sq m) of Phalaris Minor Before Sowing Wheat

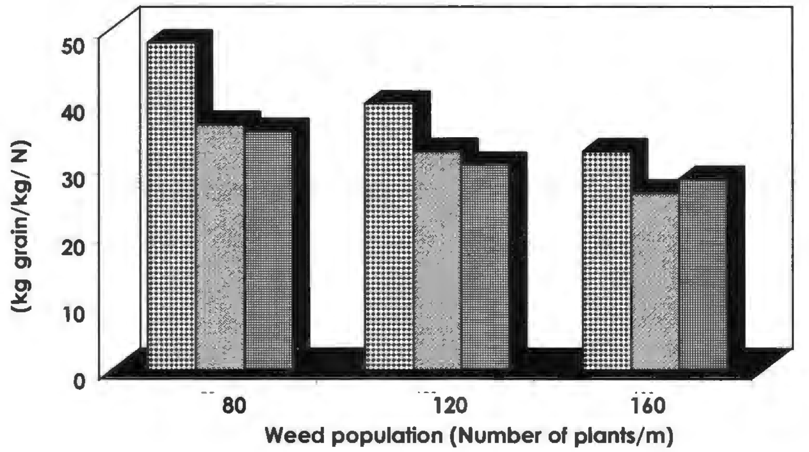
Treatment	1992/93	1993/94	Mean
Straw removal	242	380	311
Straw burning at 6t/ha	340	478	408
Straw burning at 12t ha	488	648	568

Experiments carried out in Haryana have confirmed resistance to IPU in several biotypes of *Phalaris*. The resistant biotypes required 2.7-6 times more IPU than the susceptible biotypes. The resistance factor was also found to increase if the use of herbicide implicated in resistance continued unabated. Seed samples collected from Punjab and random samples collected from both Haryana and Punjab by the National Weed Research Centre, Jabalpur showed that resistance is widespread in northern India, with the total area affected estimated to be around 1.0 million ha.

Weed-Crop Competition

In fields affected by herbicide resistance, weed populations are often extremely high causing large losses in wheat yield due to intense crop-weed competition. It is common to find *Phalaris* wheat ratios greater than 10.

Nitrogen Use Efficiency of Wheat as Affected by Different Populations of Littleseed Canary Grass and Levels of Nitrogen



Experiments conducted at the Punjab Agricultural University, Ludhiana, India indicated that nitrogen-use efficiency of the crop was greatly reduced in the presence of littleseed canary grass apart from causing soil water depletion.

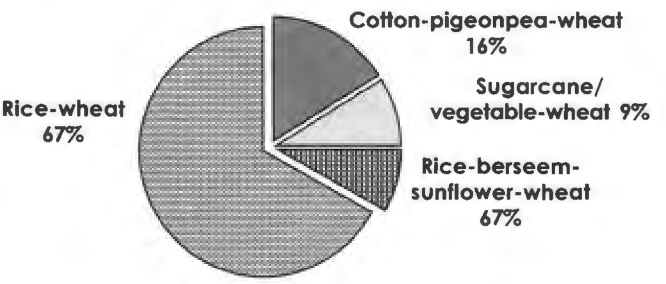
Competitiveness of the crop can be manipulated and used as a tool for integrated weed management. To achieve this, the following considerations need to be recognized:

- The influence of nutrients, particularly their rate and time of application on the competitive relationship between wheat and the weed.
- The role of cultural practices, such as zero-tillage and the furrow irrigated bed planting method of wheat sowing, that enhance the competitiveness of wheat with littleseed canary grass.
- The variation between wheat genotypes in competitiveness with weeds.

Management of Resistance

The management of resistance will undoubtedly be based on integration of alternative herbicides with mechanical, cultural and agronomic practices commonly referred to as integrated weed management. The whole system of rice-wheat production rather than just herbicide alternatives needs to be looked at. One of the core aspects of this approach is to develop techniques to maximize benefits of rational herbicide use.

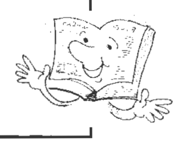
Distribution of Isoproturon Resistance in Littleseed Canary Grass in Farmers' Fields in Haryana, India



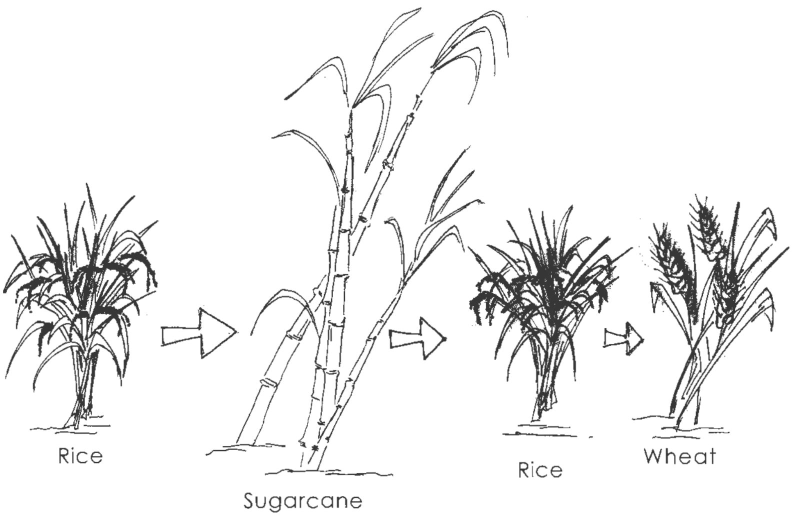
Crop Rotation

- Alternative crops do not merely delay resistance by allowing use of different management options, they also restore diversity in the weed flora.
- Some crop rotations may even be able to exhaust the soil seed bank of littleseed canary grass, thus providing a useful long-term solution.
- Strategic rotation of crops, and other weed management practices associated with these rotations, including the use of a non-selective herbicide such as glyphosate, can prevent an increase in the density of a weed species highly adapted to a monoculture system.
- If sunflower or sugarcane is grown in rows or on beds, intercultivation can be used to control *Phalaris*.
- Crop diversification is only one component of a resistance management program.

The main problem with crop diversification is that it brings uncertainties to wheat supplies for the central pool in India.



Research in Haryana showed that in rice-wheat sequence, replacement of wheat by an alternative crop is more important than the replacement of rice for delaying the onset of resistance in littleseed canary grass. Sugarcane is being grown extensively in western Uttar Pradesh in rice-wheat areas and is giving excellent control of *Phalaris*. The sugarcane and ratoons grown for several years help contain the enrichment of the soil seed bank with *P. minor*.



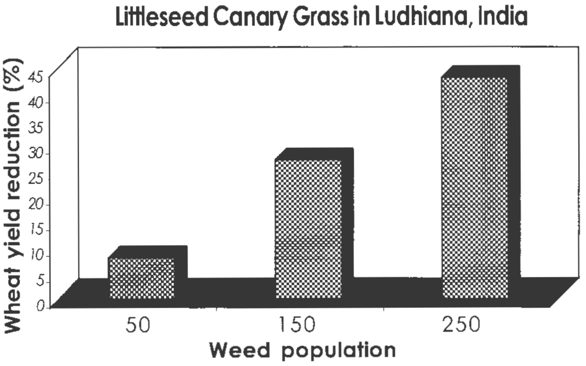
Crop Rotation

Integrated Weed Management

The use of herbicides in rice-wheat cropping system was not accompanied by improved tillage, crop diversification, herbicide rotation, herbicide application techniques, and training of users. A proper combination of all such practices could be the key ingredient of a sustainable weed management system.

Perfecting sowing techniques that allow integration of mechanical methods with herbicides or cultural methods will reduce the frequency of herbicide use which will, in turn, delay the onset of herbicide resistance.

