CASA

Conservation Agriculture – *Status and Prospects*

Centre for Advancement of Sustainable Agriculture

Conservation Agriculture –
Status and Prospects

Edited by

I.P. Abrol[1], R.K. Gupta[2] and R. K. Malik[3]

[1]Centre for Advancement of Sustainable Agriculture, New Delhi
[2]Rice-Wheat Consortium for Indo-Gangetic Plains, New Delhi
[3]Haryana Agricultural University, Hisar, Haryana

Centre for Advancement of Sustainable Agriculture
National Agriculture Science Centre (NASC) Complex
DPS Marg, Pusa Campus, New Delhi 110 012
Tel. : +91-11-25848188, 39594145
Website: www.agricasa.org

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Contents

Acknowledgement v

Preface vii

Conservation Agriculture and Resource Conserving Technologies — A Global Perspective – *Larry Harrington and Olaf Erenstein* 1

Resource Conservation Technologies in Rice-wheat Cropping System of Indo-Gangetic Plains – *R.K. Malik, Ashok Yadav and Sher Singh* 13

Conservation Tillage and Crop Residue Management in Rice-Wheat Cropping System – *K.K. Singh and S.K. Sharma* 23

Machinery for Zero-Till Surface Managed Crop Residue Systems — Progress and Prospects – *T.C. Thakur and Arun Kumar* 33

Machinery for Conservation Agriculture: Progress and Needs – *S.K. Rautaray* 43

Residue Open Burning in Rice-Wheat Cropping System in India: An Agenda for Conservation of Environment & Agricultural Resources – *Prabhat K. Gupta and Shivraj Sahai* 50

Experience with Managing Rice Residues in Intensive Rice-Wheat Cropping System in Punjab – *B.S. Sidhu and V. Beri* 55

Cropping Systems Diversification Opportunities and Conservation Agriculture – *M.S. Gill and L.S. Brar* 64

Resource Conservation Technologies and Cropping System Diversification Opportunities – *S.C. Tripathi, A.D. Mongia and Jag Shoran* 72

Cropping System Options in No/Reduced Till – Surface Residue Managed Systems – *U.P. Singh, Y. Singh, H.P. Singh and Raj K. Gupta* 79

Conservation Agriculture and Opportunities for Sugarcane Based Cropping Systems – *R.L. Yadav and T.K. Srivastava* 86

Water Management Imperatives in Zero/Reduced Till – *A.K. Sikka, A.R. Khan, S.S. Singh and N. Subash* 93

Conservation Agriculture - IPM issues – *Saroj Jaipal, R.K. Malik, Peter Hobbs, A. Yadav and Samar Singh* 100

Zero/Reduced Tillage/Bed Planting/Surface Managed Crop Residue Systems-opportunities for Crop Genetic Enhancement – *A.K. Joshi, B. Arun, R. Chand, V.K. Chandola, K. Ram Krishna1, L.C. Prasad, C.P. Srivastava, P. Raha and R. Tripathi* 115

Wheat Cultivars in Relation to Resource Conservation Technologies – *Jag Shoran, Ravish Chatrath and A.S. Kharub* 125

Transfer of Resource Conserving Technologies through Krishi Vigyan Kendras – *A.K. Mehta and Randhir Singh* 129

Ripples of Changes Through Zero-Tillage Technology for Enhancement of Productivity and Conservation of Resources: Experiences of K.V.K. Bahraich – *M.P. Singh and Vinay Kumar* 136

Laser Land Leveling- The Precursor Technology for Resource Conservation in Irrigated Eco-system of India – *M.L. Jat, S.K. Sharma, Raj K. Gupta, Kuldeep Sirohi and Parvesh Chandna* 146

Socio-Economic Impact Assessment of Bed Planting Technology in Punjab – *D.K. Grover, Joginder Singh, Ranjeet Singh and S.S. Dhillon* 156

Socio-economic Impact of Zero-tillage Technology in Wheat in Punjab – *Harjeet Singh Dhaliwal and Joginder Singh* 164

Studies on Extent of Adoption of Zero Till Seed-cum-Fertilizer Drill for Wheat Sowing in District Kurukshetra (Haryana) – *O.P. Lathwal and K.L. Banga* 172

Conservation Tillage for Enhancing Productivity and Protecting Environment: ICRISAT Experience – *S.P. Wani, P. Pathak and R.C. Sachan and Suresh Pande* 177

Prospects and Limitations of Reduced Tillage in Arid Zone – *Pratap Narain and Praveen Kumar* 192

Conservation Agriculture in Rainfed Semi Arid Tropics – Some Past Experiences, Lessons Learnt and Future Scopes – *Y.S. Ramakrishna, K.P.R. Vittal and K.L. Sharma* 200

An Appraisal of Soil Quality Assessment Indicators – *D.L.N. Rao and M.C. Manna* 212

Remote Sensing/GIS/GPS for Diagnosis, Prognosis and Management of Soil Water Domains – *Madhurama Sethi* 220

Policy and Institutional Requirements for Transition to Conservation Agriculture: An Innovation Systems Perspective – *Rajeswari S. Raina, Rasheed Sulaiman V., Andrew J. Hall, and Sunita Sangar* 226

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Preface

Indian agriculture is entering a new phase. While the major research and development efforts in the 'Green revolution' era focussed on enhancing production and productivity of selected foodgrains and other crops the new challenges demand that issues of efficient resource use and resource conservation receive high priority to ensure that past gains can be sustained and further enhanced to meet the emerging needs. Issues of conservation have assumed importance in view of widespread resource degradation and the need to reduce production costs, increase profitability and make agriculture more competitive.

The conventional mode of agriculture through intensive agricultural practices was successful in achieving goals of production, but simultaneously led to degradation of natural resources. The growing concerns for sustainable agriculture have been seen as a positive response to limits of both low-input, traditional agriculture and intensive modern agriculture relying on high levels of inputs for crop production. Sustainable agriculture relies on practices that help to maintain ecological equilibrium and encourage natural regenerative processes such as nitrogen fixation, nutrient cycling, soil regeneration, and protection of natural enemies of pest and diseases as well as the targeted use of inputs. Agricultural systems relying on such approaches are not only able to support high productivity, but also preserve biodiversity and safeguard the environment. Conservation agriculture has come up as a new paradigm to achieve goal of sustained agricultural production. It is a major step toward transition to sustainable agriculture.

Over the past three decades or so, internationally, rapid strides have been made to evolve and spread resource conservation technologies like zero and reduced tillage systems, better management of crop residues and planting systems which enhance water and nutrient conservation. Conservation Agriculture which has its roots in universal principles of providing permanent soil cover (through crop residues, cover crops, agroforestry), minimum soil disturbance and crop rotations is now considered the principal road to sustainable agriculture: Thus it is a way to achieve goals of higher productivity while protecting natural resources and environment. Conservation Agriculture is currently practiced on more than 80 million ha. worldwide in more than 50 countries and the area is expanding rapidly.

In India significant efforts to develop and spread these technologies are underway through the combined efforts of several state and national institutions and CG Centers, particularly Rice-Wheat Consortium for Indo Gangetic Plains. The new technologies, on the one hand, are exciting the farmers to take up new ways of managing their resources more productively and, on the other hand throwing new challenges to the scientific community to solve emerging problems associated with new technologies.

Developing and promoting Conservation Agricultural practices require multi disciplinary team efforts and strong farmer participation in finding answers to emergry questions. A conference 'Conservation Agriculture – Conserving Resources – Enhancing Productivity was organizational in September 2005 with a view to arrive at a shared perception of Research and Development agenda for Conservation Agriculture. The present volume is a compilation of articles based on selected presentations and submissions for this conference.

Editors

Conservation Agriculture and Resource Conserving Technologies — A Global Perspective

Larry Harrington and Olaf Erenstein
CIMMYT, New Delhi 110 012, India

ABSTRACT : With the rapid expansion of wheat zero tillage in the Indo-Gangetic Plains, there has been within that region a surge of interest in resource conserving technologies (RCTs). But other regions of the world have also made progress in fostering farmer use of these practices. This paper defines RCTs and "conservation agriculture" (CA), and then summarizes a global perspective on CA and RCTs, emphasizing recent advances in selected developing countries, among them China, Central Asia, southern Africa, and the southern Cone of South America. Success in the introduction of CA practices is found to be favored by the following factors: emphasis on development and adaptation of suitable implements often using prototypes from elsewhere; participation of the private sector in implement development, adaptation, manufacture and marketing; long-term technical mentoring; strong local champions; a crisis mentality that brings with it a willingness to consider radical departures from conventional practices; and the emergence of a dynamic innovations system.

USING A GLOBAL PERSPECTIVE

With the rapid expansion of wheat zero tillage in the Indo-Gangetic Plains, there has been within that region a surge of interest in resource conserving technologies. In the 2004-2005 wheat season, zero tillage is estimated to have been used on nearly 2m ha of sown area (RWC, 2005). And wheat zero tillage is seen by many as merely the first step in a broad movement towards the development and adoption of an ever richer collection of resource conserving, conservation agriculture technologies.

But other regions of the world have also made progress in fostering farmer use of these practices. Zero tillage direct sowing ("siembra directa") of crops has become especially widespread in the Southern Cone of South America. Work on resource conserving technologies has also been done in Mexico and Mesoamerica with some success. The use of conservation agriculture is being explored in areas of sub-Saharan Africa and is making good progress in China and Central Asia. And, of course, there are substantial areas covered by conservation agriculture in the US, Canada and Australia. Taken together, area under zero tillage/ conservation agriculture was estimated for 2000-01 to be of the order of 60m ha, most of it in the US, Australia, Canada, Brazil and Argentina.

The purpose of this paper is to provide, in brief summary form, a global perspective on conservation agriculture and the use of resource conserving technologies. We emphasize recent advances in the development and use of conservation agriculture in selected developing countries. Our hope is that this information will inform and inspire the efforts of researchers, development workers and farming communities in South Asia.

CONSERVATION AGRICULTURE AND RESOURCE CONSERVING TECHNOLOGIES

In the above, the terms "conservation agriculture" (CA) and "resource-conserving technologies" (RCTs) were used as if their meanings were similar. In the rest of this paper, a sharper distinction will be made.

Henceforth, "resource conserving technologies" will refer to those practices that enhance resource- or input-use efficiency. This covers a lot of ground. New varieties that use nitrogen more efficiently may be considered RCTs. Zero or reduced tillage practices that save fuel and improve plot-level water productivity may also be considered RCTs, as may land-leveling practices that help save water. There are many, many more.

In contrast, "conservation agriculture" practices will only refer to the RCTs with the following characteristics::

- Soil cover, particularly through the retention of crop residues on the soil surface;
- Sensible, profitable rotations; and
- A minimum level of soil movement, e.g., reduced or zero tillage.

The distinction is important because some RCTs, while attractive in the near-term, may be unsustainable in the longer-term. An example of this is the use of zero tillage without residue retention and without suitable rotations which, under some circumstances, can be more harmful to agroecosystem productivity and resource quality than a continuation of conventional practices (Sayre, 2000).

The principles listed above are defined as common to CA systems. However, the specific components of a CA system (establishment methods, farm implement selection, crops in the rotation, soil fertility management, crop residue and mulch management, germplasm selection, etc.) tend to be different across environments. Local investments in adaptive research typically are needed to tailor CA principles to local conditions. This process of "tailoring" is most efficient when an "innovation system" emerges and begins to acquire a self-sustaining dynamic. When this happens,

> ". . . technology development and adoption [become a] social phenomenon in which agents interact in several ways, creating multiple information flows in many directions. These agents (e.g., public research and extension systems, innovative farmers, commercial firms, foreign research institutions) form networks that co-evolve with the technologies that they create." (Ekboir, 2002, page 2).

CONSERVATION AGRICULTURE IN SOUTH AMERICA

In the developing world, conservation agriculture has been most successful in the South American countries of Brazil and Argentina. In these countries, 45-60% of all agricultural land is said to be managed by conservation agriculture systems (Derpsch, 2001). In the 2001-2002 season, conservation agriculture practices are estimated to have been used on more than 9m ha in Argentina and 13m ha in Brazil. Practices use include the use of specialized, locally-adapted no-till planters, a mulch cover on the soil surface, and suitable crop rotations.

The story of how CA practices came to be so predominant in Brazil is skillfully related by Ekboir (2002). The story begins with a government policy, a farmer response, and an ensuing crisis. The government policy was a decision in the 1960s to promote a shift from livestock-based farming systems to crop-based systems in the rolling, hilly, high-rainfall areas of southern Brazil. The farmer response was to take up the crops being promoted – especially soybean. The crisis that ensued was a disquieting increase in soil erosion and land degradation. In some instances, erosion so reduced productivity that farmers were unable to repay bank loans. Many people felt that the answer lay in terracing.

Some early champions, however, felt that CA practices could sustainably maintain crop-based agroecosystem productivity. Amongst these champions were an agro-chemical company (ICI), an implement manufacturer (Semeato), a technical assistance agency (GTZ) who placed a skilled agronomist in the affected region (Rolf Derpsch), a few national researchers (initially from the Instituto de Pesquisas Agropecuarias Meridional, IPEAME, in Londrina, Paraná State – later also from IAPAR and EMBRAPA), and some innovative farmers (Derpsch, 1989). Links were made with CA/ no-till specialists at the University of Kentucky, who provided technical assistance and human resource development, important in the early days of research and development of locally-adapted CA practices. A dynamic "innovation system" began to unfold. By the end of the 1970s, an efficient no till/ CA package had been developed and began to be adopted by the larger farmers and later, in the 1990s, by a large number of smaller farmers. Curiously, however, "All other research and extension institutions, including the universities, opposed the technology until adoption was widespread" (Ekboir, 2002, page 16).

CONSERVATION AGRICULTURE IN SOUTHERN AFRICA

Interest in applying the principles of CA to the conditions of sub-Saharan Africa goes back several decades. But the issues and problems that sparked this interest – and the ways in which CA innovation systems have evolved – have varied across different regions of the continent (Erenstein, 2003). Even within a given region, variability in production environments leads to the need for a corresponding diversity of CA practices. This section will focus on examples from southern Africa. It should be noted, however, that zero tillage practices have had some success in Ghana and other parts of West Africa.

Smallholder agroecosystems in southern Africa are affected by a multitude of problems. Soils often are sandy, thin (a few tens of cm on top of impermeable bedrock) and of low fertility. When these soils are farmed under the conditions of the low and variable rainfall that is typical of the region, a common outcome is drought stress in crops – and seasonal shortages of fodder for livestock. Many people feel that CA can help overcome these problems, despite complications that arise in implementing CA in areas where livestock are important components of agroecosystems.

A major champion of conservation agriculture in southern Africa has been the Africa Conservation Tillage Network (ACT), established in 1998 to promote Conservation Agriculture as a sustainable means to alleviate poverty, make more effective use of natural and human resources, and reduce environmental degradation. Early financial and technical support came from GTZ, including the services of a specialist agronomist – Kurt Steiner. It recently has evolved into a Pan African network with global links, and is active in technology development, networking, information exchange, and policy advocacy (ACT, 2003).

In many regional agroecosystems, livestock are very important, but there are some where they are not. Agroecosystems with few livestock tend to predominate in densely populated areas where farm size is very small, e.g., Malawi, eastern Zambia, northern Mozambique and parts of southern Tanzania. Systems with a greater concentration of livestock tend to predominate in drier areas where human population density is somewhat lower, e.g., Zimbabwe, southern and central Mozambique, Botswana, north-eastern South Africa, and southern and central Zambia (Waddington, 2003).

In areas where crop-livestock systems are predominant, a further distinction by landtype is useful. Landtypes vary in accord with the toposequence. "Toplands" are the relatively light, thin, unfertile soils described above. These are located towards the top of the toposequence. The problem of storing moisture in these soils is exacerbated by lateral flows that convey water away from the toplands during heavy storms. In contrast, "vleis", located at the bottom of the toposequence, feature heavier, better-watered, more fertile soils. They benefit from the lateral water and nutrient flows originating in the toplands – but are susceptible to waterlogging. A single farm may include both toplands and vleis, or only one or the other.

Early work related to CA in these systems featured diagnostic studies to better understand the reasons behind their low productivity. For farms dominated by toplands (the normal case), low productivity was traced to many factors, among them late sowing, drought stress, a scarcity of fodder for cattle, weed competition in grain crops, low soil fertility, and many more. Research to address these problems has proceeded, with some researchers and institutions focusing on soil fertility and maize-legume rotations and others focusing on tillage and establishment.

Figure 1 illustrates some of these factors, and how they interact. It also illustrates the challenges in developing true CA systems suitable for toplands. For example, one of the principles of CA is "soil cover, particularly through the retention of crop residues on the soil surface". In practice, crop residue production in these landtypes is low. Of those residues produced, most are consumed by livestock, with much of the remainder eaten by termites. In this context, the idea of using residues (grown in one season) as mulch (for the following season) often is simply not feasible. Complementary projects, however, have explored the use of agroforestry to provide the "alternative fodder sources" that Figure 1 shows to be scarce (Lazier, 1994).

Another principle of CA is the "use of sensible, profitable rotations". Here, more progress has been made. Maize-legume rotations and green manure cover crops have been a major topic of research and development efforts, and some farmer adoption of maize – pigeon pea rotations has been observed in systems without livestock, in Malawi. The beneficial effects and practicality of crop residue mulches have been well researched in Africa, and they are widely used by farmers in wetter more productive areas – largely, however, where animals form only a minor component of the system.

A third principle of CA, "reduced or zero tillage", appears more promising. Figure 1 illustrates how the low production of crop residues leads to reduced draft animal numbers and health, which in turn affect the timeliness of sowing. Given the typically short growing season, timely sowing is important to avoid late season drought. However, many farmers (especially those without their own draft animals) must delay sowing because they cannot get their fields plowed at the onset of the rains. The demand for draft power at the peak period (the onset of the rains) exceeds the supply (Shumba *et al.,* 1989). A suitable adaptation of zero tillage could circumvent this problem, allowing more farmers to plant on time, reducing the need for draft animals, and thereby freeing up crop residues for use as mulch. Not surprisingly, a good deal of research has been done on this topic, especially on the replacement of moldboard plow tillage with shallow tine tillage, the latter requiring only 14% of the draft power requirement of the former – and resulting in far less soil disturbance. However, a frequent constraint with tine tillage is increased weed competition and weeding requirements in the initial seasons (Shumba *et al.,* 1992; Vogel, 1994).

One apparent success story may be found in Zambia (Haggblade and Tembo, 2003). The manual preparation and sowing of crops in "potholes" for water retention, combined with crop residue retention in these potholes, is said to have been taken up by 50,000-75,000 farm families. However, adoption has largely taken place in areas where only about 15% of the population own animal draft power. As part of the innovation process, public sector researchers, supported by funds from an external donor, have developed an implement for animal-drawn tine tillage, known as the "Magoye Ripper". About 5000 of these are said to have been built and sold as of 2001, of which about 1000 are said to have been exported to neighboring countries. Projects in other parts of southern Africa are experimenting with the Magoye Ripper as well as with no-till implements imported from Brazil (Sims, 2005).

A good summary of constraints to farmer adoption of conservation agriculture in southern Africa – and some ways to overcome these constraints – was provided by Steiner (2002).

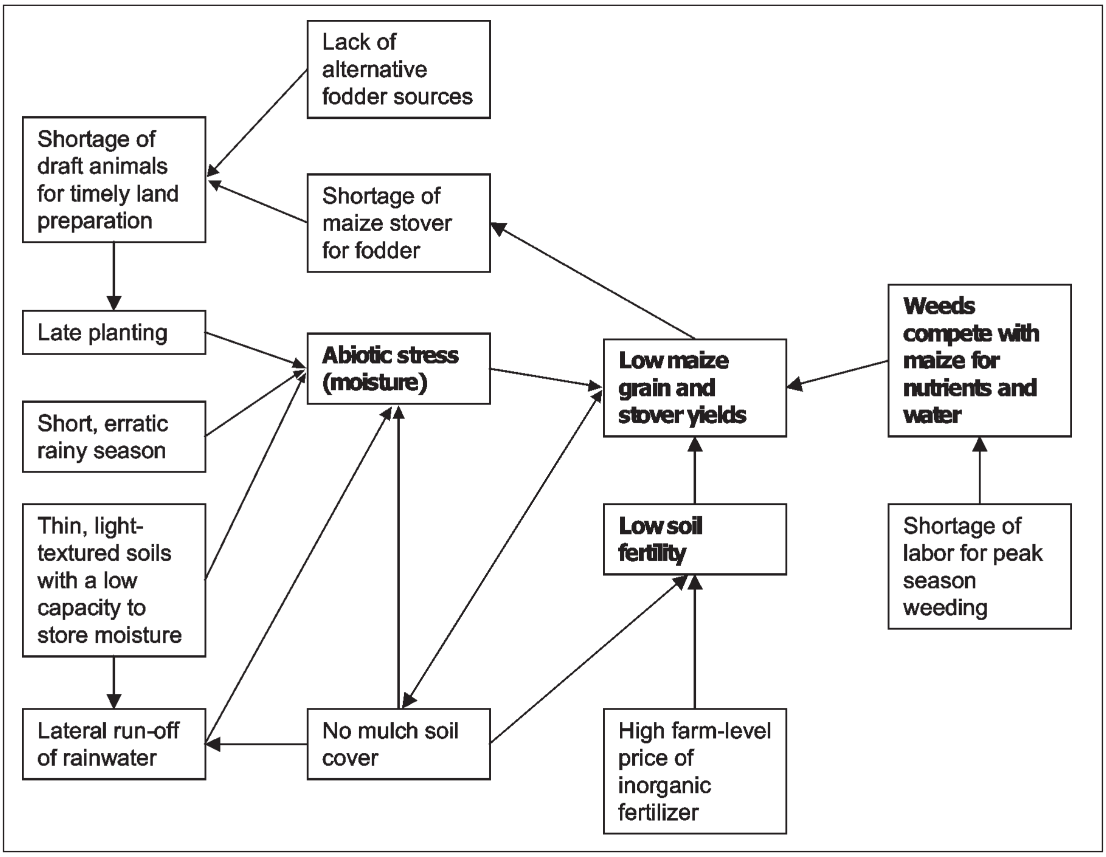

Fig. 1. Some factors affecting agroecosystem productivity in of southern Africa (top-lands).

- *Crop residues are not used for soil cover, but rather for livestock feed*. Address this constraint through installation of feedlots, agroforestry systems.
- *Uncontrolled livestock grazing of residues after harvest*. Address this constraint through local binding agreements on grazing, living fences.
- *Insufficient residual moisture for cover crops*. Address this constraint through inter- or relay cropping of green manure or cover crops.
- *Lack of credit to buy implements*. Address this constraint through development of farmer organizations, development of custom service providers.
- *Weed control becomes difficult, no access to herbicides*. Address this constraint through use of animal drawn weeders, intercropping of legumes, pumpkins, sweetpotatoes (Steiner, 2002).