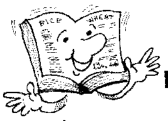
Reduction in Grain Yield of Wheat in the Presence of Littleseed Canary Grass in Ludhiana, India



Manual Weeding

Human labor in the high productivity rice-wheat cropping zone is becoming increasingly scarce and expensive. The contractual labor from poor states, such as Bihar, is more affordable but is unavailable during the critical period of weed-crop competition.

Phalaris seedlings growing within crop rows are impossible to remove by hand-weeding. Some farmers still sow wheat by broadcast method, which makes it impossible to weed out the grasses. Wet soil conditions experienced on paddy soils also reduce the effectiveness of hoeing as a method of weed control.



Missed Opportunity

There is a need for the Indian herbicide manufacturing industry to be more pro-active and work with public sector agencies in developing resistance monitoring and management programs. Such programs aim to extend the effective life of various products on the market which is in the best interest of manufacturers as well as farmers. The Indian industry has already missed important opportunities for delaying or preventing resistance.

Hello Breeders!

With the onset of herbicide resistance and the need to develop non-chemical methods of weed control, breeders need to redefine their selection criteria and select for varieties with superior competitiveness against weeds. It is necessary to test new varieties against weed competition in the same way as is done against other pests. There is a need to develop such strategies and breeders can blend height and early canopy

Mechanical Weeding

Being a shallow-rooted weed with most of the root system in the upper 5cm of soil during its early vegetative growth, it may be possible to achieve satisfactory weed control with implements such as tooth harrows in the flat bed planting system, and cultivators in the bed planted furrow irrigated system. Early season weed management through these techniques will reduce weed competition and has the potential to reduce dependence on selective herbicides.

Other Agronomic Practices: Tillage Method

The *Phalaris minor* seed longevity can be manipulated by changing the tillage system. Zero-tillage in rice-wheat cropping system significantly reduces the number of emerged seedlings of *Phalaris minor* especially up to first post-sowing irrigation. Reduction in *Phalaris* population in zero-tillage fields has been reported from many sites where farmers have accepted this technology.

Under conventional tillage, soil cultivation may result in surfacing and equal distribution of seeds which might have been burried at deeper soil depth at the time of puddling for rice transplanting. Lack of mechanical or light stimulation may also be involved in decreased population of *Phalaris* under zero-tillage. The success of zero-tillage in areas worst affected by herbicide resistance proved that it was one of the influential factors in the adoption of zero-tillage. Furrow-irrigated bed planting method improves input efficiency, and ensures better weed management. Beds are generally 70-80cm wide, depending on the tractor tyre distance with 2-3 rows planted per bed. The inter-row bed space is used to control weeds by mechanical weeding during the early vegetative growth of weeds.

Adapted from:

Malik, R. K., J.K. Verma, R.K. Gupta and P.R. Hobbs. 1998. Herbicide Resistance - A Major Issue for Sustaining Wheat Productivity in Rice-Wheat Cropping Systems in the Indo-Gangetic Plains. Rice-Wheat Consortium Paper Series 3. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

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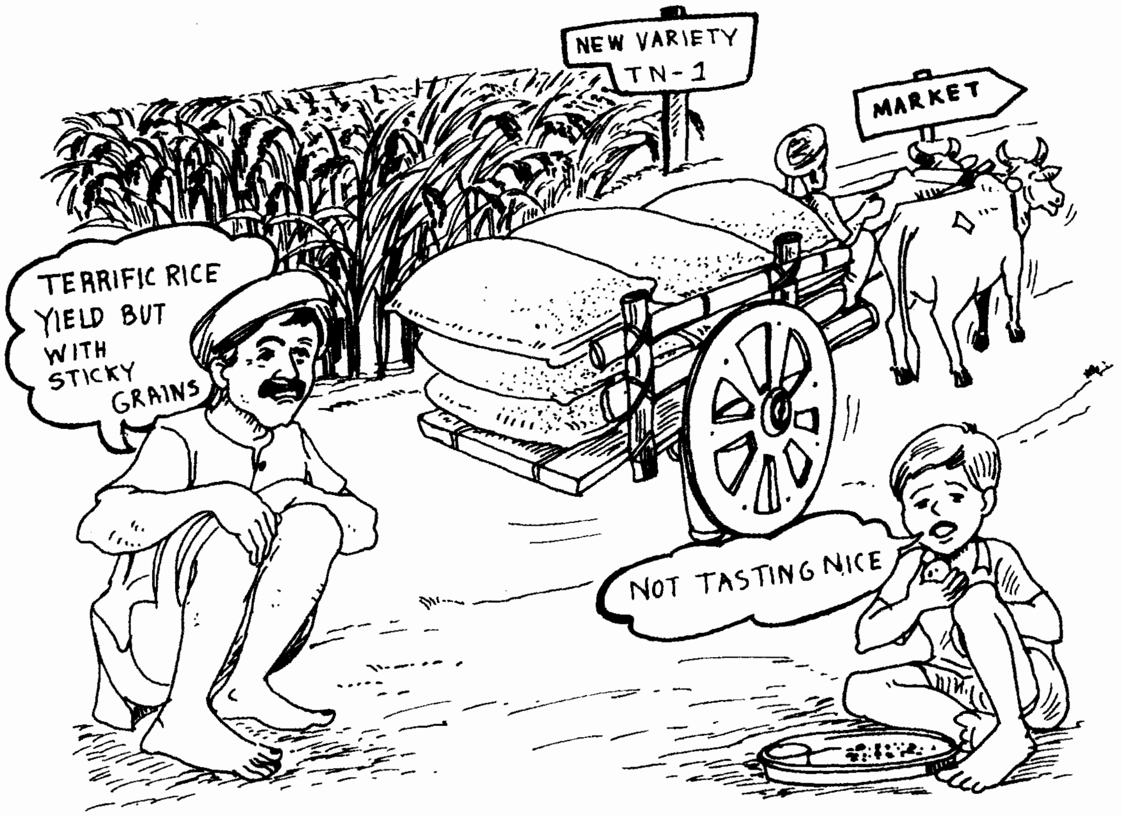
On-farm Trials and Demonstrations:
"Test as You Grow"



On-Farm Trials (OFTs) actively involve farmers to extend and adapt new ideas and innovations within local farming environments. Active participation of the farmers enhances the chances of technology adoption, whether simple or complex. Widely-utilized by researchers and development agencies, OFTs provide both farmers and researchers an opportunity to collectively contribute their intellectual abilities to modify a particular technology in a participatory mode. They support farmer decision-making relating to the on-farm adoption of a new technology. The "test as you grow" approach infers that discovery and adaptation of the new innovation takes place in a participatory manner, out in the farmers' field through the growing season of the crop. Such an approach has proved to be of immense value in accelerating adoption of innovations because ultimately the farmer takes the decision to accept or reject it. This approach is useful as a decision-making tool because other information, personal experiences, and the environment associated with the farmer and markets are taken into consideration when considering the adoption of a new practice.

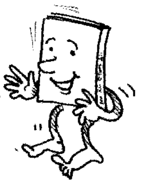
Advantages of OFT

- Farmers make better informed decisions relating to the new technology or practice.
- "Large plot" trials conducted in farmers' fields add value to the research and development process.
- Farmers, their advisers and researchers can gain higher degree of confidence in recommendations relating to new varieties.

What are On-Farm Trials (OFTs)?

Types of On-Farm Trials

- Exploratory trials to gather qualitative information.
- Site-specific trials which are similar to station trials.
- Regional trials that are conducted over a larger area for wider adoption.
- Farmer-managed trials to compare the new technology with the conventional practice as control.



OFTs are adaptive research trials conducted out in the farmer's field, allowing for exploration and discovery of the most suited treatment or practice that can then be more widely adapted across farms in that local district. OFT assists in exposing the best treatment for wider adaptability, enabling farmers to compare the best treatments with existing practices at their field. Due to farmers' participation, OFT helps farmers to evaluate and accelerate the technology adoption process. The researcher also gets an opportunity to identify farmers' priorities, determinants of technology evaluation from farmers' point of view. Both, the farmers and the researcher, appreciate each others' perspective and criteria of technology evaluation. In OFT, generally no replications are used and the treatments are kept minimum (one or two) because the farmers find it difficult to compare so many parameters at a time for a meaningful conclusion. The two main components of OFT are: to improve feedback and technology adoption; and to develop methodology for adaptive research.

Steps in Conducting OFT

1. Establish what it is that you wish to investigate, or have answered.
2. Design the trial, e.g., decide which varieties you wish to compare with the variety currently used, i.e., "control".
3. Decide where you are going to conduct the trial. Select a relatively uniform site within a field. Avoid trial in areas that differ greatly in soil type, or across areas where different crops may have been sown in previous years. Make sure that the varieties are planted in long but thin adjacent strips. Sow the plots across the known minor variations within the field, e.g., all varieties are planted down a slope, but not across a slope in a field.
4. Select a large plot of one hectare, or contiguous plots of nearby farmers for demonstration so that the impact is conspicuously visible.
5. Make sure that you sow all of the different varieties on the one day. Provide the farmer with complete package of practices so that the operations are performed timely and without error.
6. Make sure that all other practices are exactly the same for all treatments e.g., crop variety. Decide how much fertilizer should be applied, your methods of ground preparation, sowing, weed and pest control.
7. The farmer should keep all the records and provide copies to the researcher.
8. Organize wide publicity. "Farmers' Day" should be held at the site so that the farmers from the neighboring areas visit the trial, see the improvement and become convinced about the advantages of the technology. A success story should be published in the newspapers for mass circulation.

Farmer as Partner-An Indian Experience in Rice-Wheat

In participatory research like OFT, the farmer acts as a partner and helps in technology refinement and validation. Under the Government of India scheme, about 1000 trials on wheat production technologies are conducted across the country with the help of the more than 35 cooperating centers in State Agricultural Universities, Indian Council of Agricultural Research's institutes and non government organizations (NGO). A number of technologies, viz improved varieties, weed control, zero-tillage, furrow irrigated raised bed system and line sowing have been demonstrated. In certain cases, the farmers have a chance to modify/refine the technology.

Indian Innovations

- While successfully adopting bed planting (FIRB) technology for wheat, some farmers planted a relay crop of sugarcane in the furrows, thereby reducing the turn-around time.
- Zero-tillage planters are used after one plowing in weed-infested fields to achieve "reduced tillage" and avoid herbicide use.
- Sand is added to the topsoil to improve drainage instead of periodic gypsum application where only sodic irrigation water is available.

Statistical Analysis

To get a more accurate and unbiased assessment of the technology, off-farm analysis is advisable. Information received from different farmers is used to reduce "experimental error" which refers to variations (in yield, etc.) between two plots with the same treatment (e.g., crop variety, fertilizer, etc.). Replication, or repeating each treatment in a finite number of plots of one or more farmers, is done to reduce variations caused by factors other than the treatment being tested. Each farmer is given the same set of treatments (e.g., varieties) and his field represents a block, with each plot being a replication of the treatments. The order in which the varieties are planted, say from a water canal or irrigation head, is changed at random for each farmer. This is called randomization. The statistical design, consisting of blocks of random replications of each of the treatments, need not concern the farmer. The data of yield and other parameters generated in the farmers' field can be analyzed by the researchers, who could periodically monitor the crop in the farmers' fields.

Comparison by Farmers

Some parameters for comparing the performance of a new variety of wheat to an existing one are:

- yield
- grain color
- bread/roti-making quality
- taste
- response to fertilizers
- crop duration in the field
- resistance to pests
- straw strength and lodging resistance

The farmers can determine the superiority (or otherwise) of the variety under normal field conditions without any complex experimental or statistical design or analysis.

In addition, each plot should be harvested and weighed separately for statistical analysis and a sample from each plot should be assessed for quality characteristics of grain and straw. It is better to have crop cutting experiment to estimate the crop yield.

Evaluation

Monitoring and evaluation are integral part of research and development activities. Treatments at the farmers' field are evaluated to reach conclusions based on the information generated by the on-farm trials. The levels are: farmer evaluation; internal evaluation; and external evaluation.

Farmer Evaluation

The farmers evaluate the technology according to their own criteria at every step and are the ultimate evaluators who matter the most in the evaluation process. They are interested mainly in the higher returns. They evaluate the technology on the basis of benefit cost ratio of the changes made.

Internal Evaluation

The trials conducted are evaluated by the implementing agency according to defined objectives. A semi-structured interview schedule is designed to record the perception of the farmers regarding the technology demonstrated and the feedback is used to modify the technology. The suggestions given by the farmers are taken into consideration to improve upon the technology. The researcher looks at the technology from a wider angle, apart from the parameters important from the farmers' point of view. The interest would be in the sustainability of natural resources which may not be of immediate importance to the farmer.

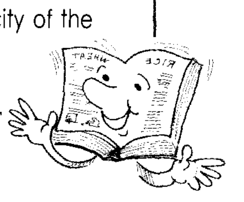
External Evaluation

In this evaluation system, an independent agency, external to the implementing agency, is given the responsibility to evaluate the technology demonstrated from agronomic, socioeconomic and other parameters along with the suggestions given by the farmers reported without any bias. The chances of mis-interpretation of data are less and the findings are impartial. This method is effective and transparent although it means higher expenditure. The "test as you grow" approach to OFTs and demonstrations provide an open participatory framework in which farmers, researchers and advisers can discover and adapt new technology to suit local farming conditions in a collaborative environment.

Limitations of OFTs

There are many limitations associated with on-farm trials, many of which can be overcome through proper planning and management. The main limitations are as follows:

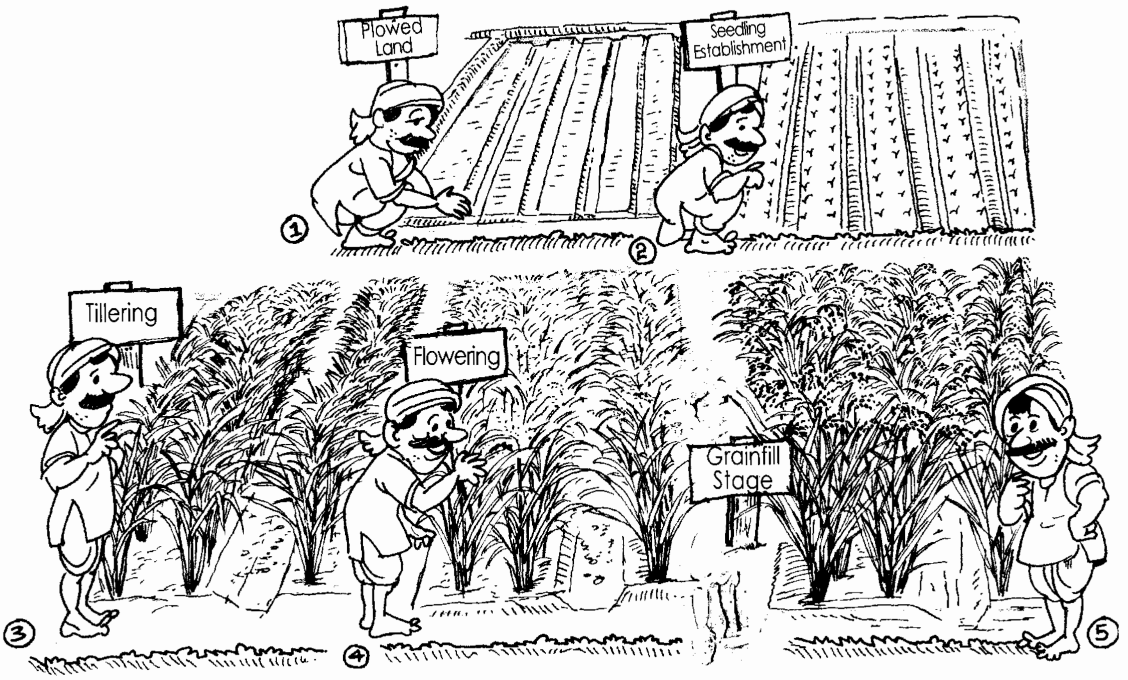
- Transport for inputs, monitoring and evaluation.
- Finance for the trial and evaluation.
- Change in operational timings at the farmer level and the need for the researcher to adopt flexible time schedules for work.
- Lack of manpower for monitoring and evaluation by the farmer and agency.
- Low risk taking capacity of the farmers to test new technologies.