In general, however, there has not been widespread adoption of conservation agriculture practices, perhaps because ". . . conservation technologies and the way they have been promoted have not considered the constraints faced by smallholder farmers for whom they are intended, such as shortages of equipment or labor, and draught animal availability. Consequently, less than 1% of smallholder farmers have typically adopted these technologies." (Waddington, 2003).

CONSERVATION AGRICULTURE IN CHINA

China, vast and diverse, has made considerable progress in fostering the use of conservation agriculture – and at the same time has barely begun to tap its potential. China devotes 80-90m ha, from an innumerable array of production environments, to the annual production of 330-400 m tonnes of grain. The development and adoption of CA practices in China will be one of the great development challenges for the 21st century.

One source suggests that there are, in north-west China alone, around 700, 000 ha of land under conservation agriculture, where CA is defined as ". . . minimum (or zero) mechanical soil disturbance, crop residue retention, permanent organic soil cover, diversified crop rotations and precise placement of all in-field traffic, applied agrochemicals and animal/ crop residues". This area is said to be spread across 94 counties in 14 provinces, with concentrations in Shanxi, Gansu, Hebei and Inner Mongolia.[4] Work on CA or RCTs is also underway in provinces of Sichuan and Shandong.

Shanxi

Early work on CA in China was begun in the early 1990s by the Mechanical Engineering College of the China Agricultural University, and the Shanxi Xinjiang Machinery Factory. This work focused on northern China and aimed to respond to widespread problems of drought, poor soil fertility, and heavy wind and water erosion in the north China plain. It became clear during the late 1980s that these problems were being further exacerbated by an on-going shift from animal to mechanized traction. In response, a project was launched to develop and disseminate CA practices. This project enjoyed financial support from Australia (ACIAR) and technical mentoring from the University of Queensland (ACIAR, 2005).

A good deal of attention was paid to the development of suitable implements for direct sowing. These implements were required to achieve good crop establishment, with seed and fertilizer drilled at different depths in the soil, while sowing into high levels of crop residues, in very small fields, and using low horsepower tractors. Several generations of sowing implements were developed, with the latest generations being capable of good crop establishment into 15 t/ha of chopped residue. Curiously, there is no evidence that Brazilian implement prototypes were used, or that contact with the Brazil direct sowing movement was established. Rather, key parts for early machines were adapted from Australian prototypes, including openers, anti-blockage mechanisms and press wheels (Gao Huanwen, Yao Jianzhong, et al, no date). The effect of continuous zero tillage was monitored by researchers, with measurements taken on yields, water use efficiency, production costs, earthworm populations, soil aggregate stability, soil organic matter, and soil porosity and bulk density. For the most part, CA practices had a beneficial effect on all of these (Gao Huanwen, *et al.* no date).

Widespread adoption of these practices have been traced to the advances in machinery described above, together with strong promotion by the Shanxi Agricultural Machinery Bureau and the Chinese Ministry of Agriculture. The project has been heavily profiled, both on provincial and national television.

Sichuan

In Sichuan, CA is being actively developed and promoted by scientists of the Sichuan Academy for Agricultural Research. As much as 500,000 ha of agricultural land in Sichuan planted to wheat, rice, rapeseed or potato may already be covered by zero tillage or bed and furrow systems. Much of this is found in the Chengdu Plain, for crops that follow wet season rice. The use of zero tillage is said to facilitate the timely sowing of crops after rice – even in waterlogged soils if field drainage ditches or bed and furrow systems are used in addition to zero tillage. Of the nearly 17m tonnes of rice straw produced in Sichuan, a large proportion of this comes from the Chengdu Plain. About 90% of this is used as mulch for post-rice crops in zero till systems. Even potatoes are grown under zero tillage! The tubers grow on the soil surface, well protected by an exceptionally thick layer of rice straw. [5]

Shandong

In Shandong, interest in RCTs is shared among policymakers, grain traders and individual farmers. Policymakers are concerned about the depletion of groundwater, an issue affecting large parts of north China plain. Groundwater levels have fallen by tens of metres in the last years, and agriculture accounts for about 70% of water use. RCTs capable of reducing the use of water in agriculture are actively sought. A technology of particular interest is bed and furrow systems, which can cut water use by half while maintaining yields and production levels.

Grain traders in Shandong are concerned about grain quality of wheat for shipping to provinces in southern China. Technologies for improving grain quality are of great interest. The observation that grain quality is higher in wheat grown in bed and furrow systems has persuaded traders to make bed shaping/ sowing equipment available for farmer testing.[6]

Finally, farmers are concerned about the low profitability of agriculture, especially in grain production. They seek ways to improve productivity and reduce production costs. They have observed that bed and furrow systems substantially reduce the costs of irrigation – not because the number of irrigations has declined, but because the time required for each one is cut by about half. Approximately 20,000 ha of bed and furrow systems in Shandong are currently managed by farmers (CIMMYT, 2004).

CONSERVATION AGRICULTURE IN CENTRAL ASIA

Countries in Central Asia and the Caucasus are heavily dependent on wheat as a source of food. Wheat covers about 15m ha, spread over two major production environments:[7]

- Autumn-sown winter or facultative wheat in southern Kazakhstan, Kyrgyzstan, Uzbekistan, Tajikistan, and Turkmenistan in Asia, and Armenia, Azerbaijan, and Georgia in the Caucasus (total about 5m ha). In this environment, wheat is grown under irrigation and in rotation with rice, cotton and other crops.
- Rainfed, drought-prone spring wheat in the north of Kazakhstan, normally planted in May and harvested in August (total about 10m ha). In this environment (similar to the prairies of Canada), wheat is typically grown as a monocrop on relatively large (ex-collective or state) farms.

At present, RCTs or CA practices are not widely used in either environment. However, in the spring wheat area of northern Kazakhstan, a dynamic is unfolding that may lead to the development and widespread adoption of zero tillage practices.

Research projects supported by GTZ (Germany) and FAO brought together international agricultural research centers, public sector Kazakh agricultural research organizations, implement manufacturers and farmers organizations. A main objective of these projects was to foster farmer testing of several Conservation Agriculture practices (FAO, 2004).

- *Residue retention*. Recent seasons of high snowfall led to glaring and widespread problems of soil erosion and land degradation, fueling interest in residue retention for soil cover.
- *Direct sowing with zero tillage*. Local drills were converted for use with zero tillage. These initially used furrow openers introduced from Brazil, but later used locally produced furrow openers. A recent achievement is the development of locally produced openers for zero tillage that are less expensive than those for conventional tillage, but that can be mounted on local seed drills with no further modification.[8] In addition, investments by the Canadian government have brought Canadian private sector implement dealers to Kazakhstan for the purpose of exploring opportunities for the commercial distribution and technical support of specialized zero till implements.[9] Direct sowing with zero tillage

was found to reduce costs and improve yields – especially during relatively dry seasons, when retained stubble is more effective than bare soil in snow capture, an important source of moisture in the following crop cycle.

- *Diversification* out of wheat monocropping into other crops such as winter rye, sunflower, chickpea and barley.
- *Chemical weed control to replace mechanical weed control*. The cultivation of continuous wheat in northern Kazakhstan had led to problems of disease, soil fertility loss – and build-up of problem weeds. Mechanical weed control methods were unable to solve the problem. Weed control practices based on residue retention, new crop rotations and the application of glyphosate, in contrast, have proven effective, with herbicide use requirements diminishing over time.

As a consequence of these and related activities, conservation agriculture has become official government policy, CA practices are advertised through public media and the Kazakh farmers union, and individual farmers are converting their drills to zero tillage at their own expenses. Early adopters observe a clear and immediate cost savings through chemical fallow and zero tillage – savings that are likely to increase as the cost of glyphosate continues to decline. It is too early, however, to predict whether this early promise will lead to truly widespread farmer use of CA technologies.

It is unclear the extent to which an "innovation system", with its own inner dynamic – of co-evolution between institutions and technologies – has emerged. The existence, however, of collaboration among International Centers, FAO, farmers organizations, private sector implement manufacturers, and Brazilian counterparts seems to be a favorable indicator, as does the apparent impact of the fledgling innovation system on public policy.

COMMON FACTORS AND LESSONS LEARNED

The above sections have illustrated the development of CA practices across a wide range of environments – from the high-rainfall, sloping fields of southern Brazil to the semi-arid sandy fields of southern Africa, and from very small farms in China to very large farms in northern Kazakhstan. In these varying situations, CA has been called upon to address a wide range of productivity and sustainability problems. Despite this variability, there are a number of factors that all examples have in common. These are discussed below, and summarized in Table 1.

- *Emphasis on development and adaptation of suitable implements, often using prototypes from elsewhere*. Without locally adapted implements, conservation agriculture rarely makes headway. It is not untypical that implement development and adaptation takes around ten years. The swift adoption of wheat zero tillage that began in the late 1990s in the Indo-Gangetic Plains would not have taken place without the Pantnagar drill, which was an adaptation of a prototype drill imported from New Zealand. In Brazil, direct sowing implements were adapted from prototypes imported form Kentucky. In Shanxi Province in China, the key components were adapted from prototypes brought in from Australia. Basic elements of the no-till drill now being manufactured in northern Kazakhstan were brought in from Brazil. Even in Tanzania, work continues on local adaptation of the Magoye Ripper, developed in Zambia.
- *Participation of the private sector in implement development, adaptation, manufacture and marketing*. Once again, this is a common factor across regions. National Agro-Industries in India, Greenland in Pakistan, Semeato in Brazil, the Shanxi Xinjiang Machinery Factory in Shanxi Province of China, and so on.

Table 1. Comparison of regional experiences in the development and use of CA practices

Location	Water regime	Problems or concerns leading to interest in CA practices	Examples of early/ major champions of CA	Sources of technical mentoring	Source of prototype implements	Role of private sector in implement development
Southern cone of Latin America/ Southern Brazil	High rainfall	Rapid erosion and degradation in lands converted from livestock or coffee to crops such as soybean	ICI, Semeato, GTZ, IAPAR, innovative farmers	Rolf Derpsch, GTZ; University of Kentucky	Kentucky, USA	Full partner through the research and development process
Southern Africa/ Zimbabwe toplands	Low rainfall	Late sowing, drought stress in crops, low soil fertility	African Conservation Tillage Network	Kurt Steiner, GTZ; Martin Bwalya, ACT	Brazil, West African Sahel	Minor role to date
China (Shanxi)	Dryland	Drought stress, soil erosion	China Agricultural University and local partners	University of Queensland	Australia	Public sector entities that act as private sector companies were important partners
China (Shandong)	Irrigated	Groundwater depletion, high cost of pumping water	Provincial authorities	Ken Sayre, CIMMYT	Mexico	Not yet determined
China (Sichuan)	Irrigated	Crop residues no longer needed for fuel, scarcity of labor for agricultural work.	Tillage and Cultivation Department, Crop Research Institute, Sichuan Academy of Agricultural Sciences	Not yet determined	Not yet determined	Not yet determined
Central Asia/ Northern Kazakhstan	Low rainfall	Soil erosion in seasons of high snowfall, problem weeds that cannot be controlled through mechanical means; low yields in dry seasons.	Government of Canada, Kazakh Farmers Union	FAO, GTZ, CIMMYT	Brazil	Full partner through the research and development process
South Asia/ Indo-Gangetic Plains	Irrigated	Concerns about the sustainability of rice-wheat cropping systems	Rice-Wheat Consortium, Haryana Agricultural University, On-Farm Water Management Program in the Pakistan Punjab	IARCs	New Zealand, China	Full partner through the research and development process

- *Technical mentoring over several years*. The technical mentoring role of Rolf Derpsch in Brazil, and of Kurt Steiner and Martin Bwalya in southern Africa is well known and was in part noted above. But this same mentoring role was played by Peter Hobbs, RK Malik and Raj Gupta in the Indo-Gangetic Plains of South Asia, by Jeff Tullberg and Gao Huanwen in Shanxi Province in China – and by Ken Sayre and Wang Fahong in Shandong Province. A technical mentor is invaluable in helping guide and bring to fruition the development and adaptation to local circumstances of CA practices – including rotations, residue management, water and soil fertility management (not just no-till crop establishment).[10]
- *Strong local champions*. Local champions – among them ICI, Semeato, GTZ, IAPAR, and innovative farmers – were vitally important to sustained progress in the development of CA practices suitable for southern Brazil. But the same can be said of other regions – the ACT in southern Africa, China Agricultural University and local partners in Shanxi and, of course, the Rice Wheat Consortium for the Indo-Gangetic Plains in South Asia – this latter embracing such pioneering institutions as Haryana Agricultural University and the On Farm Water Management program in the Pakistan Punjab.
- *A crisis mentality that brings with it a willingness to consider radical departures from conventional practices*. Just as unprecedented problems of soil erosion and land degradation drove development of CA in Brazil, so did the problem of herbicide-resistant phalaris in Haryana lead to an urgent need to try "desperate measures" (among them, zero tillage). Soil compaction in the north China plain and drought problems in southern Africa have played similar roles in maintaining interest in adapting CA principles to local circumstances.
- *The emergence of a dynamic innovations system*. Successful development and adaptation of a conservation agriculture system in a particular region is facilitated by an open, dynamic and productive innovation system, as described earlier in the paper, ". . . a social phenomenon in which agents interact in several ways, creating multiple information flows [including] public research and extension systems, innovative farmers, commercial firms, foreign research institutions [that] form networks that co-evolve with the technologies that they create.". Creative information exchange, needs-drive research, and institutions that evolve to respond to important crises at hand – these are truly key factors.
- *A blurred area between RCTs and conservation agriculture.* Estimates of adoption of CA practices are typically difficult, because the extent to which all CA principles in a particular region have been met can be hard to determine. As a rule, success with an RCT (e.g., zero tillage for wheat after rice in the Indo-Gangetic Plains) is somewhat easier to achieve than success with a full-blown CA package.

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Resource Conservation Technologies in Rice-wheat Cropping System of Indo-Gangetic Plains

R.K. Malik, Ashok Yadav and Sher Singh
CCS Haryana Agricultural University, Hisar 125 004, Haryana, India

ABSTRACT : Resource conservation technologies which include zero-till planting of wheat, bed planting of crops, laser aided land leveling etc. have emerged as a major response to stagnating crop yields and declining profitability of rice-wheat cropping system farmers in the Indo-gangetic plains. Evolution and accelerated adoption of zero tillage is a significant step paving way for more comprehensive Conservation Agriculture systems which involve retention of crop residues on soil surface and include appropriate crop rotations. The wide spread adoption of new technologies is attributed to benefit to farmers in terms of reduced production costs, enhanced productivity and improved inputs use efficiency. Retaining and managing adequate amount of crop residue is on soil surface will be a key to reversing processes of degradation and enhancing resource quality. Future R and D efforts would need to take a more holistic view of sustainability concerns in developing and promoting technological, policy and institutional options for sustained resource use and profitability of production systems of the region.

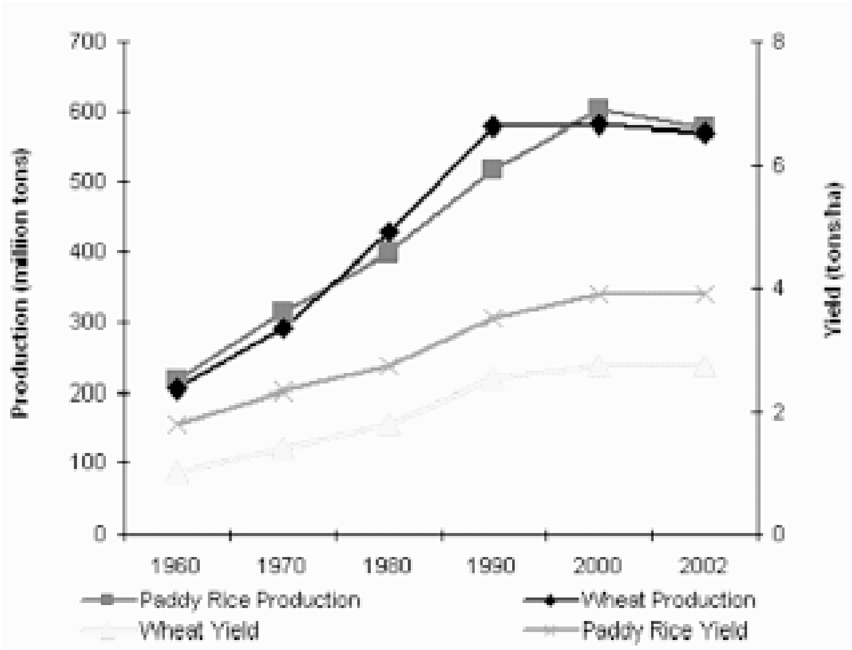
INTRODUCTION

The assessment on the scientific, technical and institutional issues associated with rice-wheat cropping system is urgently needed. For the past 40 years, the growth in the productivity of rice-wheat cropping system was the result of technological innovations in the form of green revolution. With the result, supply exceeded demand and real prices of food such as cereals went down. However, the yield growth rate of many crops especially cereals have started declining. Reasons for declining in the productivity growth rate are multiple (Duxbury *e al*., 2000; Ladha *et al*., 2000; Timsina and Connors, 2000). Sustainability and profitability of rice-wheat cropping system in Indian agriculture is the lifeline and future of Indian economy with more than 60% people living in rural areas. The challenges are enormous ranging from conservation of natural resources to investment in new technologies based on biotechnology.

GREEN REVOLUTION TECHNOLOGIES

The green revolution is one of the most striking success stories of post-independence India. The success was reflected through more efficient dry matter partitioning to reproduction and therefore, higher harvesting index with significant gain in the yield potential. It is the combination of green revolution varieties and their responses to external inputs, which produced meaningful advances in agricultural productivity. More than 90% farmers have adopted semi-dwarf wheat by 1997 (Pingali, 1999). It is not easy to escape a general relationship between grain productivity and fertilizer nitrogen especially after the evolution of semi-dwarf varieties. It is estimated that irrigated lands have expanded to reach 268 m ha with 80% in developing countries and much in Asia. This expansion is now slowing down (FAO, 1998). In addition to nitrogen fertilizers and expansion of irrigation, there has been a consistent increase in the use of external inputs including pesticides. Thanks to green revolution, the higher food availability without using the extra land represents a success story in agriculture (Fig. 1).

These were not varieties alone which transformed the food production scenario, but the response of these varieties to external inputs brought about a major change in the food production. The gross consumption of fertilizers increased 25-fold in developing countries



Source: FAO Statistical Database, 2003

Fig. 1. Global rice and wheat yield and production trends.

to reach 91 mt in 2002, but only increased 2-fold in developed countries. The use and rates in the developing countries surpassed that in the developed countries in the early 1990s (Cassman *et al*., 2003). The green revolution has slowed sharply, as has yield growth, since the 1980s. The slow down or even reversal has been due to water table lowering because of ever deeper tubewells, micronutrient depletion, mono-culture, reducing bio-diversity and buildup of insect, diseases and weeds, development of resistance against pesticides and high concentration of pesticides or fertilizer-derived nitrates and nitrites in water courses. The amelioration of above factors adds to the cost of cultivation and, therefore, a decline in the total factor productivity. With the rise in input cost, the net profit of farmers has fallen even if the productivity is increasing slightly. Each farmer, therefore, needs to maximize earnings through alternate technologies. Seen from profitability point of view, it will be important to maintain natural resources. Resource Conservation Technologies (RCT), therefore, have become a critical component to growth in agriculture. These technologies require complementary innovations through multi-disciplinary, multi-institutional and farmer's participatory approach. This is important because the livelihood of more than a billion agricultural populations in developing countries will depend on technologies that raise outputs per labour-hour and per unit area at less cost (Lipton, 2004).

ZERO-TILLAGE

The major challenge before us is to organize ourself to meet the need for continuing productivity increases. According to McCalla (1998) much of the yield increase must come in the developing countries which will depend on: (1) what mode of scientific investigation will best generate the next phase of crop yield increases across very variable economic and institutional conditions, (2) how will the technology development process best be linked to other support services and institutions in order to increase productivity in farmers' fields, and (3) how can the synergies between genetic improvement and crop and resource management research be best exploited when organizational dynamics and creating increasing separation ?

A holistic approach is needed to tackle these second-generation problems and to improve the sustainability of this cropping system. However, interventions in the form of new resource conservation technologies (RCTs) must include the component of profitability, value addition, efficiency and farmers' participatory approach for their large-scale acceptance. Introduction of zero-tillage in wheat in Haryana and thereafter its popularization in the adjoining states of India during last eight years is a unique example in this context. Benefits of zero-tillage technique in wheat realized at farmers' fields have also been summarized in this paper.

For the past eight years, the evolution and acceleration of zero-tillage in Haryana has been one of the few big ideas in introducing conservation agriculture. Farmers in the Indo-Gangetic Plains have now rediscovered the virtue of technologies like zero-tillage and bed planting because they are profitable and add value to the system as a whole.

Advances in this context will depend on the investment in public research which is much less than what existed between 1966 to 1985. Work on resource conservation technologies like zero tillage in Uttar Pradesh under NATP project has been found to increase productivity in crops like wheat (Fig. 2).

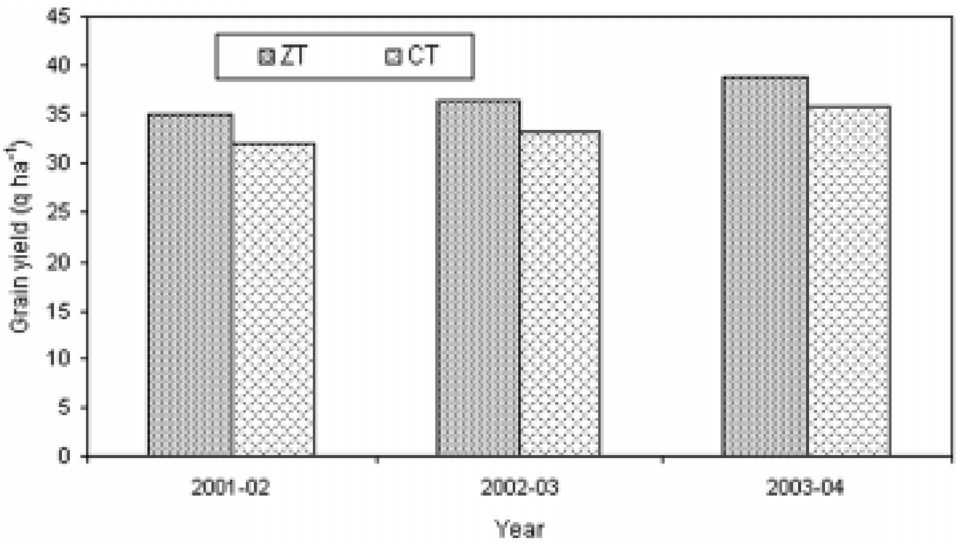


Fig. 2. Year-wise average productivity of wheat based on demonstrations conducted in 17, 20 and 23 districts covering 550, 1430 and 9510 ha area under NATP project during 2001-02, 2002-03 and 2003-04, respectively.

Such mode of scientific investigation that leads to more productivity with less input cost will help generating next phase of yield increases especially in areas where wheat sowings are delayed beyond admissible limits. Technologies like zero tillage and other resource conservation technologies including bed planting, direct seeded rice, double zero tillage, leaf colour charts, green manuring, water harvesting, water recycling will help stimulating economic growth especially in the light of projected environmental changes. The long-term yield data based on the average of six sites in Haryana have shown that such technologies like zero tillage are sustainable even in the light of favourable weather (1999-2000 and 2000-01) and unfavourable weather (2001-05; Fig. 3). The year 1999-2000 stands out to be the best year because there was no problem of terminal heat and it was considered most favourable year because crop could get maximum time to grow and reproduce. This is also the year when the yield of wheat peaked and the wheat production was at its all time high. In the subsequent years, the grain yield of wheat has remained lower and seems to be highly dependent on the weather conditions and its effect on length of the growing season. All this

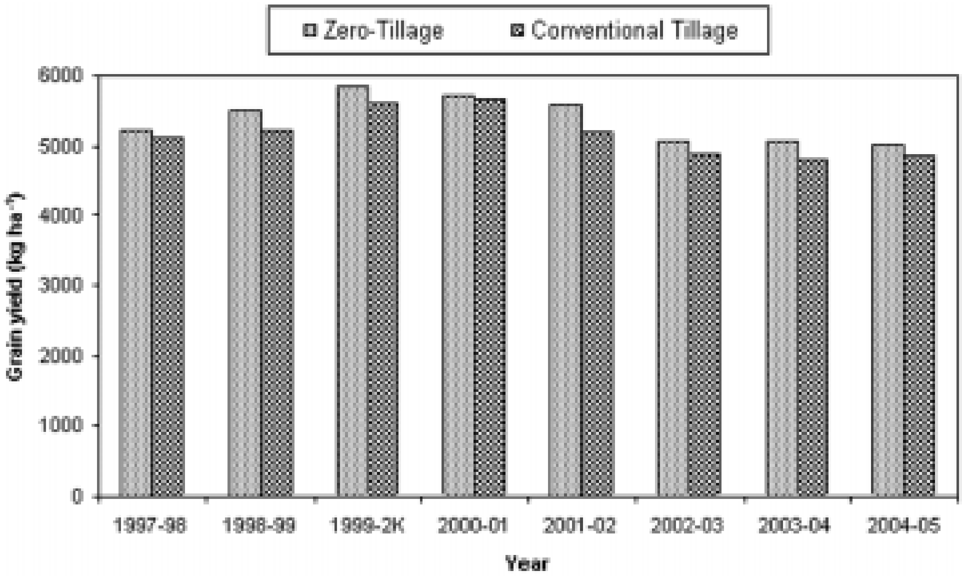


Fig. 3. Sustainability of zero-tillage based on average of six sites at farmers's fields where farmers had been practising zero-tillage continuously for eight years in Haryana.

suggests that sowing the crop as early in the season as possible is perhaps the most important issue. Only early sowings can help combating the effect of terminal heat as was experienced during last four years. The average yield of wheat under zero-tillage at six long-term sites in Haryana when plotted against the yield of conventional tillage, it was clear that productivity gains give a new meaning to the management technologies of rice-wheat cropping system which now demands early sowing of both rice and wheat. What really matters is the availability of technologies which allow sowings with anchored crop residues retained on the surface. The availability of natural resources will remain a pre-condition for sustainability of the cropping system. When choosing among research paths, we should raise the productivity of land and water at less cost so that the total factor productivity of small farms rises faster than now.

Following factors need to be taken into account for generating new technologies in rice-wheat cropping system :

1. Ideally, farmers should cut spending rather than investing more on inputs like fertilizers or pesticides.
2. We must look for extra revenues to plug the gap in net profits. The best way to increase revenue is increase yields without increase in input use.
3. It remains true that yield is primarily a time phenomenon i.e. it is a function of time for which the crop remains in the field. That means longer the crop remains in the field for its growth and development, higher the grain yield. Most parts of Indo-Gangetic Plains (IGP) have the big difference in the base line when crop is sown. For instance, in the eastern sector of IGP, sowings are delayed beyond December. This is where maximum gains in productivity will come especially from North-East plane zones where sowing of wheat is delayed beyond December.
4. Many farmers especially small farmers spend their income as soon as they receive it, in effect, they have no seed money to invest in the next season. Whatever little money they save, farmers channel most part of saving into tillage operations. Technologies like zero-tillage can help scrapping such spending and provide room for diverting the spending towards input that improve yield.

5. Per capita arable land area is getting smaller. The arable land scarcity index as measured by per capita land area was 0.36 in 1960 and 0.14 in 1990 which is expected to be 0.12 in 2025 (Kaosa-Ard and Rerkasem, 2000). Similarly, the irrigated land area per capita is also declining which is 0.06 ha per capita.
6. Increase in the soil organic matter by retaining more residues on the soil is important. Promoting existing biological cycle and soil biological activity, maintaining environmental resources and using them more carefully and efficiently and reusing residues as much as possible can help sustaining the rice-wheat cropping system. Thus, minimizing only pollution both on-site and off-site is an important feature of reducing soil degradation.
7. Rice-wheat cropping system requires enormous expenditure of energy to frequently till the land and to pump the groundwater for irrigation. To sustain the energy based activities, diesel consumption will increase in future decades. Saving of diesel consuming operations can help sustaining the import of oil for other purposes.
8. The water resources are under great stress. The real water saving will come by obtaining more crop production from same amount of water. Bed planting and laser levelling can help to reduce this stress.
9. Puddling of alkali soils further degrades the soil structure, and can facilitate formation of subsurface plough pan further restricting the percolation of water through soil profile. Reduced infiltration slows down the process of reclamation, therefore, puddling should be avoided (Gupta and Zia, 2003). Work conducted by Kumar *et al*. (2005) and Reddy *et al*. (2005) has shown that puddling can be avoided in transplanted rice.
10. The existing practices like straw burning leads to pollution, which is spread of, from smoke of burnt straw. Farmers do not bear the cost of such pollution, which is publicly unacceptable. Zero tillage can effectively serve as an opportunity to evolve residue management technologies because management of surface residue is easier than incorporation.

Retaining and management of adequate amount of crop residues (at least 30%) under conservation agriculture is the key to realize long-term benefits and also to reverse the process of soil degradation. In a soil that is not tilled for many years, the crop residues remain on the soil surface and produce a layer of mulch. Retention of crop residues improves organic carbon content, water stable aggregates, bulk density, hydraulic conductivity and reduces runoff. But most of the farmers in Haryana and Punjab burn the crop residues to get their fields well cleaned before sowing. Therefore, to replace residue burning, and to realize benefits of residue cover under conservation agriculture, its efficient management through machinery modification is the need of time.

WATER SCARCITY

The global water scarcity analysis has shown that upto two-third of world population will be affected by water scarcity over the next several decades (Wallace and Gregory, 2002). More important, wherever in the world water is scarcest, which is mostly in developing countries, irrigation for agriculture gobbles up at least 75% and sometime as much as 90% of the available water (The Economist, 17 July, 2003). The agricultural community sees continued growth of irrigation as an imperative to achieve the goals adopted to reduce hunger and poverty. International Water Management Institute, Colombo, Sri Lanka estimated that 29% more irrigated land will be required by the year 2025, but productivity gains and more efficient water use might decrease this diversion to 17% (Rijsberman, 2004). Irrigation development has impaired the ability of many eco-systems to provide valuable goods and services and therefore, more attention should be given on sustaining the existing sources of irrigation rather than alternative sources. Alcamo *et al*. (2000) projected an 8% increase in the amount of water that should be diverted to irrigation if more sustainable means of production are adopted. The difference between 17% increase and 8% decrease is on the order of 625 km^3 of water, which is close to 800 km^3 of water that is presently used globally for urban and industrial use. Therefore, there should be more emphasis on water conservation and improved efficiency of use and reallocation of water from one use to another, presumably shifting to a higher value use. Gleick (2003) calls for a soft path for water with a focus on overall productivity of water rather than seeking new supplies. That would mean a paradigm shift from supply management to demand management in the form of integrated water resources management. The most tangible proposals that have come out of this direction are: (a) to involve users more in the management of water, often through the establishment of forms of water user associations; (b) to price water and/or make it a tradeable commodity; and (c) establish river basin authorities that integrate the usually fragmented government responsibilities for water into a single authority responsible for a hydrographically defined area, river basin.

The number of tubewells has grown exponentially in North-west India. Pump irrigation now dominates gravity irrigation in many countries. In the field, the upper limit of water productivity of well-managed, disease free water limited cereal crops is 20 kg/ha/mm (grain yield per ha water used). If the productivity is less than this, it is likely that major stress other than water stress such as weeds, diseases, poor nutrition or poor inhospitable soil health so, greatest advantages will come from dealing with these first (Passioura, 2004).

A big reorientation of crop and water science is needed. Development of varieties, which can resist moisture stress through the use of biotechnology, is necessary for increasing overall water productivity. There are no immediate prospects of producing GM crops that could greatly improve water productivity. There are hundreds of patents that claim drought tolerance but it is hard to discern any of these likely to influence water productivity in the field (Passioura, 2004).

OTHER RESOURCE CONSERVATION TECHNOLOGIES

Reducing non-beneficial evaporation losses in the field will lead to water saving. Changing to non-ponding/unpuddled rice cultures may help solve such problems (Table 1). The transplanting of rice under unpuddled conditions or under zero-tillage can be an alternative for improving water productivity in the medium soils. This has been successfully demonstrated in the NATP project at CCS HAU, Hisar. Zero-tillage has enabled farmers to sow their wheat crop immediately after rice harvesting and without any pre-sowing irrigation in some cases. The water saving under zero-tillage has been recorded at the time of first post-sowing irrigation (Hobbs and Gupta, 2003; Malik et al., 2004). Similarly, the bed planting of wheat can be used for a significant improvement in the water productivity (Fig. 4) but the success of this technology will depend on the type of soil and source of irrigation (Anonymous, 2005). Laser land levelling is an important component of resource conservation technology that can improve water productivity at field level (Gupta, 2003).

Under rainfed conditions a shift towards high productivity, decentralized micro-irrigation system can help saving water. Narayanmoorthy (2004) sees the potential of drip irrigation to help solve the water scarcity in India. The hope of installing rainwater-harvesting structures can shape vegetables or horticulture based cropping system in the profitable proposition. It may not work in cereal based cropping system. To spur entrepreneurialism farmers should be assisted to change from subsistence to commercial objectives.

Table 1. Double zero-tillage in rice-wheat cropping system at farmers' fields in village Dhons district, Kaithal (Haryana)

Treatment	Grain yield (t ha^{-1})		
	Rice		Wheat Rabi 2002-03
	2002	2003	
Varieties			
IR 64	5.59	5.90	-
HKR 126	6.07	6.41	-
C.D.	0.22	0.26	
Crop establishment techniques			
Puddled-transplant	6.33	6.72	4.90
Puddled-broadcast	5.33	5.60	5.07
Zero-till-transplant	6.36	6.74	5.15
Zero-till-broadcast	5.29	5.56	5.26
C.D.	0.31	0.38	NS

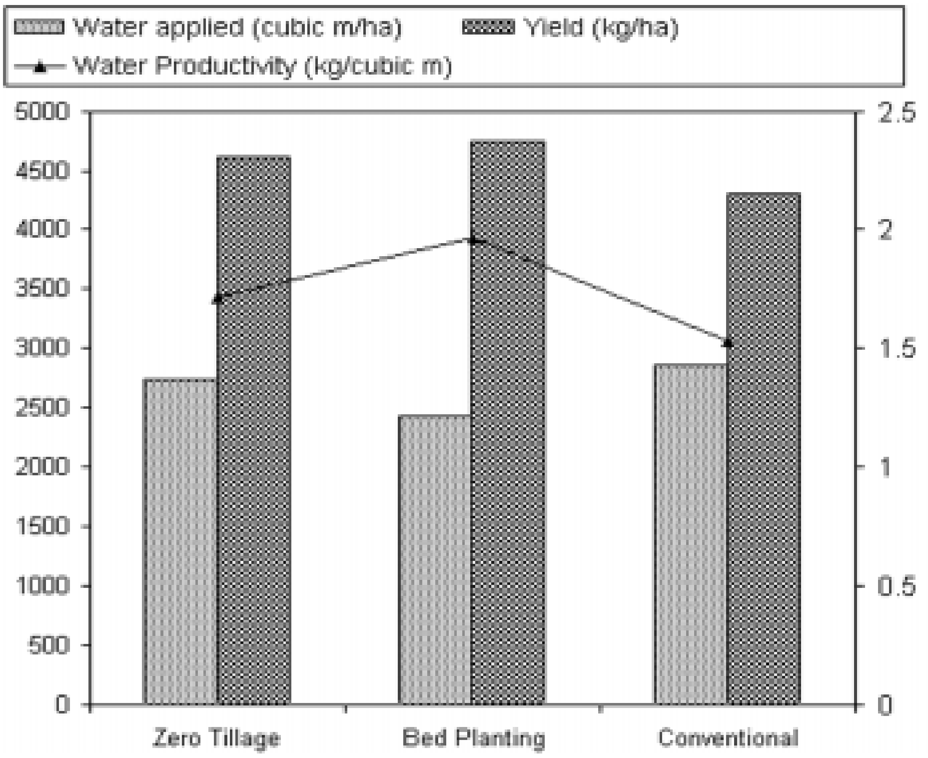


Fig. 4. Grain yield and water productivity of wheat under different crop establishment techniques.

Results of primary trials conducted in different crops under furrow irrigated raised bed system (FIRBS) in S-W Haryana have indicated immense saving in irrigation water. It can also be a very useful technique for introducing intercropping and crop diversification, however, yield penalties at some locations and overall economics under FIRBS pose a question mark on the success of this technique. Similar results have been realized in direct seeded and transplanted rice under FIRBS in rice-wheat growing areas of Haryana. Other techniques including zero-tillage in transplanted rice and zero-tillage direct-seeded rice call for efforts to be shifted from wheat to rice for measures to conserve resources. Based on multi-locational farmers' field trials in Haryana during 2001 and 2002, it was realized that puddling, the most common practice followed by the growers in rice, is not necessary to achieve higher grain yields. Successful crop growth and comparable grain yields of rice crop under zero-till-transplant and unpuddled-transplant (dry field preparation fb irrigation prior to transplanting) were attained during both the years. Direct seeded rice under zero-tillage, and puddled and unpuddled situations could be other options for raising this crop and avoiding tedious practice of transplanting.

DIVERSIFICATION

Many scientists conclude that diversification of RWCS is the only answer to sustain the productivity of this cropping system (Johl, 2002). Based on such recommendations, policy makers planned to get rid of the part of rice-wheat cropping system and concentrate on diversification of this cropping system. However, the average profitability RWCS was higher than alternate cropping system (Singh and Sidhu, 2004). The advocates of diversification need to notice that farmers specially the small land holders cannot take risk associated with the profitability of an alternate cropping system. Results of diversification so far are unimpressive (Rangi, 2004). The RWCS does seem to need diversification. However, farmers are not happy with the relative profit offered by diversification. Researchers now a days should know what is does and what does not work. Any research output is good if it attracts farmers and is bad if it repels them. So, there remains an opportunity for large scale introduction of resource conservation technologies (RCTs). The balancing effect of RCTs will allow RWCS to maintain the ecosystem without having to diversify on a large scale. It serves as an effective signal for a new avenue for research investment in management of rice fallows in places like Bihar and Eastern Uttar Pradesh. This type of measure for early sowing (a non-cash input) through the use of zero tillage technology will invariably serve the public good and will benefit all farmers.

More profits will bring about demand for better living and means to bring about such changes. The policy makers have embarked on initiatives like introduction of alternate cropping systems to conserve natural resources. However, anticipating less profits and more risk, farmers have not accepted this alternative. Correcting this may still take some time. In the meantime, on account of more profits and social benefits, accelerated adoption of zero tillage best fits the thesis of resource conservation for sustainability of RWCS

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Conservation Tillage and Crop Residue Management in Rice-Wheat Cropping System

K.K. Singh and S.K. Sharma
Project Directorate for Cropping Systems Research, Modipuram, Meerut 250 110, Uttar Pradesh, India

ABSTRACT : A 6-year field study was conducted to evaluate the effect of five conservation tillage practices (zero till drilling, strip till drilling, rotary till drilling, bed planting and conventional sowing) and crop residue management practices (retrieval, burning and recycling) in rice- wheat cropping system on crop productivity and profitability, water requirement and soil health. The zero, strip and rotary till drills recorded effective field capacities of 0.59, 0.46 and 0.49 ha h^{-1}; provided savings in time (74 to 79%), labour (64 to 71%), fuel (67 to 85%), cost (65 to 81%) and energy (67 to 85%) compared to conventional sowing. The bed planter recorded effective field capacity of 0.39 ha h^{-1} and needed slightly more time, labour and fuel; and slightly less cost and energy compared to zero, strip and rotary till drilling; but it was far superior to conventional sowing. The bed planting saved about 72, 62, 84, 78, 84, 34 and 25% in time, labour, fuel, cost, energy, irrigation water, and seed and fertilizer compared to conventional sowing. Also, around 70 kg/ha/year CO_2 emissions to the environment could be reduced by the use of zero till compared to conventional sowing. The rotary, strip and zero till drilling; and bed planting of rice and wheat provided higher yields (2 to 8%); were cost effective (9 to 27%) and energy efficient (21 to 32%); and increased the soil organic carbon by 13 and 9 percent and mean weight diameter of aggregates by 49 and 20 percent after six-crop cycles whereas conventional sowing reduced the organic carbon and mean weight diameter of aggregates by 4 and 11 percent, respectively. The recycling of rice and wheat residue needed Rs 1350 ha^{-1} cost and 1250 MJ ha^{-1} energy. The *in-situ* recycling of wheat straw provided rice yield of 6.3 t ha^{-1} that was, respectively, 11 and 7 percent higher than residue retrieval and burning. The net return for residue recycled fields was 5.7 percent higher but B: C and energy output: input ratios were 1.4 and 13 percent lower; and specific cost and specific energy 1.4 and 15 percent higher compared to residue burning and retrieval. Residue recycling of rice provided maximum wheat yield followed by burning and retrieval respectively. The recycling increased the wheat yield (13%), net returns (15%) and B: C ratio (3%); but decreased energy output: input ratio (2%); and increased specific energy (2%) and specific cost (10%) compared to residue retrieval. There was an increase in the soil organic carbon (15 and 23%) and mean weight diameter of aggregates (9.1 and 9.6%) under residue recycling, respectively, compared to residue burning and retrieval.

INTRODUCTION

Rice (*Oryza Sativa* L.) and wheat (*Triticum aestivum* L.) are now grown in sequence over 26 M ha of south and east Asia to meet the food demands of rapidly expanding human population and brings together conflicting and complementary practices (Timsina and Conner, 2001). This system covers about 12 M ha in India (Kumar *et al.*, 1998) and is the backbone of country's food security with a yield potential of 8.12 t ha^{-1} $year^{-1}$ (Singh *et al.*, 1986; Bhandari *et al.*, 1992). Rice is transplanted in the first fortnight of July in puddled (wet tillage) soil, which leads destruction of macropores (Jamison, 1953) and reduction in permeability (Bodman and Rubin, 1948), the latter is highly desirable because it reduces the need for irrigation water. However, puddling leaves poor physical conditions for the succeeding wheat crop. Under such conditions, a primary deep tillage followed by some secondary tillage for seedbed preparation for wheat sowing in the last week of November to first week of December is the common practice (referred as conventional sowing). Recently a number of workers have advocated for zero or reduced tillage due to shortage of time between rice harvesting and wheat sowing. However, in north-western India where mostly medium-duration rice varieties are grown by timely transplanting (first week of July), the harvesting is done by the end of the October and wheat can be timely sown after rice.

Rice transplanting is a labour intensive and arduous operation. It requires 200-250 man-hours per hectare, which are about 25 percent of the total labour requirement for the crop production. Besides, it is time consuming and backbreaking operation. Paddy transplanting by labour results in low and non-uniform plant population due to which crop yields are reduced. Moreover, for want of proper equipment, labour productivity is decreased. It calls for evaluation and popularization of direct sowing of rice by suitable drills so as to cater the needs and requirements of farmers (Singh and Gangwar, 1999). Strip-till and zero-till drilling are considered to be partial conservation tillage system because, whatever type of tillage is performed, it is not the same over the whole width of the implement (Anon., 1987; Wiese, 1985). Acceptance of conservation tillage depends, in part, on its profitability compared with other tillage systems, such as mould board ploughing. Profitability depends on the relative magnitude of revenues (yield x price) and total production costs. Conservation tillage systems have the potential to reduce the production costs by requiring less time, labour, fuel, energy and machinery inputs. However, conservation tillage systems may require more pesticides and a higher management level to maintain or increase yield (Brown *et al.,* 1989). Colvin *et al.* (1990) suggested how a soil tilth index could be used for tillage management, which provides a potential for saving in energy and time by avoiding unnecessary tillage operations beyond a certain tilth index. Acceptability of conservation tillage depends on its profitability compared with other tillage systems. Puddling breaks capillary pores, reduces void ratio, destroys soil aggregates, disperses fine clay particles, and lowers soil strength in the puddled layer (Sharma and De Datta, 1986). It helps control weeds, improves water and nutrient availability, and facilitates transplanting. In such soils, rice roots are largely confined within the puddled layer and few penetrate below 20 cm. This results from the shallow-rooting behavior of rice and the physical resistance to penetration offered by the compacted layer (Beyrouty *et al.*, 1987). The anaerobic condition of flooded soils immediately after rice cropping, the imparted soil structure of the puddled layer and compacted layer that strengthens to form a hard pan of increased strength on drying are major impediments to the establishment and growth of ensuing crops (Meelu *et al.*, 1979; Kirchhof and So, 1996). The deleterious effects depend upon soil type. The destruction of soil aggregates by puddling leads to the formation of surface crusts and cracks on drying, delaying preparation of a seedbed for ensuing crops. When broken by tillage, the resulting large clods provide poor contact with seed, thereby restricting germination. Subsurface compaction caused by puddling generally reduces root growth of wheat (Oussible *et al.*, 1992; Aggrawal *et al.*, 1995), although roots that penetrate the compacted layer before it hardens on drying may extend more deeply as the soil drains (Sur *et al.,* 1981). Little is known of root growth of wheat in rice-wheat systems on puddled soils of heavy texture. Deep tillage (sub soiling) reduces bulk density and soil strength and thus can enhance root proliferation (Bennie and Botha, 1986) by influencing the rate of root extension (Gajri *et al.,* 1991). Frequent wetting of the soil also reduces soil strength. Better rooting on a sandy soil helped to avoid water stress in beans (Miller, 1987). The present study was, therefore, conducted to evaluate the effect of different conservation tillage and crop residue management practices in rice-wheat cropping system on crop productivity and profitability, water requirement and soil health. Five conservation tillage practices, namely, zero till drilling, strip till drilling, rotary till drilling, bed planting and conventional sowing; and three crop residue management practices, namely, residue retrieval, residue burning and residue recycling are being evaluated.