Adapted from:
Cummins, J., R. Singh and J. Blake. Test as You Grow: On-Farm Field Trials and Demonstrations. (unpublished).

Corresponding author:
Jay Cummins

Introduction to Crop Monitoring



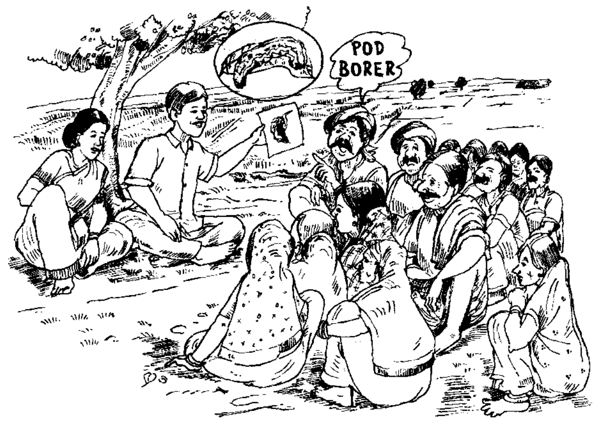
Crop yield is determined long before the crop sets seed. It is the culmination of how the crop performed during each stage of growth-establishment, seedling growth, tillering/ branching, flowering and grainfill. Monitoring the agronomic factors that are responsible for achieving profitable and sustainable yields is essential if farmers of the Indo-Gangetic Plains (IGP) are to improve their competitiveness in an economy that is characterized by escalating costs, variability in grain prices, and diminishing returns.

By identifying limitations to crop growth, action can then be taken to address such issues before significant losses occur, for increasing crop production and profitability. Crop monitoring allows farmers to be pro-active rather than reactive to factors affecting crop performance. Most farmers carry out some form of assessment of their farming systems. For example, simple measurements such as the volume and frequency of irrigation and/or rainfall allows farmers to determine likely crop yields. Assessing weed types and densities may help in deciding the type and concentration of herbicide to be applied, or the number of tillage operations that are to be performed. Final crop yield is a reflection of the effectiveness of the decision-making process and an overall indicator of crop performance.

Comparing Crop Performance

Monitoring of crops as part of a local neighborhood farm group activity allows farmers to compare the performance of their crops with others in their group, village, and district. This process is called comparative analysis. Crop monitoring is done at different stages of crop growth. At each stage, a wide range of factors are monitored. Measurement of these factors and comparing them to standards of the district help determine whether the crop is performing at an optimum level.

Monitoring through On-farm Participation



Participation in crop monitoring activities provides farmers an opportunity to develop skills in assessing crop performance, and in turn identify opportunities for improving crop yield and crop rotation performance. Through crop monitoring, it is possible for farmers to evaluate changes that are made in their cropping management so as to determine the suitability of a new technology, and to modify existing farming practices. By developing a crop monitoring system with local farmers having a common farming environment, it is possible for them to share ideas and experiences with others, as well as having direct access to technical and research expertise from research and extension officers who may be involved in facilitating the activities.

Benefits of Crop Monitoring

Activities		Benefits
Identify factors that limit crop production and introduce management practices to maximize water use efficiency, crop yield and seed quality.	→ C R	• Identification of major constraints to crop production • Water use efficiency of the crop • Crop yield and profitability
Observe the performance of the crop on the farm and in the neighborhood so as to establish standards for optimum plant density and critical thresholds of insect pests prior to management treatments.	O P →	• Crop yield and profitability
Tackle specific issues such as diseases, insect pests, weeds, herbicide resistance, nutrient imbalance and decline in soil fertility.	→ M O N I T	• Knowledge of major biotic and abiotic constraints as well as potentially important constraints • Knowledge of soil fertility
Evaluate new cropping systems, new crops, and new crop rotations and select appropriate practice for individual fields.	O R I N G →	• Knowledge of the crop rotation history of the field • Indication of the sustainability of the cropping system
Discuss and examine new technologies and their integration into the existing farming systems, e.g., zero-tillage and integrated weed management.	→	• Comparison of new technologies with existing practices • Farmers gain confidence in decision-making

Developing a Monitoring Program for Farmers

The degree of sophistication of a monitoring program developed for farmers can vary according to the skills of the farmers, and the time available to them to carry out the field monitoring activites. Although monitoring of crops forms an important part in the monitoring program, the group discussion and interaction that follows is also of great benefit to those involved, both farmer and researcher or extension officer.

Field walks and group meetings can be held throughout the year. These meetings provide opportunities for:

- pre-planting discussions (cropping patterns, fertilizer treatments and soil test results);
- reviewing activities undertaken during the year (weed control, management of pests and diseases, and irrigation practices); and
- post-harvest discussion and interpretation of results (introduction of new technology).

When field walks and group meetings are conducted, farmers should be encouraged to ask questions, and openly discuss issues with each other and the researcher. At the end of the discussion, or inspection of a crop, observations and recommendations should be summarized for future management of that crop. This will help to provide a "take home message" for the farmers involved.

Developing a Crop Monitoring Calendar

Calendar of activities and factors monitored for cereals, pulses, and oilseeds

1 Pre-season

(Time: harvest to sowing)
- Plan activities for the year
- Field selection, crop rotation planning and review
- Soil fertility testing
- Seed quality testing
- Set yield and quality targets

↓

2 Crop establishment

(Time: 3 to 4 weeks after sowing)
- Sowing depth
- Plant stand
- Weed types and densities
- Insect pests and diseases

→

3 Vegetative growth

(Time: 6 to 10 weeks after sowing)
- Nitrogen level in soil and plants
- Number of tillers (in cereals)
- Root diseases (in cereals)
- Nodulation (in pulses)
- Root and foliar diseases (in pulses)

↑

4 Flowering and grainfill

(Time: 12 to 22 weeks after sowing)
- Weed types and densities
- Insect pests and diseases
- Head numbers (in cereals)
- Flowering (in pulses)
- Pod numbers (in pulses)
- End of flowering (in oilseeds)

↑

5 Harvest

(Time: After harvest)
- Assessment of yield and grain loss
- Assessment of seed quality
- Windrowing assessment (in oilseeds)