MATERIAL AND METHODS

Site characteristics

A field experiment was conducted for 6 years (1998-1999 to 2003-2004) at the experimental farm of Project Directorate for Cropping Systems Research, Modipuram, Meerut, U.P., (29° 4' N latitude and 77° 46' E longitude) at an elevation of 237 m above mean sea level. The climate of Modipuram is broadly classified as semi-arid sub-tropical characterized by very hot summers and cold winters. The hottest months are May-June, when maximum temperatures may shoot up as high as 45-46 °C, whereas during December-January, the coldest months of the year, the minimum temperatures often goes below 5°C. The average annual rainfall is 862.7 mm, 75.80 percent of which is received through Northwest monsoon during July to September. The soil of experimental field was sandy loam (64.2% sand, 18.5% silt and 17.3% clay) in texture (Typic- Ustochrept). The pH of the soil was 8.02, EC-0.42 d S m^{-1}, OC - 0.4%, Olsen P 3.5 mg kg^{-1} and available K 36 mg kg^{-1} of soil as determined by procedures described by Prasad (1998).

Treatments

Two sets of field experiments were initiated in July 1998 with rice (*Oryza sativa* L.). The treatments aimed at evaluating resource conservation technologies consisted of five methods of seeding, viz., zero till drilling, strip till drilling, rotary till drilling, bed planting and conventional sowing both in rice and wheat in split plot design. Each of the treatment was replicated thrice. In conventional sowing and bed planting plots, 2 harrowing, 2 cultivating and 1 planking operations were performed. The sowing was done with seed- cum- fertilizer drill and bed planter at the rate of 50 and 100 kg ha^{-1} for rice and wheat, respectively. The row-to-row distance in conventional sowing and bed planting were 200 and 120 mm respectively. Sowing with the zero, strip and rotary till drills was done directly on the fields without any soil preparation. The treatments under crop residue management practices experiment were straw recycling, burning and removal of one crop before the planting of the other crop in rice-wheat system. The rice was transplanted by self-propelled transplanter after managing the straw of wheat crop. Zero, strip and conventional drills planted the wheat after managing the rice straw. Same seed as well as fertilizer rates were applied and irrigation was applied as and when required.

Crop management

Rice and wheat received 120 kg N as urea, 60 kg P_2O_5 as single superphosphate, 40 kg K_2O as muriate of potash. Rice also received 25 kg Zn as zinc sulphate ha^{-1}. Nitrogen was applied in two doses, half at sowing and other half at first irrigation (21 days after sowing). Wheat received 5-8 irrigations and rice was irrigated as and when needed. Glyphosate @ 2.5 litres in 500-600 litres water per hectare was sprayed to kill green vegetation before 2 days of sowing. The crops were sown with seed drills as and when the field was in optimum moisture. Rice was sown in the second week of June and harvested in mid- October. Wheat was sown in the first week of November and harvested in the second week of April.

Specifications of the seeding equipment

The specifications of zero, strip and rotary till drills, and bed planter are given in table 1. The field performance of the equipment was evaluated using the standard RNAM test codes and procedures.

Table 1. Specifications of the seeding equipment

Parameter	Zero till drill	Strip till drill	Bed planter	Rotary till drill
Type	Tractor mounted	Tractor mounted	Tractor mounted	Tractor mounted
Rows (No.) x spacing	11 x 180mm	11 x 180mm	6 x 120 mm	11 x 160
Working width, mm	1980	1980	1500	1760
Source of power	Ground wheel	PTO shaft and Ground wheel	Ground wheel	PTO shaft and ground wheel
Rated speed	0.96 m/s	0.9 m/s	0.96 m/s	0.9 m/s
Metering mechanism	Horizontal fluted roller, 11 in number	Horizontal fluted roller, 11 in number	Horizontal fluted roller, 6 in number	Horizontal fluted roller, 11 in number
Furrow openers	Inverted T-type	Shovel type	Inverted T-type	Inverted T-type
Location of fertilizer outlet related to seed out let	Vertical fluted roller over adjustable orifice	Variable orifice with agitator	Vertical fluted roller	Variable orifice with agitator
Ground wheel, (shape and metal)	Lugged steel ground wheel, drive through sprocket and chain drive	Tractor PTO shaft (lugged ground wheel, drive through sprocket and chain drive)	Lugged steel ground wheel, drive through sprocket and chain drive	Tractor PTO shaft (lugged ground wheel, drive through sprocket and chain drive)

Soil and crop observations

The bulk density and moisture content of the soil was measured from 0 – 150 mm depth by core method (Black and Hartage, 1996). The soil cone index was measured by standard cone penetrometer. The N, P, K and organic carbon of soil were determined by procedure described by Prasad (1998). The mean weight diameter (MWD) of soil aggregates was measured by sieve analysis. The yield and yield attributing characters, weed parameters and water requirement were measured by standard procedures.

Statistical, economical and energy analyses

The data was statistically analyzed by using standard statistical packages. The economic and energy value of each input resource and operation and output (yield) was considered for the economical and energy analyses. The benefit: cost and energy output: input ratios were calculated and considered as economic and energy efficiency comparisons.

RESULTS

Comparative performance of different seeding machines

The comparative performance of zero till drill (ZT), strip till drill (ST), bed planter (BP), rotary till drill (RT) and conventional drill (CS) for rice and wheat sowing are presented in Table 2. Zero, strip and rotary till drilling and bed planting of rice were time (74 to 79%), labour (64 to 71%), fuel (67 to 85%), cost (65 to 81%), energy (67 to 85%) and also irrigation water (2 to 39%) saving compared to conventional sowing (Fig 1). The irrigation water saving under bed planting in rice and wheat was 39 and 34 percent, respectively compared to conventional sowing.

Table 2. Performance parameters of different machines

Parameter	ZT	ST	BP	RT	CS
Area sown, m^2	4000	4000	4000	4000	4000
Effective working width, mm	1980	1980	1500	1760	1980
Operating speed, km/h	3.8	3.2	3.7	3.8	3.7
Effective field capacity, ha/h	0.50	0.45	0.42	0.40	0.50
Field efficiency,%	72	73	71	79	79
Width of headland, m	2	2	2	2	2
Time of sowing, h	2.0	2.2	2.4	2.5	9.5
Fuel consumption, l/ha	7.1	8.75	8.6	16.1	48.8
Labour requirement, h/ha	4	4.5	5	5.5	21
Cost of sowing, Rs./ha	466	610	578	873	2456
Energy requirement, MJ/ha	407	501	493	916	2784

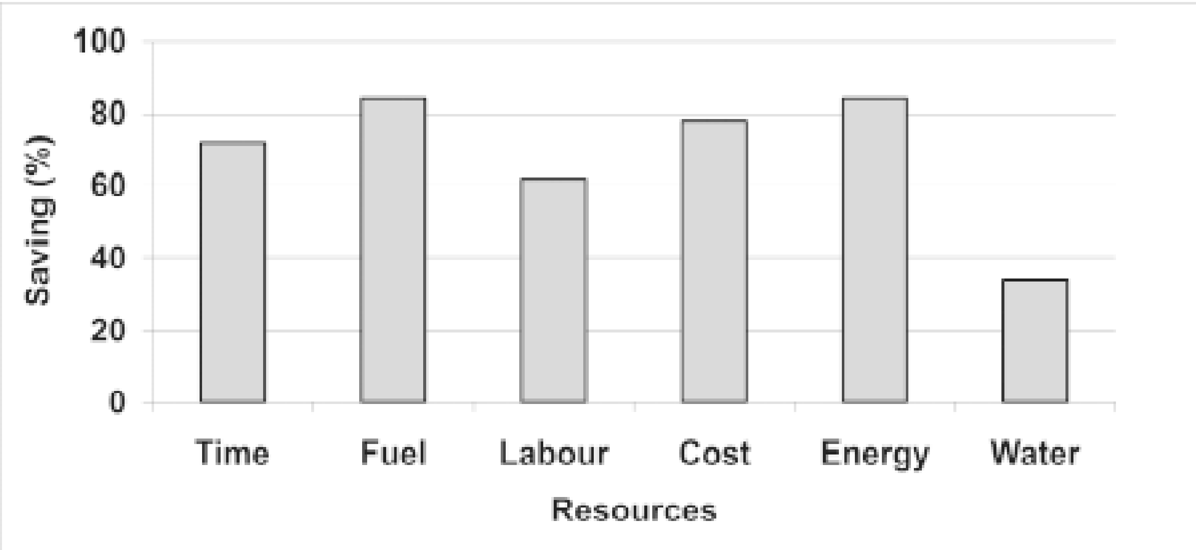

Fig 1. Average saving of resources under resource conservation technologies compared to conventional sowing.

Rice

Comparisons of resource conservation technologies

Strip till drilling provided highest rice yield, net returns, B: C ratio and energy output: input ratio; and lowest specific energy and specific cost compared to other planting methods (Figs. 2 to 4). Next in the decreasing order were rotary till drilling, zero till drilling, bed planting and conventional sowing. The advantages in strip till drilling were 8.2 percent in yield, 27.3 percent in net returns, 27.1 percent in B: C ratio, 31.5 percent in energy output: input ratio, 21.6 percent in specific cost and 24.0 percent in specific energy, respectively compared to

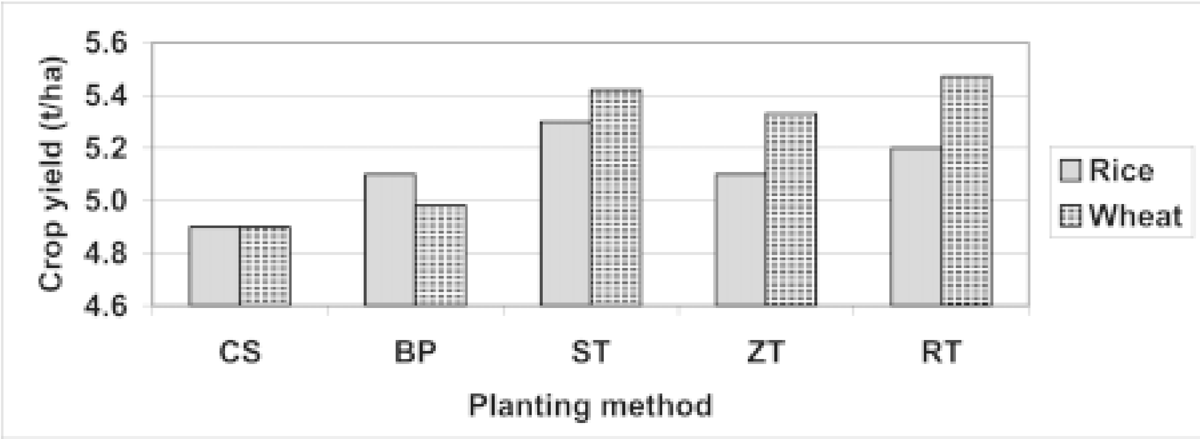

Fig 2. Effect of planting methods on rice-wheat yields (CS-Conventional sowing, BP-Bed planting, ST-Strip till drilling, ZT-Zero till drilling and RT-Rotary till drilling).

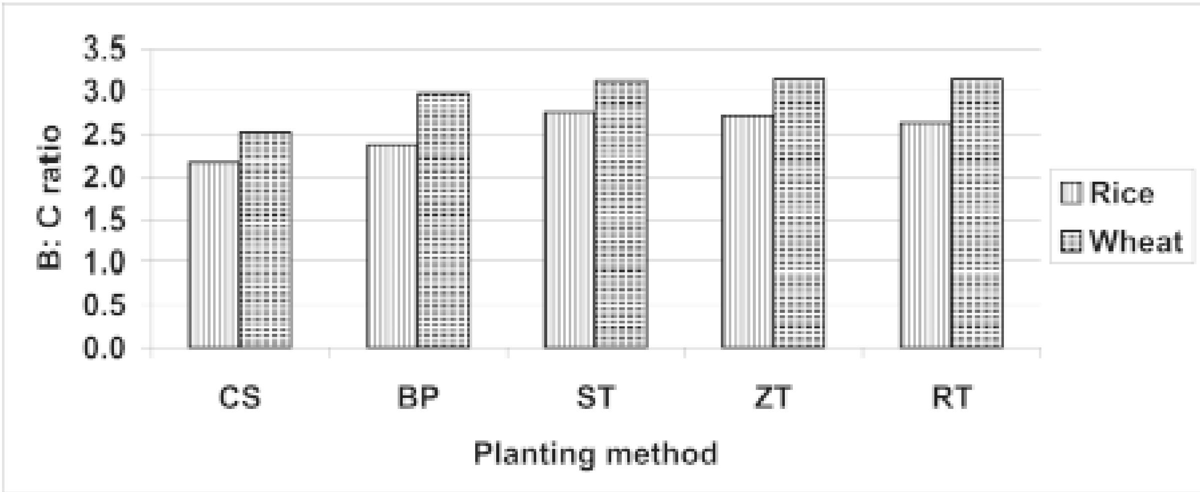

Fig 3. Effect of planting methods on benefit: cost ratio of rice and wheat (CS-Conventional sowing, BP-Bed planting, ST-Strip till drilling, ZT-Zero till drilling and RT-Rotary till drilling).

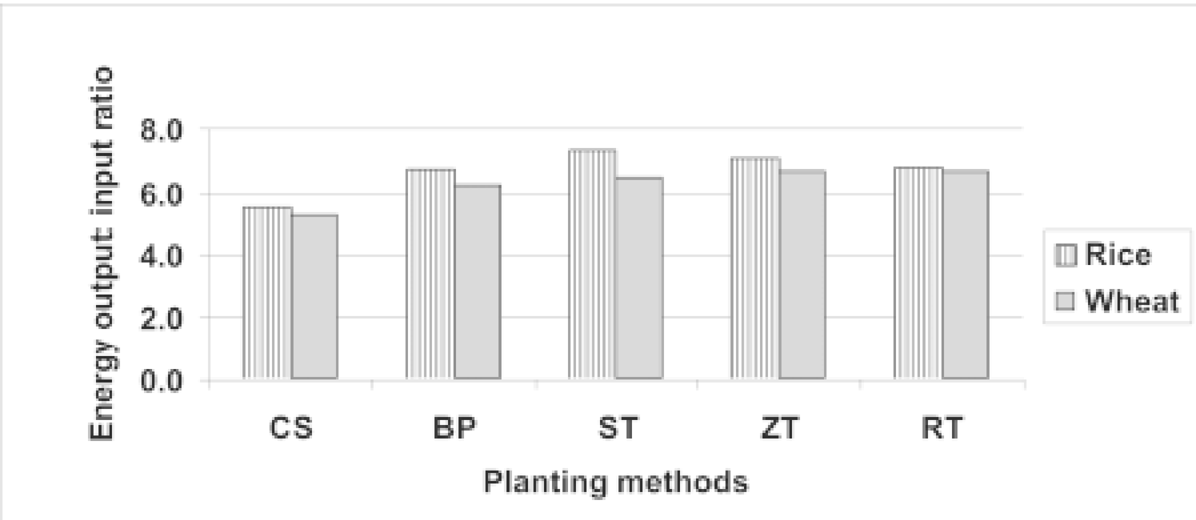

Fig 4. Effect of planting methods on energy efficiency of rice and wheat crops (CS-Conventional sowing, BP-Bed planting, ST-Strip till drilling, ZT-Zero till drilling and RT-Rotary till drilling).

conventional sowing. These advantages in rotary till drilling were 6.1 percent in yield, 21.5 percent in net returns, 21.1% in B: C ratio, 22.3% in energy output: input ratio, 17.4% in specific cost and 18.3% in specific energy, respectively compared to conventional sowing. The advantages in zero till drilling were 4.1% in yield, 21.3% in net returns, 24.8% in B:C ratio, 27.2% in energy output: input ratio, 19.7% in specific cost and 21.4% in specific energy, respectively compared to conventional sowing. The advantages in bed planting were 4.1% in yield, 10.9% in net returns, 8.7% in B: C ratio, 20.9% in energy output: input ratio, 8.3% in specific cost and 17.4% in specific energy, respectively compared to conventional sowing. The weed dry matter was, however, lowest under bed planting followed by strip, rotary and zero till drilling and conventional sowing (Fig 5).

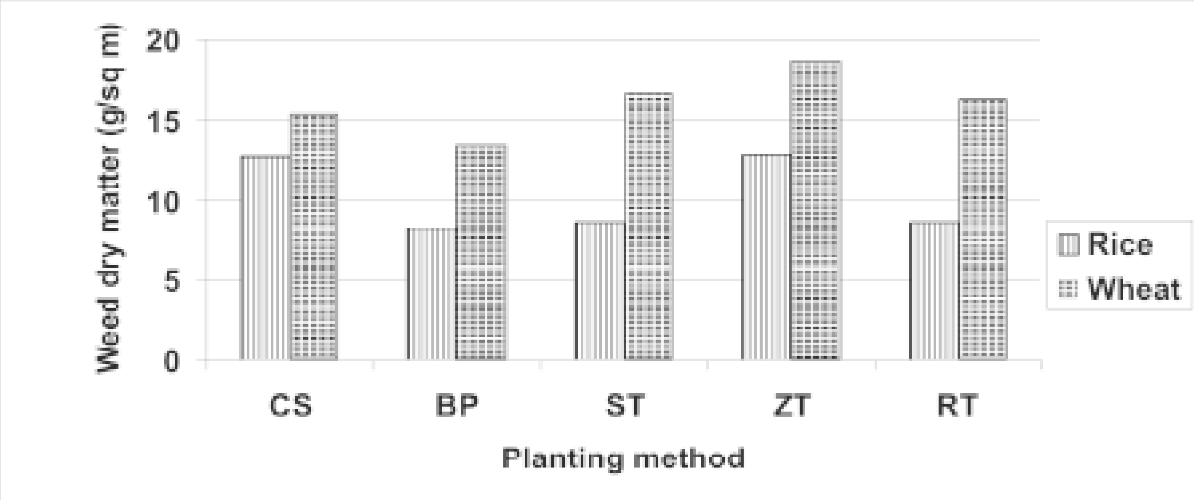

Fig 5. Effect of planting methods on weed dry matter in rice and wheat crops (CS-Conventional sowing, BP-Bed planting, ST-Strip till drilling, ZT-Zero till drilling and RT-Rotary till drilling).

Comparisons of crop residue management practices

The maximum rice yield (6.3 t/ha) was obtained under *in-situ* incorporation of wheat straw that was, respectively, 11 and 7% higher than residue removal and burning treatments (Fig. 6). The net return for straw incorporated fields was 5.7% higher but B: C and energy output: input ratios were 1.4 and 13% lower; and specific cost and specific energy 1.4 and 15% higher (Figs. 7 and 8). Different straw management practices in wheat indicated that incorporation of straw in soil was good straw management practice than burning and removal

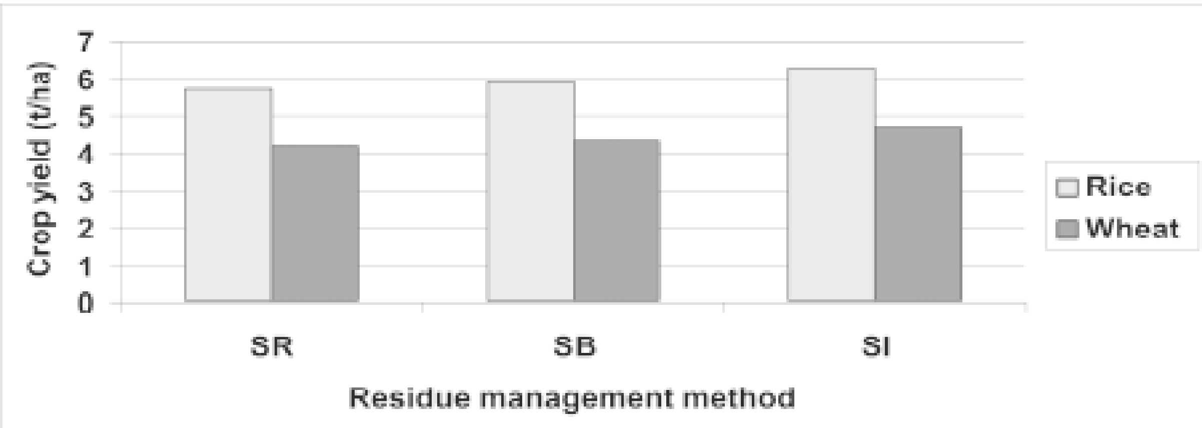

Fig 6. Effect of crop residue management practices on rice and wheat yields (SR-Straw removed, SB-Straw burnt and SI-Straw incorporated).

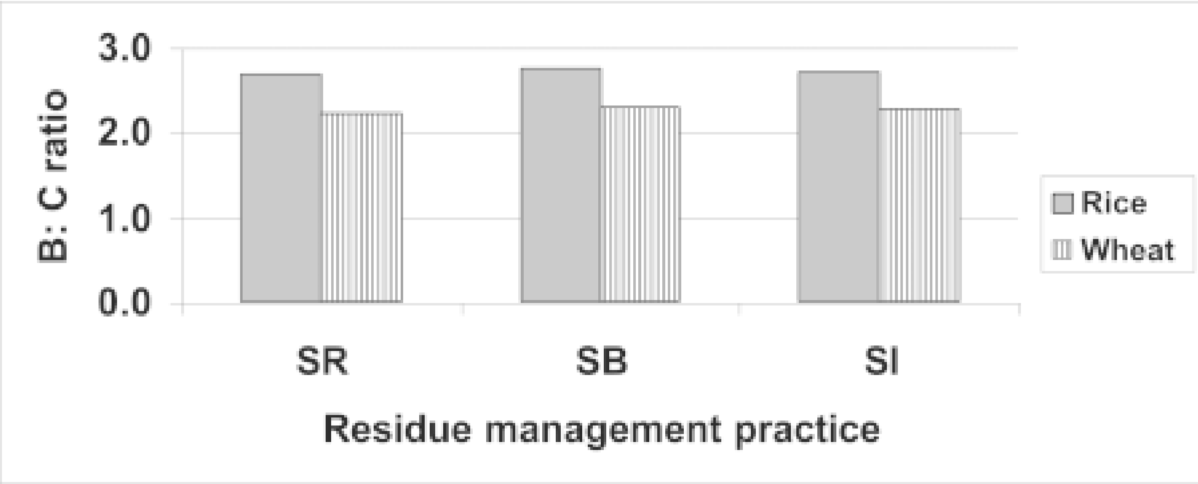

Fig 7. Effect of crop residue management practices on benefit:cost ratio of rice and wheat (SR-Straw removed, SB-Straw burnt and SI-Straw incorporated).

of straw for improving the physico-chemical properties of soil. As this practice provided lower soil cone index value and higher mean weight diameter of soil aggregates. It caused reduction in bulk density and improvement in moisture content in soil during the crop growth period. It also increased fertility status of soil by increasing organic C, available N, P_2O_5 and K_2O. The increase in soil OC and MWD under straw incorporation treatment was 14.5 and 9.1% respectively compared to straw burning, and 23.5 and 9.6% respectively compared to straw removal treatment.

Wheat

Comparisons of resource conservation technologies

The rotary and strip till drilling were economically and energetically beneficial in all the aspects of the comparison followed by bed planting, zero till drilling and conventional sowing. The rotary, strip and zero till drilling provided higher wheat yield (11.6, 10.6 and 8.8%), net returns (26.4, 25.4 and 22.3%), B:C ratio (25, 25 and 23.8%), energy output: input ratio (26.1, 26.1 and 21.9%); and required lower specific energy (20.6, 20.6 and 18%) and specific cost (20.1, 20.1 and 19.8%) compared to conventional sowing (yield – 4.9 t/ha, net returns – 25, 885 Rs/ha, B:C ratio – 2.52, energy output: input ratio (5.29), specific energy – 567 kcal/kg and specific cost – 3.49 Rs/kg (Figs. 2 to 4). The weed dry matter was again lowest under bed planting but followed by conventional sowing, rotary, strip and zero till drilling (Fig. 5).

Comparisons of crop residue management practices

Under different straw management practices, straw incorporation provided maximum wheat yield followed by burning and removal treatments respectively. The incorporation increased the wheat yield (13%), net returns (15%) and B:C ratio (3%); but decreased energy output: input ratio (2%) and increased specific energy (2%) and specific cost (10%) compared to straw removal treatment (Figs. 6 to 8). The increase in soil OC and MWD under straw incorporation treatment was 14.5 and 9.1% respectively compared to straw burning, and 23.5 and 9.6% respectively compared to straw removal treatment. Among planting methods, zero, strip and rotary till drilling of wheat were found more or less same but superior to bed planting and conventional method of wheat planting as far as the physico-chemical properties

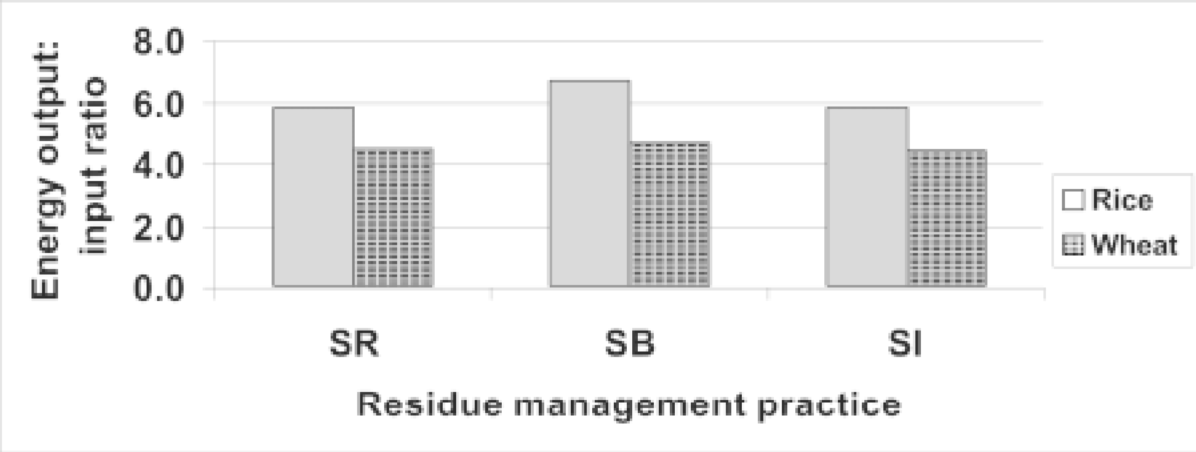

Fig 8. Effect of residue management practices on energy efficiency of rice and wheat crops (SR- Straw removed, SB- Straw burnt and SI- Straw incorporated).

of soil were concerned. Zero till drilling resulted in maximum moisture content at all the growth stages of crop and also had maximum bulk density, cone index and mean weight diameter of aggregates than any other method. In case of chemical properties of soil, there was no significant effect of any wheat planting method. ZT and ST also increased organic carbon (OC) by 13 and 9% and mean weight diameter of aggregates (MWD) by 49 and 20% after six crop cycles whereas CS reduced OC and MWD by 4 and 11% respectively.

CONCLUSIONS

The resource conserving technologies (RCTs) of zero, strip and rotary till drilling, and bed planting of rice and wheat saved 64 to 85% resources (time, labour, cost, fuel and energy). The bed planting also saved 39 and 34% irrigation water in rice and wheat, respectively. The RCTs provided higher rice yield (4 to 8%), B: C ratio (9 to 27%) and energy efficiency (21 to 32%) compared to conventional sowing. In case of wheat, the RCTs provided higher yield (9 to 12%), B: C ratio (23 to 25%) and energy efficiency (22 to 26%) compared to conventional sowing. Among the crop residue management practices, the incorporation of rice and wheat straw increased the yields of wheat (13 and 9%) and rice (11 and 7%), respectively, compared to burning and removal treatments but this treatment was not cost effective and energy efficient though soil organic carbon increased by 24% after six-crop cycles.

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Machinery for Zero-Till Surface Managed Crop Residue Systems — Progress and Prospects

T.C. Thakur and Arun Kumar
G.B. Pant University of Agriculture and Technology, Pantnagar 263 145, Uttaranchal, India

ABSTRACT : Combining of rice and wheat is increasing at a fast pace in Indo-Gangetic Plains (IGP). The loose straw delivered behind the combine harvesters poses many management problems but could be either collected mechanically and utilized in numerous ways or chopped and spread in the fields for conservation agriculture. The zero-till drills mounted with rigid tines and inverted-T openers work satisfactory under anchored stubbles but clog frequently under loose straw conditions. In recent past, a number of ZT-drills for loose straw conditions equipped with double disc openers, triple disc openers either with powered or unpowered plain disc coulters as well as star wheel type planter have been introduced whose working regimes need to be established. The requirements and prospects of these new generation ZT-drills for conservation agriculture have been critically analysed and a research agenda has been set for their further improvements.

INTRODUCTION

The recent past has seen not only a steady increase in zero-tillage, and specially in reduced cultivation, but also a significant change in attitude to these conservation practices. The deeply rooted tradition that thorough cultivation was essential for good husbandry, made it easy to assume that new methods at best be a convenient short-cut, lacking merit except for the economy of effort, and likely to incur a considerable risk, specially if practised for an extended period. But, all opinions did not support this view. Many years before, on the basis of extended research on cultivation at Rothamsted (U.K.), Keen and Russel (1937) had found "no justification for operation beyond the minimum to get a seedbed and to check weeds until the crop is well established. Work in excess on his minimum, far from increasing the crop, appreciably diminishes it". The clear hint that there could be positive benefits by avoiding the disturbance of soil at first attracted little attention.

Alternative tillage systems were created as a result of research or field experiments and they go in the direction of minimizing the machinery interference with the soil. They are known by various names such as minimum tillage, zero tillage, no-till, ridge till, strip till, mulch till, reduced-till or with their extreme form as direct sowing. Any tillage system that causes less than 25 percent of row width disturbance by planting equipment i.e. coulters, disc openers, in-row chisels or roto-tillers is considered a no-tillage system. Weed control is primarily done through weedicides, but cultivation may be done for emergency weed control.

Intensive research carried out in India during past one decade on zero tillage in farmers and manufacturers partnership has shown that if other inputs for higher productivity like nutrient management, water management, integrated pest management, crop diversification are same, then there is no difference in the yield between zero-tillage and conventional tillage practices. The expansion of zero-till technology in rice-wheat systems of IGPs could be viewed as a success story which started only on a few hectares during 1995-96 to a present level of over 1 M ha (ICAR report, 2004). The zero-till seed drill developed at Pantnagar has done wonders in promotion of zero-till technology in wheat after rice.

Current ZT drills are not so versatile and adequate for seeding under various soils and crop residue conditions encountered in zero-tillage practices. Proper seed placement is a very important component of the crop production system. Zero- till seeding requires drills capable of cutting through large quantities of crop residues, penetrating into untilled soil and dropping the seeds at 25-50 mm depth. The disc openers meant for trashy conditions fail to cut through the crop residues resulting in the seeds being placed either in the residues or on the soil surface. In softer soil, the trash is pushed into bottom of the furrow without being cut. With the fixed type inverted-T openers, crop residues tend to collect in front of the tine and block the machine operation resulting in improper seed placement. Therefore, there is a need to work out the operating parameters for ZT openers which can cut the residue and help to place the seeds at proper depth. In this paper, therefore, the issues related to production and management of crop residues with emphasis on the design requirements for different types of furrow/slit openers for surface managed residue systems have been discussed.

COMBINE HARVESTING IN INDIA

The combine harvesters were introduced at the advent of 'Green Revolution' in India and their numbers grew from 800 in 1971-1972 to over 18,000 at present (Thakur, 2004) . These combines are manufactured by over two dozen manufacturers of Punjab and Haryana and every year 900-1000 combines are added on Indian farms. Earlier the combines were used in Punjab, Haryana and Western U.P., but at present, they are being used extensively in whole of U.P., Uttaranchal, Bihar, Rajasthan, M.P. and southern states for harvesting of rice and wheat. The major reasons for popularization of combine harvesters in different states have been consistent labour shortage, high wage rate during harvesting season and uncertainty of weather. The combines have become a source of income to many of the agro-industries and private entrepreneurs who use them on hire-purchase basis at the rate varying from Rs. 1200-1500/ha for wheat to Rs. 1500-2000/ha for rice in different regions.

The 'combining intensity', defined as the ratio of total area of combine harvestable crops to the area actually harvested by combines expressed on percentage basis, is very high in the states like Punjab vis., 72.35 percent for wheat and 81.80 percent for paddy. The overall combining intensity of five different zones viz. Ludhiana (Punjab, Haryana and Rajasthan), Pantnagar (Western U.P. and Uttaranchal), Faizabad (Eastern U.P.), Bhopal (M.P., Bihar and Jharkhand) and Tavanur (Kerala, A.P., Tamil Nadu and Karnataka) has been reported to vary from 48-58 percent for paddy and 40-57 percent for wheat (NATP Project Final Report, 2003).

Availability and utilization of straw

The straw yield is usually calculated from grain production data based on grain: straw ratio which is averaged at 1:1.5 for wheat and 1:1.3 for rice. For the current level of rice and wheat grain production of about 165 million tonnes, nearly 225 million tonnes of straw is produced every year which shows a huge amount of straw available for disposal . According to an estimate out of over 10 million tonnes of paddy straw produced in Punjab, about 5 percent is used as cattle feed, 2 percent for making farm structures, 5 percent for paper and cardboard, 7 percent as packaging material for horticultural crops and other industrial goods like Chinaware and glass, and remaining 80 percent is burnt in the field. In India, field baling has been suggested as an option for collecting straw after combining in order to decrease the adverse effects of open field burning on environment and soil health.

It is to be emphasized that all of the straw cannot be recycled as it would pose problems in incorporating the huge quantity in every season on one hand while on the other, it would make the straw unavailable to other sectors of economy. Every part of straw could be utilized in one or other forms as cattle feed, paper, pulp and board making industries, chemicals, power generation, mushroom cultivation and other horticultural uses as shown in Fig. 1. This indicates that a comprehensive planning is needed so that each sector could get its share of straw on long-term basis.

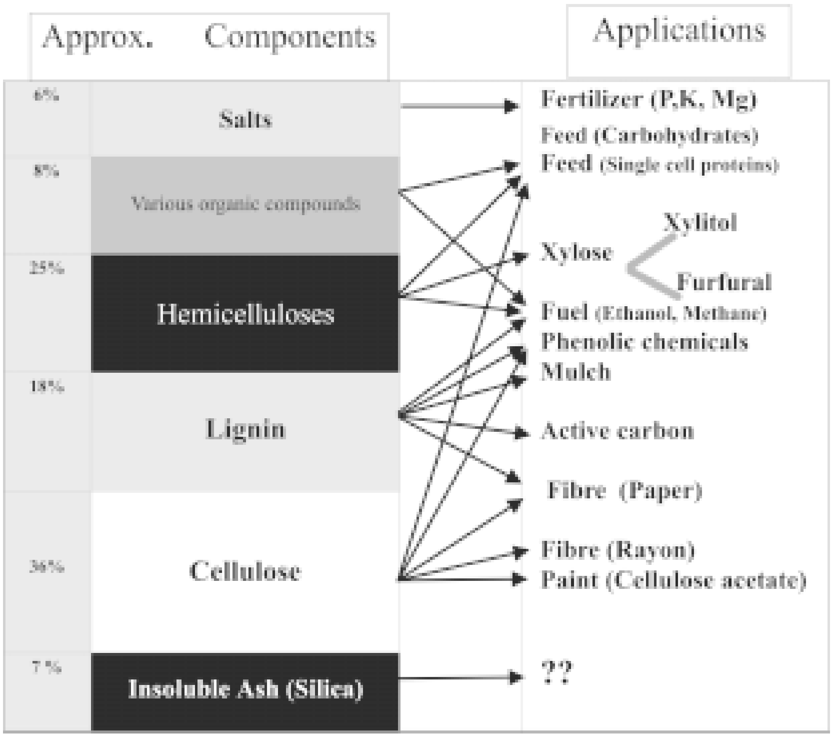

Fig. 1. Chemical composition of wheat straw and possible utilization.

The main issue is that in what form the straw is to be supplied for industrial utilization. The straw based power plants prefer straw in the baled form whereas the paper and board making industries prefer chopped (5-10 cm) and split straw. On the other hand, the livestock feed industry would prefer ground straw or straw of 2-4 cm size for making ready-to-eat complete feed blocks/pellets. Therefore, from economics and environmental points of view, the straw collected from the fields is processed on the farm itself from where the chopped straw of 5-10 cm size could be supplied to paper and board industries, straw less than 5 cm size could be supplied to subsidiary straw based livestock feed plant and the very fine particles including dirt, dust etc. could be re-cycled on the farm itself as organic manure.

Currently, five types of conventional field balers i.e. three imported models and two indigenous models manufactured in Punjab have been introduced on Indian farms for collection of straw after combining. The total straw which is actually available for baling after combining at different heights of cut is presented in Table 1. In the existing combining and baling system, over 35-40 percent of the potential available straw could be recovered and the remaining will be left in the fields which alongwith over 2.5 t/ha of root biomass would be enough to meet the soil health needs. As a thumb rule for conservation agriculture at least 30 percent of the crop residues should remain at the soil surface and the remaining could be removed from the field for further utilization. In direct drilling of wheat after rice, the stubble height of 15-20 cm has been found beneficial. Also, the lower portion of the crop is soiled by irrigation water, has less nutritive value, and not preferred either as animal feed or other uses and, therefore, could be recycled in the field itself. Presently, the combine harvesting is done at a height of 30-40 cm to recover mainly the grain but this could be reduced to 20 cm or so. If farmers have an assured market for straw at a sufficiently attractive price, they will consider paying the small penalty cost of slower combine speed which may be required for low cutting in order to harvest more straw. The planning of straw management system should be location specific and it should be such that where there is soil health problem, particularly on light soils, more straw could be incorporated, while in other situations, it could be removed from the field for industrial purposes.

Table 1. Zone-wise total straw availability after combining of wheat and paddy crops at different heights of cut

Zone	Total area (Mha)		Overall combining intensity (%)		Total area under combine harvesting (Mha)		Potential straw availability (Mt)		Maximum straw availability at different heights of cut (Mt)			
									Height of cut (cm)			
									15		30	
	Wheat	Paddy	Wheat	Paddy	Wheat	Paddy	Wheat	Paddy	Wheat	Paddy	Wheat	Paddy
Pantnagar	1.08	0.93	56.55	50.11	0.62	0.47	4.22	3.25	2.28	1.76	1.79	1.31
Faizabad	4.28	4.42	54.50	48.16	2.34	2.41	11.63	5.72	5.91	3.10	4.68	2.55
Bhopal	5.62	-	39.96	-	2.25	-	6.07	-	3.29	-	2.44	-
Ludhiana	5.21	3.52	43.03	58.07	2.24	2.05	13.15	8.73	7.11	4.72	5.29	3.51
Tavanur	-	7.67	-	49.90	-	3.83	-	14.36	-	7.78	-	5.78
Total	35.07	32.06	18.59	17.36	14.20	13.15						

Source: NATP Project Final Report, 2003.

MACHINERY FOR SURFACE MANAGED CROP RESIDUE

The importance of maintaining trash cover has long been recognized. However, this often interferes with the placement of seed in firm and moist soil, therefore, farmers frequently burn the fields which is not an eco-friendly practice. Seed could be placed in the soil in anchored stubble condition after partial burning for removal of loose straw. Uniform spreading of straw during harvesting itself by mounting a device at the rear of combine and then using drills under loose straw condition or chopping loose as well as anchored stubbles with a rotary shredder followed by residue drills are some of the viable options. The seeding machinery needed for such varied conditions and their limitations are discussed below.

Zero-till drills for anchored stubble conditions

A zero-till drill which could place seed into undisturbed soil was developed at Massey University, New Zealand. Scientists from CIMMYT made this drill available to G.B. Pant Univ. of Agril. and Tech., Pantnagar during early ninties. This drill worked well for sowing of wheat in anchored rice stubbles but was over 4-times costlier than Indian drills, needed more repair and maintenance due to frequent damage of sponge of metering system by rodents and was too heavy for 35 h.p. tractors commonly owned by Indian farmers. The ZT drill had inverted-T type slit openers. Using the basic design of ZT drill, mainly the inverted-T opener and existing conventional drill, an improved drill named as 'Pant zero-till ferti-seed drill' was developed in the Department of Farm Machinery and Power Engineering, Pantnagar. Further, design improvements were made in inverted-T opener for tearing of anchored stubbles, easy penetration of opener by changing rake and relief angles and by depositing wear resistant material at vulnerable sections of opener for its enhanced life. Subsequent modifications were also made in seed and fertilizer delivery system as well as depth control arrangements.

The Pant ZT drills are now manufactured by over 60 recognized manufacturers who have manufactured over 18,000 drills and supplied to different states. These drills are available in two-in-one version also, as raised bed planter-cum-ZT drill. The loose straw after combining could be collected with field balers, the drill can be used directly without any surface manipulation of residue and a system for combining, field baling and zero-tillage could be a viable option. To manage the straw from combine harvested wheat fields, the straw (*bhusa*) combine is also used extensively. The straw combine harvests the uncut straw as well as pick up the combine ejected loose straw from the field, chops the straw into fine pieces (bhusa) and blows it into an enclosed trolley trailed behind the tractor. The field could be drilled directly with rigid tines mounted inverted-T openers. Another option of using ZT-drill in combination with flail type residue chopper known as 'Happy Seeder' is also under trial in Punjab with promising results.

ZT-Drill for loose straw condition

Loose straw as well as anchored stubbles are left on the surface of the field after combining of crops. The ZT seeding of crop requires drills capable of cutting through loose straw, penetration into soil and placing seed at proper depth. Generally, four types of furrow openers i.e. single disc opener, double disc opener, triple disc opener i.e. double disc opener equipped with either powered or unpowered rotary disc coulter and star wheel punch planter are being introduced in rice-wheat cropping systems.

Single disc opener

The single disc type furrow opener cuts a furrow slice in the soil and pushes it to the side, thereby causing disturbance to the top layer soil. The boot for seed tube is placed at backside of disc. Generally, a single disc of 34 cm diameter sharpened at an angle of 9-10^0 and with concavity of about 2-2.5 cm is used. The openers are mounted at disc angle of 6^0 (with horizontal) and tilt angle of 3° (with vertical) to move the soil laterally. These furrow openers are recommended for tilled but trashy field conditions.

Double disc opener

These openers are provided with two flat and sharpened discs opposed to each other and set at a small angle to the direction of travel as well as to vertical with included angle of about 10^0. Discs are positioned in such a way that they form a V-groove in the soil by pushing the soil downward and sideways. The penetration of discs is obtained by applying downward force. The seed boot is located between the two discs. The openers are used in various soil conditions, especially tilled and trashy fields.

Performance of disc openers under loose residue condition

The double disc opener requires less draft (< 70 kg) but a large vertical force of 70 to 230 kg for penetration. However, in case of single disc opener, the draft is found less than 30 kg and a higher vertical force of 20 to 80 kg depending upon the depth of penetration and amount of residue. Investigations on the performance of various types of furrow openers and their combinations viz. inverted-T, inverted-T and coulter combination, inverted-T and row cleaning combination, single disc and double disc furrow openers under soil bin as well as combine harvested rice field conditions have been carried out at Pantnagar (Brahma Prakash, 1997). The results indicated that in case of inverted-T and coulter combination, the appropriate coulter position with respect to tip of the opener, in terms of horizontal and vertical clearances, should be about 9 cm and zero or little less (-1 cm), respectively, to obtain a depth of cut of 6 cm, maximum residue cutting, minimum clogging and draft. The adequate vertical load for necessary depth in zero-till residue condition should be 60-65 kg per opener-coulter combination. However, the vertical force for the same range of operation for single disc and double disc openers was found as 73.60 and 88.00 kg, respectively. The draft requirement per opener was found minimum with inverted-T and coulter combination (30 kg) followed by inverted -T opener (37 kg) and single disc (37 kg) but double disc opener required the maximum of 56 kg draft (Tables 2 and 3).

Table 2. Force requirements and residue handling capability of different furrow openers for 6 cm furrow depth under simulated zero-till wheat residue condition in soil bin

Parameter	Zero-till drill furrow openers[1]				
	Inv.-T alone	Inv.-T & coulter	Inv.-T & RCD	Single disc	Double disc
Vertical force per opener, kg	37.36	63.89	28.5	73.6	88.0
Draft/opener, kg	37	30	40	37	56
Residue handling capability	Poor	Good	Good	Good	Good
(a) Clogging,%	90-100	1	8	0.0	0.0
(b) Cutting,%	0.00	98	0.0	48	28

Source: Brahma Prakash (1997).