Contributed by:
Jay Cummins, Randhir Singh and
Ashok Yadav

Acknowledgement
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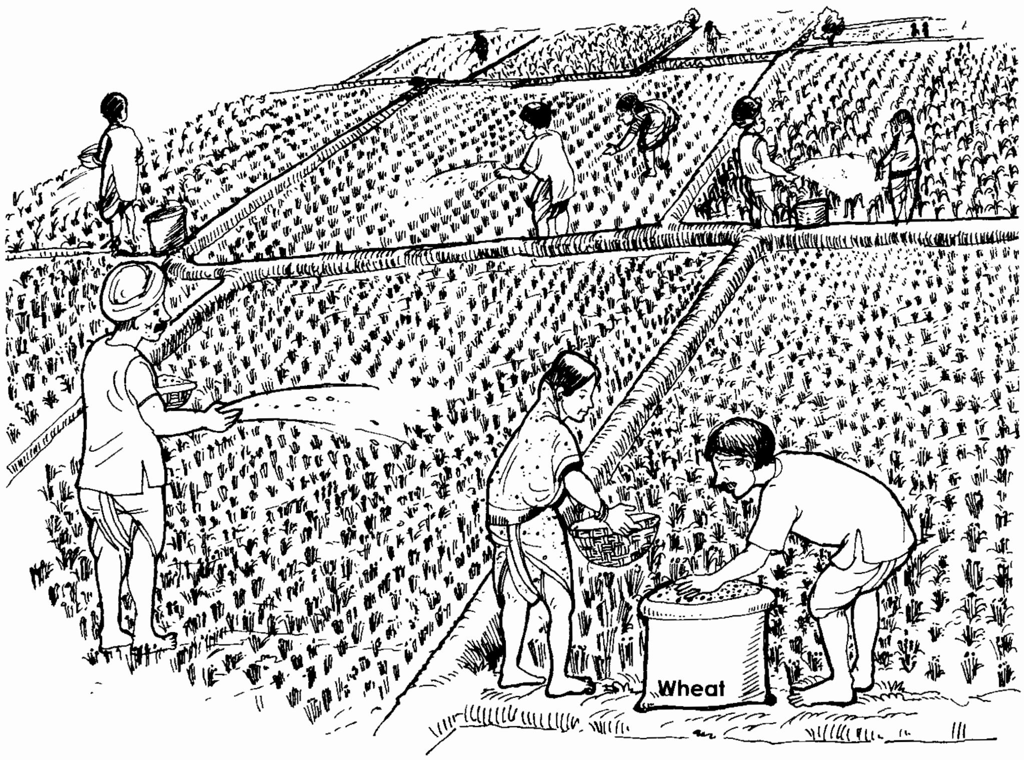
Enhancing the Adoption of Innovations by Farmers



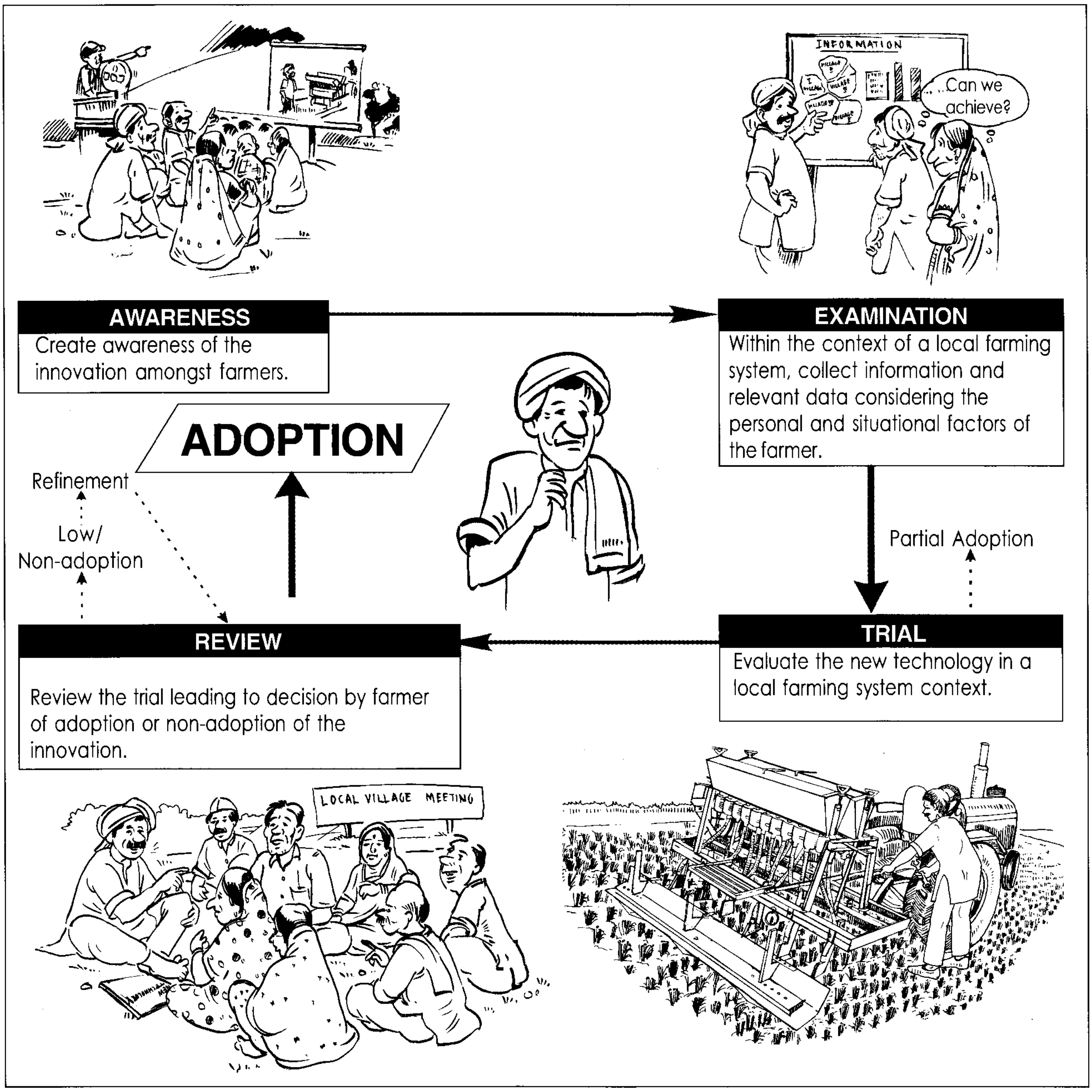
It is often assumed that all technology is good for farmers. But there is a great variation in the perception of the appropriateness of the technology between agricultural scientists/extensionists and farmers. Often farmers are in the best position to consider the degree of usefulness of the technology, and its applicability to their own local farming system.

> **How Effective is the Extension Process?**
> Promotion of a new technology or innovation may be successful as it reaches the target farmers. But farmer awareness of a particular technology does not necessarily mean that adoption has taken place. Extension is a process in which farmers are made aware of the technology. The process is extended further from awareness to a change in behavior, where a conscious decision is made by the farmer whether to adopt or reject the new practice.

The professionals sometimes discount the personal and situational characteristics associated with farmers, when examining the reasons given for non-adoption. It is the individual farmer's reasons for non-adoption that may, in many instances, represent barriers to adoption. By understanding these perceived barriers, there is the opportunity to better design and promote new innovations and farming systems that identify and address such barriers to the adoption of new practices. If dealt within the context of the localized farming systems, there is every opportunity to enhance the level of adoption of the new practice. This leads to the development of an open participatory framework for collectively involving the agricultural professional and farmer in the development and promotion of new innovations and improved farming systems.

The Adoption Cycle

Awareness of a new farming practice may lead to adoption, but only after favorable attitudes towards the practice have been generated amongst the farmers concerned. The adoption of an innovation is part of a continuous process and there are many models for the adoption process. A simple approach that leads to adoption is described. It emphasizes the individual decision-making processes undertaken by farmers that lead to the adoption of a new technology.



Farmer Decision-making Leading to Adoption

Farmer decision to adopt a particular technology will only take place after a farmer has considered all options, viewing them within the context of their own farming system. The decision to adopt will be guided by the farmer's particular attitude to risk, past experiences, and the behavior of other farmers in the vicinity. The decision leading to non-adoption, dis-adoption, and adoption by farmers should be respected in many instances, provided farmers have been made fully aware of the advantages and disadvantages of the particular technology or farming practice.