[1]Inv.-T : Inverted-T opener; Inv.T and Coulter : Rolling smooth coulter of 46 cm diameter and 3.5 mm thickness with 6-7^0 sharpening angle; RCD : Row clearing disc (34 cm diameter, 1.4 cm concavity and 18^o mounting angle) set 9 cm ahead of inverted-T opener; Single disc opener : A disc of 34 cm diameter, 2.25 cm concavity, sharpening angle of 9.5^o, mounted at disc angle of 6^0 (with horizontal) and tilt angle of 3^0 (with vertical); Double disc opener : Two flat discs of 34 cm diameter set at an included angle of 10^0.

Table 3. Performance of single disc and double disc openers under varying vertical loads in simulated zero-till crop residue condition in soil bin

Vertical load (kg)	Furrow depth (cm)		Draft/opener (kg)		Paddy straw cutting (%)	
	Single disc	Double disc	Single disc	Double disc	Single disc	Double disc
25	1.50	1.00	5.60	8.97	0.0	0.00
45	3.00	2.42	14.30	21.07	15.50	0.50
65	5.12	4.30	30.00	35.17	33.20	14.00
85	6.82	5.75	44.20	53.05	63.50	24.20
105	8.62	7.25	59.70	74.30	87.20	46.20

Source: Brahma Prakash (1997).

Coulter attachment with double disc opener

The failure of disc openers to cut through the surface residue results in seed being placed either in the residue or on the soil surface. In softer soil, the trash is pushed to the bottom of the furrow without being cut. The seeds are placed on the trash resulting in poor germination. However, smooth or ripple coulters with diameter greater than 40 cm have been used ahead of double disc coulters for effective residue cutting. Such arrangement has been termed as 'Triple Disc Combined Drill'. The effectiveness of residue cutting depends on many factors such as: (a) soil parameters i.e. bulk density, moisture content, soil strength parameters and surface conditions; (b) crop parameters: straw density, type of crop and variety, straw moisture; and (c) machine parameters i.e. type of coulter, position of coulter in relation to furrow openers in three orthogonal planes, edge shape, sharpness, size, vertical load on coulter, power supplied to coulter viz. ground driven or powered.

Disc diameter and forward speed have negative effect on coulter penetration whereas the disc sharpness has positive effect on coulter depth. Kushwaha *et al.* (1986a) evaluated the disc coulters under no-till residue conditions in the soil bin. The wheat straw cutting of 46 cm diameter coulter was found nearly 100 percent for all the straw densities and depths. The 36 cm coulter cut straw nearly 100 percent for all the straw density of lower than 1 t/ha but gave erratic performance for straw density of 1-2 t/ha and no cutting of straw with 3-5 t/ha density. Similarly, the 60 cm coulter cut the straw almost 100 percent for straw density 1-2 t/ha at 5.5 cm depth of operation but inferior performance for straw density of 4 t/ha.

The triple disc coulters having a plain disc mounted rigidly in front of twin disc coulters have been found to penetrate to a depth of 4-8 cm into soil with bulk density upto 1.3 g/cc (soft soil) under surface trash with vertical force of 0.8-1.2 kN (Kovalev, 1982). The effectiveness of loose straw cutting could be improved either by holding the loose straw through vertical loading and then cutting by a plain disc coulter or using a powered coulter in front of the opener which provides a sliding component parallel to the cutting edge, thereby avoids 'bunching effect' due to slippage of straw.

Holding of loose straw and cutting with unpowered plain coulter

Preliminary investigation carried out by Singh (1999) revealed that for loose straw density of 1500 kg/ha, the straw cutting with a coulter having a vertical loading of 88 kg was only about 36.4 percent. However, a coulter fitted with a roller of about 26 cm diameter gave higher cutting percentage of 55.6 percent because of firm pressing and holding of loose straw. Further, studies were conducted by extending the research work already done by Brahm Prakash (1997) at Pantnagar on double disc opener. Different sizes of rollers were provided between the plain disc coulters for holding and cutting of loose straw in front of the double disc opener as well as inverted-T opener and tested at three loose straw densities of 500, 1500 and 4500 kg/ha (Table 4). The results revealed that best result in terms of loose straw cutting, clogging and furrow depth could be obtained with double disc opener and coulter combination when coulter to roller diameter ratio was 1.75 (coulter diameter of 46 cm and roller diameter of 26.3 cm) with vertical force of about 88 kg.

Rotary powered disc coulter ahead of double disc opener

The effectiveness of loose straw cutting could be enhanced by providing a power disc (plain/ripple) coulter in front of double disc opener (Kushwaha, 1986b). One such machine has been developed by DWR, Karnal (2004) and is under extensive trials at a number of locations in IGPs. This machine is a modification of existing rotavator in which case the rotary tiller blades have been replaced with plain disc coulters mounted on the same flanges and operates at a speed of about 200 rpm for cutting of loose straw. It has also been provided with a seed-cum-fertilizer box with flutted roll type metering system and double disc openers synchronised behind each powered disc for placement of seed and fertilizers in cut residues. The field trials conducted during *Rabi* 2004 have revealed that the power coulter becomes blunt after about 20-25 ha of operation in loose paddy straw. As the paddy straw contains over 13 percent silica, the blunt cutting edge design worns out quickly which effects the straw cutting and draft. However, the powered disc residue drill has performed

Table 4. Effect of coulter to roller diameter ratio, furrow opener and straw density on furrow depth, residue cut and residue clogged under zero-till loose straw condition

Parameters*		Furrow depth (cm)	Residue cut (%)	Residue clogged (g/opener/ 15 m length)
C_1 0_1	S_1	4.71	67.20	0.0
	S_2	3.96	62.60	0.0
	S_3	2.83	43.60	0.0
C_10_2	S_1	4.71	65.90	113.3
	S_2	3.41	57.50	281.7
	S_3	2.27	32.70	543.3
C_20_1	S_1	6.15	71.53	0.0
	S_2	5.19	60.93	0.0
	S_3	4.57	59.13	0.0
C_20_2	S_1	5.19	64.86	105.0
	S_2	4.15	58.83	295.0
	S_3	3.47	48.93	561.7
C_30_1	S_1	6.65	63.80	0.0
	S_2	5.48	53.80	0.0
	S_3	5.39	40.83	0.0
C_30_2	S_1	6.51	44.40	527.3
	S_2	6.10	34.90	221.3
	S_3	4.11	26.06	104.7

Source: Singh, 1999.
*C: Ratio of coulter to roller diameter i.e. 1.35 (C_1), 1.75 (C_2) and 2.15 (C_3); 0: Type of opener i.e disc coulter (0_1) and Inverted-T opener (0_2) and S: Straw density i.e. 500 (S_1), 1500 (S_2) and 4500 (S_3) kg/ha; Soil type: silty clay loam, moisture content: 15-20% (d.b.) and bulk density: 1.38-1.59 g/cc of soil

satisfactorily for planting of pea with surface managed paddy residue which was otherwise a failure in surface seeding conditions adopted by organic farmers' group of Uttaranchal. In a study conducted by Nieuwenbury *et al.* (1992), the cutting force reduction of upto 55 percent has been obtained with wedge shaped edge disc than blunt edge design. A number of design improvements in power transmission system, metering shaft, tapered roller bearing for disc, replaceable rotor shaft mounted with powered disc for mounting rotary tiller shaft are being incorporated for efficient functioning of the machine.

WEIGHT OF ZT DRILL VIS-À-VIS TRACTOR SIZE

Ensuring the minimum or adequate mass of ZT drills is one of the main design requirement for their better performance. Weight is required for providing vertical force for opener's penetration, which can be placed by any suitable means like springs, hydraulic cylinder, pneumatic system and also by tractor weight transfer or ballasting. The weight of drill should be limited as per available hydraulic lift capacity of average Indian tractors. The 35 h.p. range tractors have capacity in the range of 1000 ± 200 kg. However, in practice the actual capacity is often found less than that quoted by manufacturers. At maximum loading capacity, the spool valve may split the oil, thereby, making the whole system inoperative.

The Indian tractor operated seed drills are invariably mounted type with 9 to 11 rows openers. The gross weight of empty conventional drill varies from 250 to 300 kg i.e. weight per opener varies between 30 and 40 kg. The limitation on the weight of tractor mounted drill should be imposed as per IS 6813:1993. It is stated that the weight of tractor mounted drill including the weight of seed and fertilizer filled at rated capacity of box, shall be within the limit of 18.50 kg/drawbar h.p. In contrast, the direct drilling machines require over 2.5 times more weight for their efficient working. Gray and MacIntyre (1983) reported the unladen weight of 15 to 18 rows commercial direct drilling machine available in England to vary from 2050 to 3563 kg with mean unladen weight per coulter opener of 114-238 kg. However, by tractor-weight-transfer method, the drill weight could be kept low and the maximum applicable downward force i.e. the sum of the drill weight and weight transfer from tractor without tyre slippage can be kept low. Fink and Currence (1995) suggested the mounting of drill frame with the tractor frame through a remote hydraulic cylinder on the tractor so that when the pressure is applied to the opener cylinders, the tractor weight is transferred to the drill. Therefore, any attempt to increase the weight of ZT drills for their better performance is limited to hydraulic capacity of tractor.

FUTURE RESEARCH AGENDA

The future research needs on machinery for conservation agriculture are summarized below:

1. There is much development work needed on producing suitable ZT-drills for loose straw conditions. Ideally, they should be multipurpose and not heavy. Standardization of metering system for planting of pulses, oil seeds, rice and wheat, and interchangeability of different components especially furrow on different makes of drills needs to be worked out in researchers and manufacturer's partnership.
2. There is still considerable uncertainty on the consequences of straw left on the soil surface on the development of the succeeding crop. It is possible to chop and spread the straw behind the combine to allow drills to work. Such straw management devices mounted on the combine itself need to be developed and evaluated.
3. The rotary powered disc residue drill developed for planting under loose surface straw condition should be modified to serve as a multiple machine, by incorporating active and passive soil cutting elements as single pass tillage machine and also for formation of permanent beds of size within tractor wheels for controlled traffic drilling condition.
4. For alleviation of subsoil compaction due to indiscriminate movement of heavy traffic in the field, systematic research work on controlled traffic ZT-drills needs to be initiated.
5. Surface seeding of wheat, mustard and lentil in combine harvested rice fields followed by chopping of loose straw and stubbles with a rotary mower/shrub master and then irrigating the field is getting popular in Tarai region of Uttaranchal and could be tried elsewhere also, as it requires least time, energy, and cost for crop establishment.
6. Straw residues and stubbles can still give many management problems, and any positive or harmful effects of these residues on the development of the following crops need to be assessed.
7. Twin cutterbar type combine harvester for harvesting of top portion of crop for grain recovery and a lower cutterbar for straw harvesting at a suitable height and windrowing should be developed for proper management of straw.
8. There is a need to recognize the soils that are likely to give difficulties in zero-till

drilling. One great limitation of so much present work is that many of the soils on which the experiments have been done, or on which farmers are gaining experience, have been very poorly characterised or described. It is most important that at least the soil series be identified for proper selection of drills and their working regime.

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Machinery for Conservation Agriculture: Progress and Needs

S.K. Rautaray
Central Institute of Agricultural Engineering, Bhopal 462 038, Madhya Pradesh, India

ABSTRACT : Development, refinement and adoption of machinery for a range of soil and cropping situations will be fundamental in any success to promote conservation Agriculture Systems. This paper reports on the performance of machinery for zero tillage- crop residues management in rice-wheat cropping system and outlines the need for continuing efforts. Particularly important will be to develop equipment for fixed path / controlled trafic minimizing the ill effects of wheels in the longer terms.

INTRODUCTION

Machinery for conservation agriculture generally refers to the cultivation systems with minimum or zero tillage and *in-situ* management of crop residues. Minimum tillage is aimed at reducing tillage to the minimum necessary that would facilitate favorable seedbed condition for satisfactory establishment of crop. Zero tillage is however an extreme form of minimum tillage. With the development of direct drilling machines almost all research work was based on the criteria of firstly attempting to define the responses of direct drilled seeds in relation to soil micro-environments. Thereafter machine design specifications especially of critical components were finalized to bring about the more desirable micro-environmental conditions. The performance of equipment was concentrated both on biological and mechanical parameters.

Selection of most appropriate equipment (combinations) for specific situation is essential in respect of field requirements (alleviate soil compaction, soil loosening only in crop rows or surface soil loosening with or without straw mulching); soil working condition (high moisture-plastic, moist-friable or dry-friable soils); type of equipment (discs or inverted 'T' openers, narrow rotary strips or wide rotary gangs) and cultivation practices. Besides the chosen equipment (design: implement geometry) should match the power unit. Skilled operation is important to maintain work rate and avoid fuel losses.

MACHINERY FOR NO-TILLAGE AND MINIMUM TILLAGE CULTIVATION OF WHEAT

No-till drilling, strip till drilling and roto till drilling of wheat after harvest of rice were compared to the conventional tillage sowing as practised by farmers. Brief specifications of the direct drilling machines are given in Table 1.

The sowings at shallow depth (50-60 mm) under residual moisture condition (21.8-23.6%) with 100 kg/ha seed rate and fertilizer dose of N:P:K::120:50:30 kg/ha were compared to the conventional practice of 03 tillage operations by duck-foot sweep cultivator (size = 1800 mm) and sowing by seed-cum-fertilizer drill (09 row/row spacing = 180 mm). The time required as per actual field capacity of the machines, fuel used and cost of operations are given in Table 2.

Table 1. Specifications of direct drilling machines

Particulars	No-till drill	Strip till drill	Roto till drill
Source of power	45 hp tractor	45 hp tractor	45 hp tractor
Type/no. of furrow openers	Inverted 'T' type/09	Shoe type/09	Shoe type/11
Row spacings, mm	180 (adjustable)	200 (fixed)	160 (adjustable)
Working width, mm	1600	1800	1750
Drive wheel	Angle lug – front mounted	Angle lug – side mounted	Star lug – rear hinged
Weight, kg	250	280	300
Unit price, Rs	15000	35000	45000

Table 2. Minimum tillage seeding compared to conventional tillage-sowing of wheat

Particulars	No tillage seeding (Fig.1)	Strip tillage seeding (Fig.2)	Roto tillage seeding (Fig.3)	Conv. tillage (3 passes)– sowing
Time, h/ha	3.23	4.17	3.45	10.82
	(70.15)	(61.46)	(68.11)	
Fuel used, l/ha	11.30	17.50	13.80	34.62
	(67.36)	(49.45)	(60.14)	
Operational energy, MJ/ha	648.96	1001.76	783.60	1976.11
	(67.16)	(49.31)	(60.35)	
Cost of operation, Rs/ha	639.54	979.95	807.30	1903.04
	(66.39)	(48.51)	(57.58)	

() values show percent savings over conventional practice.

The results showed that no tillage drilling was time, energy and cost-effective to the extent of 70.15, 67.16 and 66.39 percent respectively over the conventional practice. The roto tillage seeding combined with full width shallow tillage in single pass operation was 60.35 percent energy efficient and 57.58 percent cost-effective compared to the conventional practice. The strip tillage seeding was advantageous over conventional tillage-seeding but for the intermittent strip tillage the operational energy and cost requirements were higher compared to the roto tillage and no tillage seeding.

Cultural practices specific to these conservation systems were developed in terms of frequency of irrigation and fertilizer applications. First irrigation of 40-50 mm was critical for all the direct seeding systems for initial establishment especially in no tillage seeding. Performance of direct drilled wheat (Table 3) showed that in direct drilling systems although the grain yields were at par, the benefit-cost ratio were higher by 15.2-23.4 percent with savings in operational energy of 8.4-14.7 percent compared to the conventional practice.

Table 3. Production economics and operational energy of direct drilled wheat (HI-8498) after harvest of rice (IR-36) in vertisols

Particulars	Zero till drilled	Strip till drilled	Roto till drilled	Conventionally sown
Grain yield, t/ha	4.84	4.62	4.78	4.60
Cost of production, Rs/ha	8635	9114	9315	10710
Benefit-cost ratio	3.64	3.29	3.34	2.79
Operational energy, MJ/ha	8114	8712	8444	9516

* Sale price of wheat (HI-8498), Rs/kg = 6.50.

MACHINES FOR STRAW INCORPORATED TILLAGE-SEEDING OF RICE AND WHEAT

The straw incorporated tillage in rice-wheat fields showed that (Table 4) direct rotavation under chopped straw condition followed by drilling was 28.5 percent energy efficient and 24.9 percent cost-effective compared to the mould board plough + rotavator + drill operations. The mould board plough and rotavator operations gave almost straw free surface (Straw incorporation = 89.7 percent at 50-125 mm depths) for unimpaired drillings. With direct rotavation the average incorporation of straw was 60.4 percent and it affected the performance of drill due to chockings. The values of benefit-cost ratio (Table 5) were at par in straw/non-straw fields indicating no immediate advantage of straw incorporated cultivation although it may prove beneficial in long term being of organic base.

It was observed that the effectiveness of straw incorporation may not necessarily be a guide to overall benefit-cost. Therefore direct rotavation under chopped straw condition was considered to be more appropriate being shallower working system (depth = 50-100 mm) with higher work rate and substantially less energy demanding than the mould board plough based cultivation system.

Table 4. Energy requirement and cost of incorporation of rice-wheat straw for subsequent sowings

Type of straw field	Treat-ment	Implement used	Time* required (h/ha)	Direct energy used (MJ/ha)	Cost of opera-tion (Rs/ha)	Amount of straw incorpo-rated (%)	Total opera-tional energy (MJ/ha)	Total cost of operation (Rs/ha)
Combine harvested rice and wheat straw fields	T1	Stubble shaver (1)	2.75	508	511	-	3000	2895
		MB plough (1)	5.13	1151	1041	76		
		Rotavator (1)	3.00	644	617	13		
		Seed-Fertilizer drill (1)	3.71	696	678	-		
Combine harvested rice and wheat straw fields	T2	Stubble shaver (1)	2.75	508	511	-	2145	2173
		Rotavator (1)	3.58	721	768	60		
		Seed-Fertilizer drill (1)	4.88	916	893	-		
Non-straw rice and wheat fields	T3	Duck foot sweeps (3)	7.71	1446	1386	-	2007	1933
		Seed-Fertilizer drill (1)	2.99	560	546	-		

() Figures show number of passes.

* Data represent average value for wheat straw incorporated-rice sown and rice straw incorporated-wheat sown.

Table 5. Production economics and energy used for rice-wheat cultivation in straw fields

Particulars	Wheat straw/non-straw (control)-rice sown			Rice straw/non-straw (control)-wheat sown			Rice-wheat straw/non-straw (control)-fields		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
Grain yield, t/ha	3.54	3.18	2.94	4.68	4.64	4.60	8.22	7.82	7.54
Cost of production, Rs/ha	10569	9805	10610	12020	10128	10710	22589	19933	21320
Benefit-cost ratio	1.67	1.62	1.39	2.53	2.98	2.79	2.10	2.30	2.09

* Sale price of wheat (HI-8498), Rs/kg = 6.50; Sale price of rice (IR-36), Rs/kg = 5.00.

Minimum tillage rice and wheat under straw and non-straw conditions

The minimum tillage experiments showed that no tillage seeding of wheat in surface covered chopped rice straw (Table 6) was energy efficient and cost effective by 13.4 and 15.3 percent respectively over roto till drilling and 26.9 and 30.1 percent respectively over rotavator followed by drill operations. The production economics showed that under straw covered no tillage condition (Table 7) although the yield gain of wheat was marginal the benefit-cost was higher by 11.8 percent over the straw incorporated roto till drilled wheat (benefit cost ratio = 3.29). In case of roto till drilled rice (Table 8) under wheat straw condition the yield gain was 2.11 percent with savings in operational energy and cost of production of 15.5 and 9.6 percent respectively compared to non-straw roto tillage rice. Similar trend was found with no tillage rice under straw and non-straw conditions. In general with direct drilling systems although the grain yields of wheat were at par the benefit-cost ratio were higher by 15.2-23.4 percent with savings in operational energy of 8.4-14.7 percent compared to the conventional practice.

Table 6. Operational energy and cost of seeding of wheat in rice straw fields

Treat-ment	Equipment used	Time required (h/ha)	Operational energy (MJ/ha)	Cost of operation (Rs/ha)	Total time required (h/ha)	Total operational energy (MJ/ha)	Total cost of operation (Rs/ha)	Amount of straw incorporation (%)
T_1	Stubble shaver	3.45	653	648	8.71	1859	1979	54.4
	Roto till drill	5.26	1205	1230				
T_2	Stubble shaver	3.45	653	648	8.21	1610	1591	-
	No till drill	4.76	956	942				
T_3	Stubble shaver	3.45	653	648	11.57	2201	2277	62.1
	Rotavator	3.57	710	763				
	Seed cum fertilizer drill	4.55	837	864				

Table 7. Production economics and operational energy of straw incorporated and straw covered cultivation of wheat after rice

Parameters	Rice straw condition			Non-straw condition			Non-straw conv. practice
	Roto till drilled wheat	No till drilled wheat	Rotavator + drill combination wheat	Roto till drilled wheat	No till drilled wheat	Rotavator + drill combination wheat	
Grain yield, t/ha	4.92	5.10	4.80	4.78	4.84	4.64	4.60
Cost of production, Rs/ha	9728	8885	10503	9315	8635	10128	10710
Benefit cost ratio	3.29	3.73	2.97	3.34	3.64	2.98	2.79
Operational energy, MJ/ ha	8746	8345	8946	8444	8114	9116	9516

Table 8. Performance of straw incorporated and straw covered minimum tillage dry seeded rice after wheat

Particular	Straw incorporated roto tillage rice	Non-straw roto tillage rice	Straw covered no tillage rice	Non-straw no tillage rice	Conv. Tillage-rice
Grain yield, t/ha	3.31	3.24	3.36	3.30	2.94
Cost of production, Rs/ha	8801	9740	8640	9115	10610
Benefit-cost ratio	1.88	1.66	1.94	1.81	1.39
Operational energy, MJ/ha	5579	6605	5512	5594	9642
Sp.cost of production, Rs/kg	266	3.00	2.57	2.76	3.61

* Sale price of rice (IR-36), Rs/kg = 5.00.

Raised bed planter for planting on fresh and permanent beds

Raised bed planting of wheat (HI-8498) by bed planter on fresh and permanent beds were compared to flat sown and no tillage condition (Table 9).

Table 9. Energy and economics of raised bed planting of wheat compared to flat sown

Particular	Planting on fresh beds with preparatory tillage	Planting on permanent beds	Flat sowing-no tillage	Conv. flat sowing
Time required, h/ha	13	4.80	3	10
		(55.6) [63.2]		
Operational energy, MJ/ha	2605	1154.03	648	1976
		(41.6) [55.7]		
Cost of operation, Rs/ha	2479	1060.80	639	1903
		(44.3) [57.2]		

()% savings over conv. practice, []% savings over fresh bed planting.

It was found that planting on permanent beds was energy efficient and cost effective by 41.6 and 44.3 percent respectively over conventional flat sowing of wheat (03 tillage + 01 sowing operation). Similar advantages of time, energy and cost-effectiveness of 63.2, 55.7 and 57.2 percent respectively were found for planting on permanent beds than on fresh beds (03 tillage + 01 planting operation).

The production economics (Table 10) showed that although the grain yields on fresh and permanent beds were at par the benefit-cost ratio in respect of the permanent beds was higher by 15.8 percent over the fresh beds mainly because of the reduced cost of cultivation (14.9 percent) due to the elimination of preparatory tillage. Further in permanent beds water retention was higher in furrows than in fresh beds due to compaction effect by tractor wheels and it helped to provide catchment effect for longer period by slow infiltration of water to the root zone of crops on beds. In fresh beds although there was 30 percent savings of water compared to the conventional flat sown (water requirement = 650 mm/ha) further savings of 10 percent of irrigation water was recorded in permanent beds over the fresh beds.

Table 10. Production economics and operational energy in raised bed wheat

Particular	Raised bed wheat		No-tillage wheat–flat sown	Conv. flat sown wheat
	Fresh bed	Permanent bed		
Grain yield, t/ha	5.03	5.08	4.84	4.60
Cost of production, Rs/ha	10030	8540	8635	10710
Benefit-cost ratio	3.26	3.87	3.64	2.79
Operational energy, MJ/ha	8750	7684	8444	9516
Sp. operational energy, MJ/kg	1.74	1.51	1.74	2.07
Sp. cost of production, Rs/kg	1.99	1.68	1.78	2.33

* Sale price of wheat (HI-8498), Rs/kg = 6.50.

Compared to no tillage flat sown the cultivation on permanent beds being of no tillage on beds showed 4.7 percent higher grain yield with higher benefit-cost ratio of 5.9 percent may be due to the combined no tillage and bed effects in terms of better stand establishment and growth. Compared to flat sown the performance of crops on fresh and permanent beds were found better in terms of higher grain yield (8.5-9.4%) and higher benefit-cost ratio (14.4-27.9%). Cultivation on permanent beds was found to be energy efficient by 9.0, 12.2 and 19.3 percent over no tillage flat sown, fresh beds and conventional practice respectively.

Traffic and compaction

Once-over tillage-seeding practice, although depend on soil conditions which remain for only limited periods on many soils, has imposed higher loads on the soil due to higher weight of the tractor (1.5-2.0 tonnes) and soil reactions including compaction. High throttle operation for faster travel in single pass operation especially with zero-till drill in wet soil gave wheel slippage (30-40%) and hampered operational control of the drill besides causing non-uniform dropping/bunching of seeds in drill rows. Due to compaction of soil under the wheels (bulk density = 2.26 g/cc at soil moisture = 25.62% db in vertisols) the drill tines just behind the wheels remained above the ground level without contact of soil and dropped the seeds virtually on the surface of the soil affecting germination and making the seeds more vulnerable to birds.

It was found that in zero tillage wheat the performance of crops on wheeled area was low due to erratic and uneven establishment of crop at the initial stage. During first flood irrigation which is critical to the initial establishment the seeds remained partially/fully submerged due to more accumulation of water in wheeled area for longer time creating temporary logging condition. Penetrometer observations to 150 mm depth in wheeled area showed signicant increase in soil strength compared to the adjacent non-wheeled zone (soil resistance = 72.4 – 108.6 kPa in profile of 25-150 mm) in vertisols.

Sample observations from wheeled areas showed lower wheat yields (3.88 t/ha) than the non-wheeled areas (5.78 t/ha) and it was more pronounced at the headlands due to repeated passes of the tractor compounding the effect of compaction (soil resistance = 168.6-280.4 kPa from surface to 150 mm depth).

Need for current research

Following the adoption of minimum and zero tillage techniques by many farmers the main focus of researchers currently drawing attention is towards the controlled traffic cultivation systems. The production operations therefore from tillage-seeding to harvesting may have to be planned to grow crops in between the wheels by following the fixed path operations in the field. To this, the controlled traffic lining and bed systems (flat-bed/broad-bed) may be the immediate need to go someway towards avoiding the ill effects of wheels. During combine harvesting the controlled traffic lines may only be breached but in longer run one may plan for controlled traffic harvesting or tracks on the combine to reduce compaction. The ultimate controlled traffic system may however be based on the gantry system to get off the ground.

Residue Open Burning in Rice-Wheat Cropping System in India: An Agenda for Conservation of Environment & Agricultural Resources

Prabhat K. Gupta and Shivraj Sahai
National Physical Laboratory, Dr. K.S. Krishnan Road, New Delhi 110 012, India

ABSTRACT : Disposal of straw in the very short time available between the harvesting of rice and the sowing of wheat is a potential problem for the agriculturists in the rice–wheat cropping system, which is widely practiced in large part of India. Other available options lacks motivation and feasibility and farmers find it easier to opt for burning the residue in the open field. The intensive agricultural practices as a result of green revolution viz. increased use of combine harvester have further added to generation of crop residue left in open field in this cropping system. Dry straw of rice and wheat are estimated to be generated in India alone in the year 2000 is about 78 and 85 million tons and a major fraction of which ends up in open field burning. It adversely affects the air quality, leads to nutrient loss, degrades soil properties and cause wastage of residue that is now considered tremendous resource worldwide. Trace gas and aerosols emissions due to open field burning of such large quantity of residue leads to adverse implications of the local and regional environment, which also has linkages to the global climate change. The impacts of such burning need to be arrested fast through various strategic policies, scientific, technical and social measures for sustaining conservation of environment and agricultural resources of the country.

INTRODUCTION

Rice and wheat are currently grown in rotation on about 26 million hectares area of South and East Asia. The Rice-Wheat cropping System (RWS) in the Indo-Gangatic Plain (IGP) span from the Swat valley in Pakistan through the states of Punjab, Haryana, U.P, Bihar and West Bengal in India, and into Nepal and Bangladesh. The other parts lay in Madhya Pradesh, Himachal Pradesh, and Brahmaputra flood plains of Assam and southwestern parts of India and Bangladesh. The total area under RWS in India is roughly around 20 million hectares[1]. The major RWS residue-generating states include UP, MP, Punjab, Bihar, Maharashtra, Haryana, Gujarat, Himachal Pradesh, that generate about 133 Gg of residue (Table 1) from the two crops in the year 1994[1]. The residue generated is utilized mainly as: Industrial /domestic fuel, fodder for animals, paper production, packaging, bedding, wall construction, in-situ incorporation & green manuring, thatching and left in field for open burning.

Table 1. Residue generation from major states in India for 1994 (Gg)

States	Rice	Wheat	Total
Uttar Pradesh	13284	33189	46473
Punjab	9890	20251	30141
Madhya Pradesh	8115	10727	18841
Bihar	8041	6443	14484
Haryana	2810	10928	13738
Maharashtra	3112	1646	4757
Gujarat	1179	2555	3734
Himachal Pradesh	141	829	970
Total (Gg)	46571	86567	133138

Rice is grown during warm humid monsoon (kharif) season between June to October and wheat in cool dry (rabi) season between November to March. There is very small time available between harvesting of rice and planting of wheat and moreover performance of the wheat crop is highly susceptible to any delay in planting. Due to the use of combine harvesters (Figure 1) there has been a sharp increase in the share of residue that is left in the field as it leaves major portion of the residue including the husk in the field and burnt. About 5-7 tons/ha of rice straw is left unused in the field[2]. The number of combine harvester has increased from nearly 2000 in 1986, to 3000 in 1991 and about 5000 in 1996[3]. Northwestern part of the IGP has about 75% of the cropped area under combine harvesting, which comes to about 15 million hectares[1]. A total of about 78 and 85 million tons dry rice and wheat straw are generated in India alone in the year 2000 of which a major share ends up in field burning[1]. Thus the use of combine harvesters, whose number is increasing, though otherwise very efficient, has a cause for concern that needs serious attention. In case of combine harvesting almost all portion of the residue generated is left in the field as loose straw that finally end up in burning.

IMPACTS OF CROP RESIDUE BURNING IN RWS

The impacts of burning of crop residue include are discussed below:

1. Regional air quality due to trace gas and aerosol emissions

Open field burning of crop residue (Figure 2) leads to emission of trace gases like CH_4, CO, N_2O, NO_X and other hydrocarbons. It also emits large amount of particulates that are composed of wide variety of organic and inorganic species. One tonne straw on burning releases 3 kg particulate matter, 60 kg CO, 1460 kg CO_2, 199 kg ash and 2kg SO_2[4]. Assuming that one fourth of the available residue is burnt in the field, it is estimated that the emissions of CH_4, CO, N_2O and NO_X were 110 Gg, 2305 Gg, 2 Gg, and 84 Gg, respectively in the year 2000 from rice and wheat (Table 2). Our studies have shown considerable emission of pollutants such as $PM_{2.5}$ (particulate matter), CO, NOx, NO2, NO, OC (organic carbon), BC (black carbon) and EC (elemental carbon)[5]. These are also the major cause of concern for respiratory symptoms, Tuberculosis, Asthma and lung functioning of animals as well as humans apart from the potential risk for lung cancer as many of the pollutants found in large quantities in biomass smoke are known and suspected carcinogens.

Table 2. Annual national emissions from rice & wheat straw open burning[1] (All in Gg)

Years	Production	Qt. of dry residue	CH_4	CO	N_2O	NOx
1994	145720	150576	102	2138	2.2	78
2000	156485	162125	110	2305	2.3	84

2. Soil nutrient loss

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/ ha of rice and 4 tons/ha of wheat removes more than 300 kg N, 30 kg P and 300 kg K / ha from the soil[6]. Though little is known about the effect of burning on soil nutrient losses and dynamics in RWS, it has been reported that 40-80% of the wheat crop residue N is lost as ammonia when it is burnt in the field, and that the emission of ammonia decline from 20Gg N per year in 1981 to 3.3 Gg N yr^{-1} in 1991 as a result of changes in the agricultural practices because of a imposed ban on the burning of crop residue in U.K. According to Samara et al.[7], in New Zealand for every ton of wheat residue burnt 2.4 Kg of N was lost. Likewise, sulphur (S) losses from the burning of high S and low S rice crop residues in Australia were 60 and 40 % of S content respectively. Thus burning may lead to considerable nutrient loss also.

3. Impact on soil properties

Pedology is the basis for agricultural and rural sustainability. The heat from burning cereal straw can penetrate into soil up to 1 cm elevating the temperature to as high as 33.8-42.2 °C (Figure 3). About 32-76 % of the straw weight and 27-73 % N are lost in burning. Bacterial and fungal populations are decreased immediately and substantially only on top 2.5 cm upon burning. Repeated burning in the field permanently diminishes the bacterial population by more than 50%. Burning immediately increased the exchangeable NH_4^+ -N and bicarbonate extractable-Phosphorus content but there is no build up of nutrients in the profile. Long term burning reduces total N and C and potentially mineralized N in the 0-15 cm soil layer. One of the recognized threats to RWS sustainability is the loss of soil organic matter as a result of burning[2].

4. Wastage of residue in RWS

The straw collected from the fields is of great economic value as livestock feed, fuel and industrial raw material. In northern India, wheat straw is preferred while in south India rice straw is fed to livestock[8]. The residue generated from RWS can be put to many uses as discussed earlier, but this is possible if residue is separated from the grain and carried out of the field. However, in case of combine harvesting most of the residue is left in the field that can only be burnt thereby hampering RWS and rural sustainability.

Mitigations Options

Firstly, sustainable residue management, which may include developing systems to plant crops into residue, baling and removal for use as animal feed or for industry (Figure 4). These may include initiatives like microbial sprays for fast decomposition of residue, raised bed planting for planting into residue, use of crop residue as fuel etc. One good example could be the substitute for use of bagasse as fuel in sugar industry, where off late it has been proved that residues like rice husk and pigeon pea waste can provide much cheaper energy i.e, Rs. 1.78, Rs. 1.31 and Rs. 2,35 per unit of power (kw h^{-1}) respectively. Moreover encouragement to such activities will generate employment. Straw can also be used for paper-making (Figure 4). Secondly mitigation is possible through technological modifications in harvesting methods e.g., to facilitate the drilling operation in combine-harvested fields enabling shredding of rice residue and their uniform spread, modification of zero till-drill, etc.

The future focus areas for mitigation options may be;

- In-situ incorporation being the best option may be further investigated for fast decomposition of residue.
- Technological improvements in the implements used, so that the option of planting into residue, drilling operation, in-situ incorporation etc can be made feasible.
- Modification of combine harvesters whereby the residue also is separately collected and removed from the field.
- More reliable data, on the effect of RWS management (including residue quality, application rate, application method, timing, interactions with inorganic fertilizers,

temperature, soil moisture, soil type and tillage) on decomposition and nutrient release rates and the production of phyto-toxic compounds for rice and wheat residues, are needed.

- Proper researcher-farmer interface need to be established.
- Realistic process-based computer simulation models may be developed for RWS to accommodate the variables and the complexities of interactions among soil, crops and climate, and for accurate prediction of the affect of crop residue management practices on nutrient cycling, crop growth and yield and soil properties. Moreover, Geographical Information System (GIS) should be used for natural resource management.
- Long term experiments at sites carefully selected for variation in temperature, moisture regimes, soil mineralogy and agriculture management covering the RWS may be established.
- Custom duty on implements like balers should be exempted to reduce the cost involved in residue management.
- Operation of field balers over large areas (400 ha annually) should be facilitated to break-even with existing harvest price and price of straw to enable RWS sustainability.
- Government should monitor and discourage burning of crop residue through incentives and technology transfer and utilization.

The various possible scientific/technological and social activities required for combating open burning air pollution may be presented in the form of a flow diagram as in figure 5.

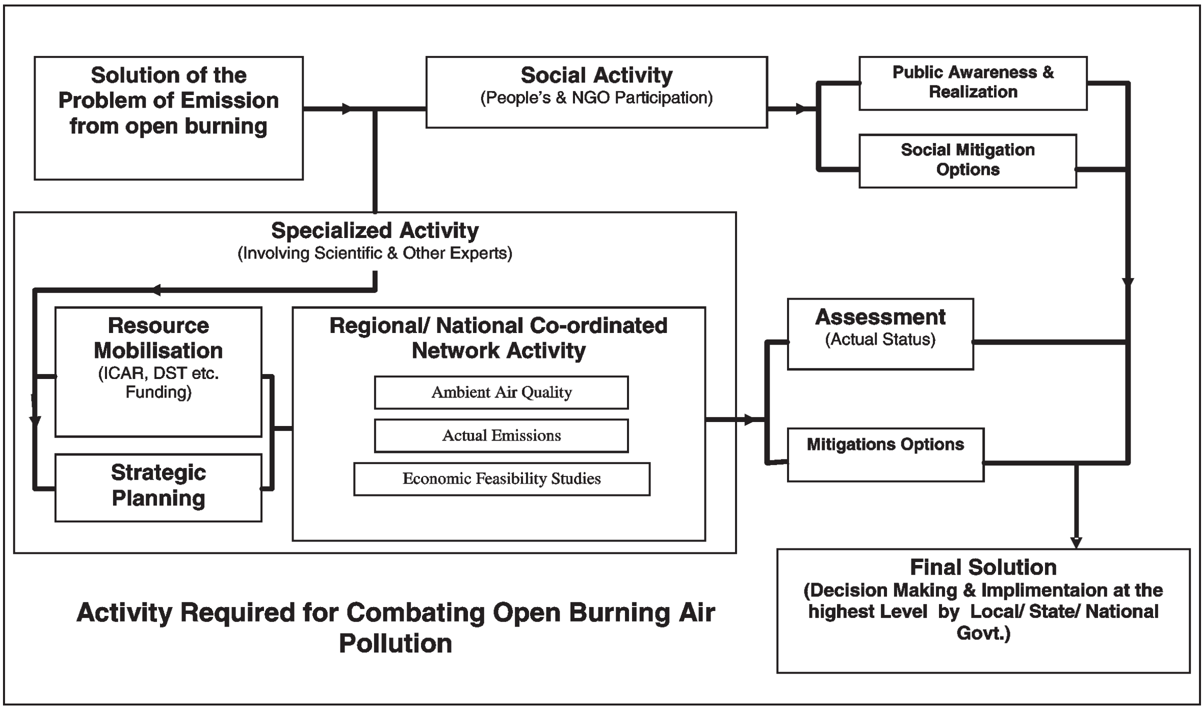

Fig. 1. Activity required for combating open burning air pollution.

CONCLUSION

Residue burning in RWS due to the use of combines results in atmospheric pollutant emission, loss of nutrients, diminished soil biota, and reduced total N and C in the topsoil layer. The gaseous emission have been estimated to be 110 Gg, 2306 Gg, 2 Gg, and 84 Gg, respectively for CH_4, CO, N_2O and NO_X from rice and wheat straw burning in India in the year 2000.

High concentrations of $PM_{2.5}$, CO, NOx, NO_2, NO, OC, BC and EC in the ambient air have also been supported by in-situ experiment on straw burning in rice-wheat system.

Thus, there is a need to review and upgrade the technology involved with mechanized harvesters, for sustainable utilization of residue thereby overcoming the compulsion to burn residue in the rice-wheat cropping system, the major concern being short time between harvesting of rice and planting of wheat. Long-term studies on residue incorporation, investigation on resource depletion and related environmental and rural sustainability are required to address the much concerning linkages of the above burning with the global climate change and its direct adverse affect on human health.

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Experience with Managing Rice Residues in Intensive Rice-Wheat Cropping System in Punjab

B.S. Sidhu and V. Beri
Department of Soils, Punjab Agricultural University, Ludhiana 141 004, Punjab, India

ABSTRACT : Rice has become the important *kharif* crop of Punjab covering 60 percent of the cultivated area in the state. The production of paddy has reached 15 million tonnes (m t) in 2004-2005, which results in the production of 18.75 m t of rice residue. The residue can be used as animal fodder, fuel and in paper and cardboard industry. The combined use of both options does not exceed 10 percent. The farmers are in a hurry to sow the following wheat crop and therefore immediately dispose off the straw by burning. Constant research efforts are being made to return it to the soil by direct incorporation or through composting. The machinery for direct incorporation and collection has been developed but still is in infancy and not available to the farmers. Even with the use of the latest machinery like happy seeder direct incorporation involves higher cost than normal operations after burning the residues. It increases the drudgery of the farmer. The farmers are very busy in this period (October-November) of the year, where they have to harvest the rice, market it and prepare the seedbed for next wheat crop. Sowing of wheat by no-till drill is the cheapest option but cannot be practised without burning/ removing the rice residue. The incorporation of the residue results in better physical, chemical and biological properties, but even in the long term experiments increase in wheat yield ranges from 0.0 to 0.5 t/ha over burning treatments. The rice straw can be composted into value added phosphocompost with a cost of Rs. 1.47 per kg. The value on the basis of the fertilizer elements (N, P and K) is approximately Rs. 1 per kg. However, results of the field experiments on sandy loam soil showed that the incorporation of the residue and rice straw manure have favourable effect on soil properties in addition to supply of the nutrients. It was found that addition of 4 t/ha of phosphocompost result in compensation of the cost in treatments where 30 kg P_2O_5 or 60 kg P_2O_5 was added.

INTRODUCTION

The rice has become the most important *kharif* crop of Punjab. It was grown on about 0.25 m ha in 1966-67 that increased by ten-fold (2.53 m ha) by 2002-03. The production of rice in the state has also increased to 9.9 m t (provisional) in 2004-05. With the increase in production of rice there is concomitant increase in the production of residue (rice straw), which is approximately 18.75 m t. About 80 percent of the rice residue produced is burnt in the fields, particularly after harvesting rice by combine harvesters. It is estimated that about 15 m t of rice straw was burnt last year in Punjab. The burning of residue results in substantial loss of plant nutrients contained therein and also adversely affects the nutrient budget in the soil. Straw carbon, nitrogen and sulphur are completely burnt and lost to atmosphere while burning the residue. The other nutrients are partially lost in the particulate matter, which blows with the wind. The approximate amount of the nutrients present in the straw, which was burnt last year were 106, 65, and 237 thousand tonnes N, P_2O_5, and K_2O, respectively in addition to secondary and micronutrients. The approximate quantity of major elements is 0.408 m t. The cost of N (Rs 10/kg), P_2O_5 (Rs15/kg) and K_2O (Rs 5/kg) elements present in this residue at current prices is 1060, 975 and 1185 million rupees, respectively. Burning of rice straw results in the pollution of air. It adds carbon dioxide, carbon monoxide, nitrogen oxide, sulphur dioxide and suspended matter in the air. The oxides of N and S are potent reasons for acid rain. The acid rains cause scorching effect on the vegetation and results in corrosion of buildings. The residue, which was burnt last year, contained about 6.0 m t of carbon. On burning it produced about 22.0 m t of carbon dioxide in a short span of 15-20 days. The nitrogen oxides formed during burning also interfere with the ozone shield in the stratosphere. Both these gases contribute toward global warming. The aerosol creates health problem for humans and animals, as they have to inhale the polluted air. It results in many lung and throat diseases. The bronchial (Asthma) patients have difficulty in breathing. The nightmare of 15^{th} October 1998 when the thick smog made the atmosphere suffocating in Punjab is a living example of the recent past. The open fires of residue burning results in burning of trees in addition to adjoining standing crops. The ash is a very good adsorbent. The ash on the surface of the soil, if not mixed properly, adsorbs the applied weedicides, which results in decreased efficacy of herbicides. Therefore, burning of rice residue is not advisable.

The rice straw can be put to many uses. It can be used as dry fodder for animals, but due to the availability of better quality fodder (wheat straw) in the state, it is not preferred. Presently about 5 percent of the straw produced is used for this purpose particularly by *gujjar* community. The *Gaushalas* in Punjab can use this cheap fodder for Gaushala animals. The *Gaushalas* can develop their own collecting and storage facility. Attempts have been made by PSEB to use the rice straw as fuel for generating electricity by installing a 10 MW plant at Jalkheri in Fatehgarh Sahib district. It has its own problems like collection and storage of huge biomass. The plant operation time can be increased by contract storage of the bailed biomass at farmers place, which can be brought to the plant as and when needed. The custom hiring of field bailer can further help in storage. The paper industry uses a fraction of it owing to their difficulties. The cardboard industry uses this as an important raw material. The number of such units is less; therefore the consumption is not substantial. The combined use for these two purposes is less than 2 percent.