It is important that farmers complete the "adoption cycle" by evaluating the changes that have occurred in their farming system. They should also be made fully aware of the net benefits, and the changes that have occurred in the system. Crop yield is an easily identifiable measurement, however, other factors such as ease of management, improved sustainability of the natural resource base, improved product quality, and reduced farmer stress should also be considered when evaluating the relative benefits of the innovation.

Developing an Open-Participatory Approach

It is important that discussion is encouraged between farmers and research and extension officers. This helps to ensure that all stakeholders become familiar with the personal and situational characteristics of the other party. Open hands-on participatory research is but one means to create an environment conducive to this process.

Open discussion through a participatory approach will, in turn, assist in achieving greater ownership of the new practice by local farming communities. If they can achieve higher levels of ownership and empowerment, the improved farming systems are hence "developed from within the group" as opposed to being a potential directive from an outside research or extension organization. This in turn leads to the development of improved problem-solving skills by the farmers themselves. Sharing the results and benefits of the technology through farmer advocacy is perhaps one of the best forms of promotion of a new innovation or enhanced farming system. Farmer "case studies" provide a practical approach to promoting the benefits of a particular innovation. Often farmers can better relate to the benefits of the improved systems when expressed "through the eyes" of local farmer advocates.

Supporting Farmer Group Networks in the Adoption Process

It is essential that local farmer group networks are adequately supported where an open participatory research and development framework is to be promoted. Groups require the services of research and extension professionals that have practical skills and knowledge of local farming systems and technical issues, a clear understanding of participatory processes, and well-developed group facilitation skills.

Group empowerment of the overall extension process will result in more open participation by the farmers and research/extension professionals involved. Many of the elements of group participation rely on adequate group needs analysis. This analysis is a process that aims to identify what issues are important amongst the group members. Such issues can relate to production, environmental, social, and management concerns linked to the needs of participants. By undertaking a group needs analysis, the farmer group is being invited to identify constraints or issues which may be limiting the adoption and development of local farming systems.

Key issues and themes can then be developed around a range of group activities, allowing for research, demonstrations, and group learning activities to be tailored to the immediate needs of the farmers involved. As the farmers themselves have identified the issues, they in turn have greater ownership over the process, resulting in higher elements of participation and personal interest.

"Farmers learning together, in a participatory process" is the main outcome achieved. This outcome helps to ensure that the research, demonstrations, and training activities can be readily applied within the context of the local farming system and conditions. Relevance and farmer ownership over the identification and design of the process in turn assists in enhancing the potential adoption of the improved farming system.

How Do We Identify the Needs of a Group of Farmers?

Identifying the needs of groups will help ensure that the group becomes motivated, committed and interested in further developing their local farming systems. It is important that the group remains focussed on local issues that are of common interest. Farmers should have a high level of participation in the identification and prioritization of needs and opportunities which involves the following steps:

1. What are the group needs?
   - List all needs and reach group consensus on a common issue (keep a list of other issues for future reference).

2. Identify specific opportunities linked to the issue.
   - How will these opportunities meet the identified group needs?

3. What activities will be carried out?
   - How will these activities be conducted in an open participatory manner?

4. Conduct group activites, evaluate and review.
   - Identify key opportunities for introducing change on the farm.

An example of need identified by a group may be to improve weed control in crops. Specific opportunities may be to examine the effectiveness of the herbicide application and/or rate and type of herbicide product used. The group may then conduct an on-farm trial or demonstration, involving different application techniques, herbicide rates and timings.

On-farm trials on a particular 'group need' are supported by an extension or reserch officer, who also assists in monitoring and evaluating the results. The group collectively is involved in reviewing and evaluating the results. Group discussion is concluded with an emphasis on the changes in farming practices identified through the participatory trial work that would lead to improvements in individual farming systems. This process is then repeated with other group needs forming the basis of developing further participatory activities and learning opportunities.

Contributed by:
Jay Cummins

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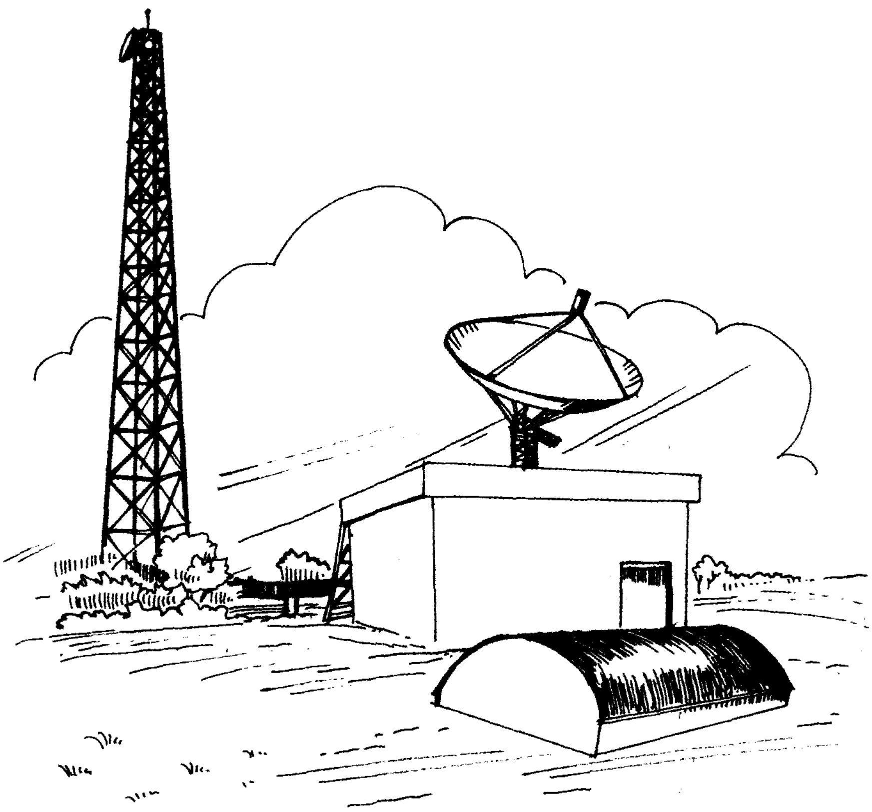
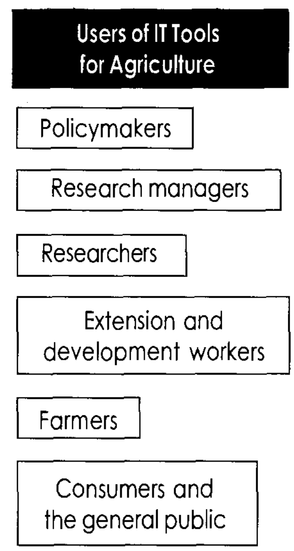
Modern Information Technology Tools for Efficient Management of Natural Resources





Modern tools from information technology such as simulation models, decision support systems (DSS), geographic information system (GIS) and databases offer promise towards greater efficiency in fields such as natural resources management, yield forecasting, and developing contingency plans for monsoon variation.

Why Information Technology?

There is an increased interest in applying information technology (IT) to agricultural research and development. Diagnosing and solving problems at the local or farm level often requires consideration of factors ranging from impact of specific pests, to local management of water resources to availability of off-farm employment. Such a "systems approach" requires strong interdisciplinary collaboration, which in turn implies ready flow of data and information among stakeholders - a clear niche for databases and internet access. Furthermore, to view interactions of systems components, systems methodologies often rely on computer-based tools such as simulation models and GIS.

Information technologies offer numerous mechanisms for improved synthesis and interchange of information. There is potential for major "spillovers" in fields such as molecular biology and remote sensing. The "Web" is rapidly becoming a major storage place for information. Web-based technologies greatly improve accessibility thereby offering great opportunities for timely, targeted, and high quality information which can influence the various actions.

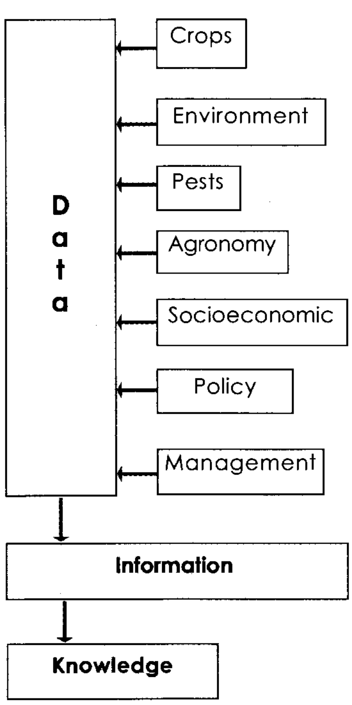
Types of Information

Information required in agricultural research and development efforts ranges from project descriptions to specific results of field or laboratory evaluations to qualitative indicators of farmer or consumer perspectives. Although "information" is used as a blanket term, the hierarchy of data, information, and knowledge better represents the spectrum used in agricultural research and development. Within "knowledge," a further distinction can be made between explicit and tacit knowledge. Explicit knowledge can be expressed in a symbolic form (e.g., a written description or a mathematical formula), while tacit knowledge is the more subjective "know-how" that grows from professional experience.

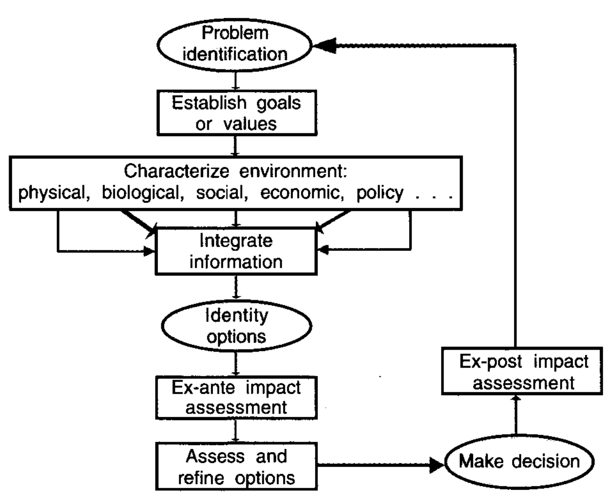
Information-based Tools for Agricultural Research and Development

While individual tools are useful, their value is multiplied when linked to required data and complementary tools to create a DSS. Information technology provides the tools that allow us to systematically generate, organize and make knowledge available to those who require it most – passing it from the hands (and minds) of researchers to the "real" users of the land and natural resources so that they are better empowered to manage their resources in a more informed and rational manner. These tools can be matched to user groups with the

Hierarchy of Data



Categories of Tools Useful in Decision-making for Agricultural Research and Development



Note: Rectangular boxes indicate tools and oval boxes indicate actions of decision-makers or other stakeholders. Source: English *et al.* 1999.

addition of categories of tools for technology diffusion (e.g., expert systems) and project management (e.g., project information databases).

Project Information and Knowledge Management Systems

For more effective collaboration within and among research and development networks, it is important to be able to keep track of 'who is doing what, where?', as well as the status and progress of on-going projects. Avoiding duplication saves substantial funds whereas targeted partnership and use of information are key factors to developing timely solutions to identified key problems. In addition, information systems can greatly contribute to build up and utilize institutional memories of information available with individuals and institutions in the different stakeholder groups. Management information concerns data on organizations, activities carried out in the past or on-going, collaborators, funding agencies, and expertise available. For monitoring data on allocations, expenditures as well as progress and outputs achieved are essential. Re-use of basic information is important to enhance efficiency of research and development efforts. Thus, three interlinked systems (see box) are being developed or are available in the Indo-Gangetic Plains (IGP).

Interlinked Systems in the Indo-Gangetic Plains

- The web-based **project information management system (PIMS)** was developed as a response to the need of the Indian National Agricultural Technology Project (NATP) management to monitor its program. The on-line version is being developed by the Indian Agricultural Statistical Research Institute (IASRI).

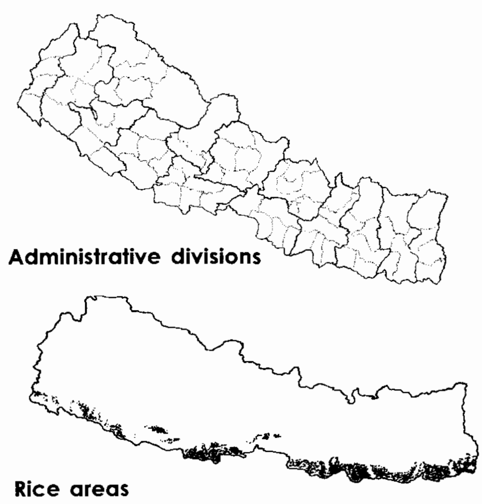
- The **regional-level information system** is a shared platform of the four national partners of the Rice-Wheat Consortium (RWC) in the IGP region. It is called Project and Research Information System Module (PRISM) and can be accessed at www.wis.cgiar.org/rwc. PRISM was developed on the lines of WISARD.

- **WISARD,** the web-based information system on agricultural research and development (www.wisard.org) contains detailed information and advanced search tools for projects and organizations. It creates stakeholder specific country directories and organizational profiles of projects. It allows free text, pre-defined, and advanced searches on-line on thematic, geographical, and institutional aspects. It is compatible with Interdev, the non-governmental organization (NGO) initiated system that provides interactive information on local knowledge and best practices.

The Country Almanac Series

Most agricultural and natural resource management decisions are strongly influenced by the spatial environment. GIS offers enormous potential for improving the efficiency of agriculture and natural resource management. However, the impact of GIS has been limited due to high costs of hardware and software, limited data availability, shortage of trained specialists, and lack of "spatial awareness" among potential end-users. The Country Almanac Series lowers barriers to effective use of GIS by packaging simple yet powerful analytic tools with a core set of data of spatial data relevant to agricultural and natural resource management issues (climate, soils, population, topography, land-use, etc.). To further enhance the utility of the Almanacs, tools for exploring daily weather data records and for viewing electronic documents are packaged with the Almanacs.

A Sample Almanac Map for Nepal



Almanacs are distributed on CD-ROM and accessed through a familiar Microsoft Windows user interface. Almanacs are in use in eight countries of sub-Saharan Africa and in Nepal. Proposals are under discussion for development of Almanacs for Bangladesh and India as well as a regional version that would cover the entire rice-wheat region of South Asia at lower resolution.

The Map Layers tool of the Almanacs provide standard map viewing and overlaying functions. Users may add or remove data layers as needed, and a meta-database documents data sources. The characterization tool permits creating zones using user-defined criteria for any data available in the Almanac. Although current Almanacs focus on national-level datasets, the system works equally well at sub-continent or district level.

The Sustainable Farming Systems Database

The Sustainable Farming Systems Database (SFSD) is an implementation of the International Crop Information System (ICIS Project 2000) developed by the Natural Resources Group of Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT). It can store results from natural resources research on crop performance, cropping practices, and environments from the experimental level to farm level to regional level.

Users can enter their own data from experimental results, surveys, expert opinions, on-farm monitoring results, census data, and scouting reports. Data may be selectively up-loaded to the central depository. Planned improvements to the SFSD will permit flexible queries about locations, single crops or rotations, maintenance and harvest practices, use of labor, machinery and chemicals, and traits of systems. Data can be extracted for use in other applications. These include spreadsheets, statistical packages, crop simulation models and GIS.

Models for Estimating Potential Yields and Yield Gaps

Potential yield is the integrated expression of the influence of radiation and temperature on crop growth and development of a particular crop or variety. Adequate water and nutrient supply and absence of all yield-reducing factors such as pests and diseases characterize this production level. Potential yield can be interpreted as the upper limit that is achievable by current varieties in a no-constraint environment. Simulation models can also be used to analyze yield gaps. Economic yields based on potential yield estimates, cost of cultivation, and simulated response to fertilizer can be used to determine the possible yield levels for different land evaluation units. Using the WTGROS model, variation in potential wheat yields was examined over India (Aggarwal *et al.*, 1995).

Rice Supply and Demand Analysis System

Another example of taking crop and economic modeling further in the development of DSS is illustrated by the Rice Supply and Demand Analysis (RSDA) system developed to model and analyze the balance between rice supply and demand at sub-national level (i.e., within the country), taking into account biophysical, socioeconomic, and policy factors.

GIS is used to explicitly provide the spatial dimension in modeling the three RSDA components, rice supply, rice demand, and rice balance, and to facilitate integration of biophysical and socioeconomic data and analysis. Such outputs from the model help in identifying areas of rice-deficit and in designing the rice distribution system in the country.

The RSDA system can be used also for exploring future scenarios of rice supply and demand. For example, one scenario could be increasing rice production by intensification of cropping through improvement and expansion of irrigation systems while another scenario could be lowering the reduction factor due to pests and diseases and post-harvest losses. From the demand aspect, different scenarios of income and price elasticities of consumption, and projections on population growth rate and urbanization will change estimates of future rice demand.

A Decision Support System for Land Use Analysis

A systems approach is needed to translate policy goals into objective functions integrated into a biophysical land evaluation model. A DSS has recently been developed to meet these needs (Aggarwal *et al.,* 2000). Quantitative policy goals for food security of the region are first established. Then policy views of the stakeholders in relation to production, income, social issues, and environmental degradation are quantified using published documents or personal discussions. A detailed land evaluation is conducted that considers spatial and temporal variation in soil and climatic resources of the region using relational databases, GIS, and remote sensing. This results in a number of homogenous agro-ecological units. Regionally-developed and tested transfer functions are used to determine soil moisture and nutrient characteristics of each agro-ecological unit.

Advantages of DSS

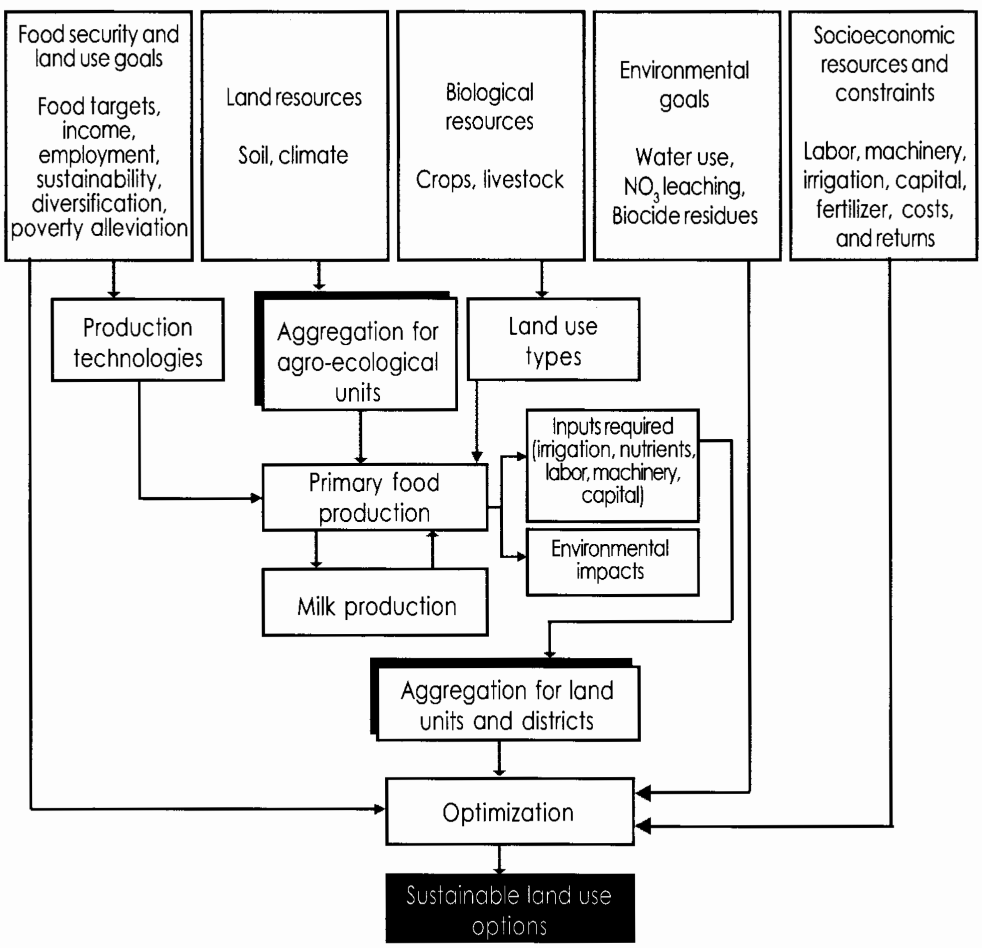
- Explores the opportunities for land use analysis and planning.
- Integrates the knowledge base of scientists from different disciplinary backgrounds.
- Addresses issues put forward by diverse stakeholders.
- Helps the user analyze whether the development goals are feasible and at what cost.

Considering the crops and livestock resources of the region, key land use types are defined. The possible production technologies and activities are defined based on the policy goals and socioeconomic resources of the region. Regionally calibrated and validated crop models are then used to estimate the food production potential of the different land use types with different production technologies for each agro-ecological unit. Potential yields are adjusted for the agro-ecological unit.

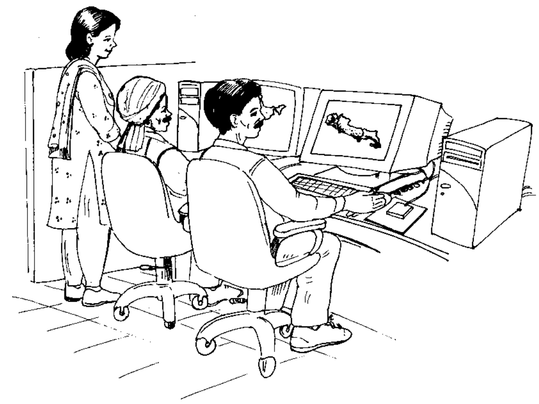
The model can assess environmental impacts and monitor the main ancillary agricultural output, crop residues. The latter provides energy to the livestock which, in turn, produce milk. Resulting dung produced is used for fuel or for organic manure, which in turn can further affect crop production.

By overlaying the district boundaries on the agro-ecological units map, the number and area of different land evaluation units in each district is determined. This is essential because socioeconomic data are generally available at this scale. Together with the assessment of socioeconomic resources of the region and specific goals for food security, environmental conservation and alternate land use, and options for sustainable land use are determined using interactive multiple goal linear programming.

Operational Steps Followed in the DSS for Land Use Analysis for Sustainable Food Security



Future Efforts



- Managers must ensure that end-users have the capacity and confidence to use IT tools.
- Tools and data should be updated.
- Good basic products are available in the region which need to be technically further developed and integrated in a continued interactive process with end-users.
- There is a dire need for further regular interaction on concepts, standards and implementation.
- Funding for finalization and integration of the various prototypes and products should be ensured.
- Meeting of key developers and users should be held once a year to develop standards, common procedures, share experiences, and plan future interaction.
- A web-platform for intermediate contact and exchange of ideas should be established.
- A user-group network for the various key domains should be created.

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