Presently there is not much alternative use of paddy straw out of agriculture. The viable use at present can be *in-situ* management in the field, composting or mulching.

The combine harvester spreads the residue in the field, which are difficult to collect. The rice residue can be incorporated in the soil before sowing wheat. It was recommended that the residue should be incorporated in the soil and allowed to decompose for 2-3 weeks before the sowing of wheat The normal fertilizer management practices for wheat may be followed there after. The grain yields of wheat and the following rice were not adversely affected by incorporation of rice straw (Table 1). In another 6-year study, *in-situ* incorporation of rice straw 10, 20, or 40 days before sowing wheat did not affect the wheat significantly (Table1). Rice straw incorporated in wheat did not show a residual effect on the succeeding rice crop. Several reports show similar rice and wheat yields under different residual management practices such as burning, removal, or incorporation (Walia *et al.,* 1995; Singh *et al.,* 1996; Bijay Singh *et al.,* 2001). Singh *et al.* (1996) reported that the incorporation of rice straw 3 weeks before sowing significantly increased wheat yield on clay loam soil but not on sandy loam soil. Studies conducted by Sharma et al., (1985, 1987) showed no adverse effect of straw incorporation on the grain yield of wheat and the following rice (Table 2).

On the other hand, the incorporation of rice straw (5 t ha^{-1} dry weight) 30 days before the sowing of wheat produced significantly lower wheat yields than the removal or burning of straw in the first two years. The incorporation of straw over longer periods produced wheat yields similar to those with straw removal or burning (Table 2) (Verma and Bhagat, 1992). In another long-term experiment on sandy loam soil (Table 3), the yield of wheat was at par or an increase of 0.0-0.5 t/ha with rice straw incorporation over the straw burning in the field in different years was observed.

Table 1. Yield (t ha^{-1}) as affected by rice straw management in wheat and its residual effect on rice in the rice-wheat cropping system

Treatment	Experiment 1**		Experiment 2***	
	Wheat	Rice(Paddy)	Wheat (1993-2000)	Rice (Paddy) (1994-99)
Straw removed	5.06a	4.90a	4.94a	6.19a
Straw burnt	5.11a	5.13a	5.10a	6.25a
Straw incorporated (40 DBS*)	4.89a	4.87a	5.17a	6.34a
Straw incorporated (20 DBS)	5.00a	4.97a	5.22a	6.29a
Straw incorporated (20 DBS) and 25% N applied at incorporation	4.79a	5.02a	4.95a	6.33a
Straw incorporated (10 DBS)	-	-	4.97a	6.29a

In a column figure followed by a common letter are not significantly different.
* DBS = days before sowing of wheat.
** Bijay Singh *et al.* (2001).
*** Yadvinder Singh *et al.* (2004).

Table 2. Effect of rice straw management on wheat and its residual effect in the following rice crop in rice-wheat cropping system

Experimental details	Crop	Grain yield of rice and wheat (t ha^{-1}) with rice straw management as			Reference
		Removed	Burned	Incorporated	
Himachal Pradesh data averaged for 4 years, acidic clay loam soil, rice straw chopped and incorporated 4 weeks before sowing wheat	Wheat	2.8	-	2.8	Sharma *et al.* (1985, 1987)
	Rice	2.4	-	2.5	
Himachal Pradesh, 5-year study, acidic clay loam soil, rice straw chopped and incorporated 4 weeks before wheat sowing	Wheat (1984-87)	2.6	2.6	2.2	Verma and Bhagat (1992)
	Rice	3.7	3.6	3.7	
	Wheat (1987-89)	2.4	2.4	2.4	
	Rice	3.8	3.7	4.0	

Eleven percent of the rice area has already been brought under the partial incorporation of the rice residue. Farmers burn the loose straw left by the combine and incorporate the half burnt stubbles. The complete incorporation is a laborious exercise, which farmers generally shirk. Punjab Agricultural University has developed some machines/implements especially for the purposes. Various options are available for the farmer for incorporation of the straw in the soil depending upon the resources and availability of the implements and the quantity of the straw to be managed before sowing wheat. The operations involved and the cost of each option are given in Table 4. All the other implements are common with the farmer except the chopper, which was recently developed by the university. The tillage operation after rice harvesting and before sowing wheat has been mechanized in the state. The option number V is the cheapest, where rice residue is burnt and the seeding of wheat is done by no-till drill. The option IV that is adopted by most of the farmers in the state costs Rs. 2687 per hectare. Therefore, the incorporation options are incurring higher expenditure to the tune of Rs.800 to 1675 per hectare.

Table 3. Wheat yield (t/ha) as affected by rice residue management (Sidhu and Beri, unpublished data)

Year	Burnt	Incorporated*	CD(5%)	Increase in yield by incorporation over burning
1993-94	4.27	4.36	0.27	0.09
1994-95	4.38	4.50	0.28	0.12
1995-96	4.09	4.29	NS	0.20
1996-97	4.85	4.78	NS	-
1997-98	4.85	5.21	NS	0.36
1998-99	4.25	4.37	NS	0.12
1999-2000	5.55	5.71	NS	0.16
2000-2001	4.73	4.87	0.12	0.14
2001-2002	6.01	5.97	NS	-
2002-2003	4.70	5.20	0.12	0.50
2003-2004	4.10	3.90	0.30	-

* Rice residue incorporated 2-3 weeks before sowing wheat.

The rice straw can be collected and used as mulch, for some crops. Mulching with straw has favourable effect on the yield of maize, soybean and sugarcane crops. It also results in substantial saving in irrigation water. Rice straw mulching in the no-till sown wheat with a newly developed Happy seeder machine is being tried. Happy seeder does cutting, lifting and spreading the standing rice stubbles and loose straw along with sowing in one operation. The field trials are in progress. Rice residue collection and mulch application result in additional cost of Rs.2000 per hectare. This can only be compensated by additional yield of. 2 t/ha of sugarcane and 0.20 t of soybean. The farmers feel that mulching accentuates the rodent problem in the crop, particularly sugarcane.

The collected residue can be composted by using it as animal bedding and then heaping it in dung heaps. Each kg of straw absorbs about 2-3 kg of urine from the animal shed. This was the practice in the past, where excess cereal residues were used for compost. It can also be composted by alternative methods on the farm itself and used there in the field. The residues of rice from one hectare give about 3.2 tonnes of manure as rich in nutrients as FYM. The collection of the residue can be done manually or with little modification in the Happy seeder machine. The Happy seeder is twin purpose machine, which can spread the residue in the field, or it can cut and load the straw in the trolley for collection. It has high collection efficiency as compared to manual. The cost of collecting the residue by this machine is approximately Rupees 1000 per hectare. The cost of preparing the enriched compost at the prevailing prices is Rs.1.47 per kg of finished compost (Table 5). The total nutrient analysis of the phospho-compost for fertilizer elements, and their value for the compost prepared from one-hectare straw is Rs.2021 approximately, which is less than the total cost of Rs. 4600.

The organic manure affects the yield by improving the physical, chemical and biological properties of soil. The effect of the rice straw compost was measured in the field experiment

Table 4. Options for managing rice residue in the soil *in situ* and approximate cost (Rs/ha) of each option

Straw incorporation options						Straw burning options			
I		II		III		IV (Farmer practice, General)		V	
Operations	Cost*	Operation	Cost	Operation	Cost	Operation	Cost	Operation	Cost
Stubble shaver (1)	375	Choper (1)	1500	Choper (1)	1500	Stubble shaver (1)	375	Stubble shaver(1)	375
MB/disc plough (1)	1125	Disc harrow (2)	1125	Rotavator (1)	1125	Complete burning	-	Complete burning	
Irrigation (1)		Irrigation (1)		Irrigation (1)		Discs harrow (1)	562.5	Irrigation(1)	
Disc harrow (2)	1125	Cultivators (2)	875	Seeding by no-till drill	750	Irrigation (1)		Seeding by no-till drill	750
Planking (1)	250	Planking (1)	250	Bunds by disc type ridger	125	Cultivators (2)	875	Bunds by disc type ridger	125
Seeding normal drill (1)	500	Seeding normal drill (1)	500			Planking (1)	250		
Bunds by ridger	125	Bunds by ridger	125			Seeding normal drill (1) (ND)	500		
						Bunds by ridger	125		
Total	3500		4375		3500		2687.5		1250

Note: The costs are as if the operation was conducted on hire basis. Cost of operations may vary according to area and availability of machinery. Irrigation cost not included as common to all options.

on rice-wheat system (Table 6). The benefit cost ratio of compost treatments to rice and wheat along with recommended fertilizers give economic benefit of Rs.1.28 per rupee spent (Table 6). The application of 30 kg P_2O_5/ha water soluble phosphorus just compensated the cost of compost if environmental damage is considered due to straw burning.

SOIL HEALTH

The incorporation of the residues has favourable effect on soil physical, chemical and biological properties such as pH, organic carbon, and water holding capacity and bulk density of the soil (Singh *et al.,* 2005). Field experiments on the rice-wheat cropping system show that incorporation of crop residues can increase soil organic C and total N contents (Table 7). Incorporation of crop residues increased organic C by 14-29 percent over residue removal treatments in 3-10 years of experiments. In an 11 years field experiment on a loamy sand soil in Punjab, the incorporation of residues of both crops in the rice-wheat cropping system increased the total P, available P, and K contents in the soil over the removal of residues (Table 8). The total P, and available S were in the order of residue incorporation > residue removal > residue burning. In another study over a 5-year period on a silt loam soil at Palampur in Himachal Pradesh having a relatively cooler climate than Punjab, the incorporation of rice straw in wheat caused a slight increase in a availability of P, Mn and Zn and a marked increase in the availability of K (Verma and Bhagat, 1992). The incorporation of crop residues on a long-term basis increased the DTPA-extractable Zn, Cu, Fe.

Table 5. Preparation of phospho-compost from rice straw collected from one hectare rice field

		Cost (Rs)
1	Collection of straw (8.0 t/ha)	1000
2	Urea (@ 1 g/litre of water)= 12 kg Rate=Rs 5/kg urea	60
3	Rock phosphate 480 kg Rate Rs 3/kg	1440
4	Water and electricity	200
5	Labour, 20 person @ Rs.100/ person	2000
	Total	4600
	Phospho-compost output 3.2 tones (Recovery 40%)	
	Price per kg of compost	1.47

Compost composition and its price (Rs)

	Nutrient	Content(%)	Nutrient amount in 3.2 tonnes (kg)	Price* (Rs)
1	N	1.78	57	570
2	P_2O_5	2.20	70	1056
3	K_2O	2.47	79	395
4	Secondary micronutrients and Humus			
	Total			2021

*Approximate price of the nutrient with subsidy on the fertilizers N @ Rs. 10/-, kg, P_2O_5 @ Rs 15/ kg, and K_2O Rs 5/kg.

Table 6. Economics of phosphocompost treatments

Treatment	Price of rice wheat (Rs)	Increase in profit over recommended fertilizer (Rs)	Cost of phosphorus saved (Rs)	Total profit (Rs)	Benefit cost ratio†
Recommended fertilizer (RF*)	72225 (4.89+7.02)§	-	-	-	-
N+Phospho-compost(PC) @ 4t/ha/yr	74139 (4.66+7.59)	1914	900	2814	0.48
N+30 kg P_2O_5 (ws) + PC @ 4t/ha/yr	76485 (4.92+7.71)	4260	450	4740**	0.80
N+60 kg P_2O_5 (ws) + PC @ 4t/ha/yr	79287 (5.14+7.95)	7062	-	7512**	1.28

RF*=120 kg N to rice and wheat each, 60 kg P_2O_5 to wheat only, N=120 kg N/ha to rice and wheat each.
ws = water soluble P_2O_5 through SSP.
† Cost of 4 t Phosphocompost @ Rs 1.47 /kg.
**Includes the value of additional wheat straw.
§ The average yield of wheat and paddy in a phosphocompost experiment (average of 5 years).

Table 7. Effect of crop residue management on organic C and total N content of soil under the rice-wheat cropping system

Reference	Type of crop residue	Duration of study (Years)	Residue management	Organic C (%)	Total N (%)
Beri *et al.* (1995)	Rice straw in wheat and wheat straw in rice	10	Removal Burned Incorporated	0.38 0.43 0.47	0.051 0.055 0.056
Sharma *et al.* (1987)	Rice straw in wheat and what straw in rice	6	Removed Incorporated	1.15 1.31	0.144 0.159
Yadvinder Singh *et al.* (2004)	Wheat straw, Green manure, and wheat straw + green manure (GM) in rice	6	Removed Incorporated GM Straw + GM	0.38 0.49 0.41 0.47	- - - -

Table 8. Effect of crop residue management on soil fertility of a loamy sand soil over 11 years of the rice-wheat cropping system at Ludhiana (Beri *et al.*, 1995)

Soil property	Crop residue management		
	Burned	Removed	Incorporated
Total P (mg kg^{-1})	390.0	420.0	612.0
Total K (g kg^{-1})	17.1	15.4	18.1
Olsen P (mg kg^{-1})	14.4	17.2	20.5
Available K (mg kg^{-1})	58.0	45.0	52.0
Available S (mg kg^{-1})	34.0	55.0	61.0

The rates of paddy and wheat grain used were Rs 5900 and 6300 per tonne, respectively and wheat straw Rs 1000/ tonne and Mn content in the soil (Yadvinder Singh *et al.,* 2000). In a long-term study carried out in the eastern part of the Indo-Gangetic Plain (Bihar), Misra et al. (1996) observed increases in available N, P and K in the soil with incorporation of crop residues in the rice-wheat rotation. The decrease in bulk density with straw addition definitely has a bearing on wheat yield in rice-wheat rotation, where soil aeration becomes a limiting factor. The incorporation of residue also prevents the leaching of nitrates. It adds a plenty of organic carbon and thus increases bacteria and fungi in the soil. In a rice-wheat rotation, Beri *et al.* (1992) and Sidhu *et al.* (1995) observed that soil treated with crop residues held 5-10 times more aerobic bacteria and 1.5 to 11 times more fungi than soil for which residues were either burned or removed. Due to increase in microbial population, the activity of soil enzymes responsible for conversion of unavailable to available form of nutrients also increases.

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Cropping Systems Diversification Opportunities and Conservation Agriculture

M.S. Gill and L.S. Brar
Department of Agronomy & Agrometeorology, Punjab Agricultural University,
Ludhiana 141 004, Punjab, India

ABSTRACT : Green revolution witnessed self-sufficiency with current food grain production of 212 m tonnes which primarily accrued on account of the evolution of high yielding genotypes. Their extensive cultivation irrespective of land capability resulted in over-exploitation of the resources (decline in water table, micro-nutrient deficiencies, emergence of new bio-types etc.). Since mid sixties, growth in irrigated area from 20.1 to 38.6 percent in 1996-97 helped to increase the productivity per unit area. To cope-up the present situation cropping system approach proved as a useful option by identifying the alternate crops led to increase the productivity by 25 to 117 percent over the existing rice-wheat system. Simply, by shifting 10 percent wheat area in Punjab (34 lakh ha) to gram and *gobhi sarson* would lead to save irrigation water by 76500 and 25500 ha m, respectively. It fulfills the fundamental aim of agricultural conservation by following high intensity cropping system under assured inputs, intercropping concept, growing of crops as per land capability, integrated nutrient management, inclusion of legume in different cropping systems, precision agriculture concept and integrated watershed management proved necessary tools for enhancing and sustaining the productivity along with conservation of resources.

INTRODUCTION

India has not only achieved self-sufficiency in food grains but also disproved all good-intentioned projections about the food situation, in the world. Paul Eldrich, a noted economist, predicted in 1966 "sometime between 1970 and 1985 the world will undergo vast famines-hundreds of million people are going to starve to death. The United States should announce that it will no longer ship food to countries such as India whose dispassionate analysis indicated that food and population imbalance is hopeless".

Green revolution in India increased the food grain production from 50 million tonnes in 1951-51 to 133.0 million tonnes in 1980-81 and proved the prediction wrong. An impressive current production level of 212 million tonnes is a testimony of the concerted efforts of farmers,scientists and extension workers. Though significant strides have been made for total food grain production but simultaneously Indian agriculture is facing second generation problems comprising soil fatigue due to intensive cultivation, saturation of high yielding varieties in terms of yield, continuous decrease in the in-put use efficiencies, a declining water table and a virtual halt in further expansion of the irrigated area have posed major challenge to maintain higher production levels without endangering the environment.

Soil and water are the two most important natural resources available to mankind upon which depends the very survival of the living being on this earth planet. Data on growth in irrigated area by 1966-67 and 1996-97 in different states of India (Table 1) clearly indicates about regional imbalance and extent varied from 32.3 to 92.9 percent in Indo-Gangetic Plains – considered as the most productive resource enriched zone of the country (Tewatia *et al.*, 2001). Although, these regional disparities are unavoidable due to availability of water resources in a region, they do create a problem for uniform sustainable agricultural production in the country. The only option left is to develop different agricultural production systems in general and cropping systems in particular for different states/regions depending upon their water and soil resources so that the difference between money earned per hectare are minimized.

Table 1. Growth in irrigated area (%) in Indo-Gangetic Plains

State	1966-67	1996-97
Punjab	58.8	92.9
Haryana	37.8	76.2
Uttar Pradesh	36.1	68.7
West Bengal	26.5	35.0
Bihar	21.6	49.4
Madhya Pradesh	6.3	32.3
Rajasthan	14.4	33.3
India	20.1	38.6

Source: Tewatia *et al.* (2001).

The growing of crops in a sequence to study their interaction effects with the resources available, other enterprises available at the farm and technological inputs which determine their make-up denote cropping system. The cropping system investigations play an important role in using the inputs in a synergistic manner. The appropriate choice of the crops and cropping system help to achieve the maximum return, maximizing input use efficiency by developing cohesion among the resource applied. Choice of a crops combination by the farmers is primarily governed by profitability, household needs, competitiveness of the product in the market, resource base, input supply, etc. Hence the alternative crops of cropping system have to be carefully examined in the light of these factors prior to recommendation. Similarly, the fundamental aim of conservation agriculture is to conserve, improve and make the most efficient use of natural resources, using integrated management of soil, water, biological agents and input materials (Gonzalez-Sanchez *et al.*, 2002). Moreover, it includes the principal problems associated with the agricultural environment including erosion, desertification, low organic matter content, compaction, emission of carbon-dioxide and other green houses gases, decrease of biodiversity, contamination of surface water and contamination caused by pesticides (Garcia-Torres *et al.*, 2003).

The depletion of soil fertility by the intensive cereal-cereal production systems is considered to be a major cause of the yield decline. A rice-wheat system yielding 7 t/ha of rice and 4 t/ha of wheat removes 315 kg nitrogen (N/ha), 28 kg phosphorus (P/ha) and 333 kg potassium (K/ha) and significant amounts of micro-nutrients (Hegde, 1992). Refinement of nutrient management strategies would help maintain the crop productivity and soil fertility, but other rotational strategies could also help especially in situation where exhaustive cropping system are not proving well and yield are stagnating. Therefore, under such situations inclusion of legumes, commercial crops, oilseeds, aromatic and medicinal crops play a pivotal role in the rationalization of the resources use and to break the yield barrier.

In agricultural production systems, plant nutrients are continuously removed from the system with each harvest. This is more so in India where both grains and crop residues are removed; grain for human consumption and crop residues for feeding the cattle, thatching and fuel etc. Various investigations conducted in Indo-Gangetic Plains amply testify the negative balance is being created on account of high removal over addition (Table 2).

Table 2. Annual nutrient balance (‘ 000 tonnes) in Indo-Gangetic Plains

State	N	P_2O_5	K_2O	Total	Reference
Punjab*	- 4.7	- 0.0	- 7.0	- 11.7	Aulakh and Bahl (2001)
Haryana	- 22.5	- 92.0	- 480.0	- 594.5	Kumar *et al.* (2001)
Uttar Pradesh	- 6.8	- 0.06	- 55.9	- 62.7	Pal *et al.* (2001)
Jharkhand	- 1.0	- 0.4	- 0.3	- 1.7	Sarkar (2001)
Bihar	+ 136.5	+ 49.0	- 437.5	- 252.0	Mishra *et al.* (2001)
West Bengal**	- 185.3	- 24.8	- 590.9	- 801.0	Mandal and Khande (2001)
Madhya Pradesh	- 17.7	- 86.7	- 824.7	- 929.1	Swaroop *et al.* (2001)
India	+ 1061.9	- 1741.2	- 5119.1	- 5798.4	

* Approximate from figure.
**Values for 1995-96 based on nutrients covered by cereals, pulses and oilseeds.

Therefore, there is an urgent need to develop and promote different cropping systems in different farming situations including leguminous crops, shallow and deep root systems, low, medium and high water requiring crops, crops having smothering effects and oilseed based cropping systems.

High intensity cropping system under assured inputs

The high intensity cropping sequences in major ecologies, have shown marked advantage over existing cropping systems. The introduction of new cropping systems or diversification of one or more component crops resulted in enhanced annual productivity ranging between 25 and 117 percent over the existing cropping systems at different AICARP-CS Research Centres (Sharma *et al.*, 2002). Proper genotypes of a crop should be selected which can mine the nutrients from soil and applied sources and convert them with desired out-put. Crops and cropping systems should be selected such that the residual nutrient left by one crop is efficiently utilized by the following crops. From a 10-year study in an Ustochrepts in Punjab, it was seen that the apparent recovery of P declined in rice-wheat > rice-berseem > cotton-wheat > corn-wheat > groundnut-wheat > pearlmillet-berseem (Acharya *et al.*, 2002). Studies on evaluation of prominent cropping systems at PAU, Ludhiana revealed that there is sufficient scope to shift from rice-wheat cropping system spread over 69 percent of the cultivated area. The rice crop occupied the area which was exclusively not suitable for its cultivation. But , on account of favourable Govt. policies viz. supply of electricity at subsidized rate, no legislation about the installation of tubewell towards depth and intra-space, committed procurement and fixed support price do not encourage the farmers to shift from rice-wheat cultivation to other sustainable cropping system. There are different cropping systems which not only gave more productivity than rice-wheat system but also helped to save substantial quantity of irrigation water, namely, maize-wheat-summer moong bean, maize-potato-summer moong bean, maize-potato-onion, summer groundnut-potato-bajra fodder produced rice equivalent yield as 15.6, 18.2, 27.6 and 16.0 t/ha/annum, respectively as against 13.7 t/ha in rice-wheat system (Table 3). The corresponding saving of irrigation water over rice-wheat system was 88, 81, 78 and 100 cm, respectively. It is thus clear that appropriate selection of cropping systems improve productivity on one hand and ensure rational use of the resources on the other hand (Anonymous, 2003).

Inter cropping

Intercropping is one of the important ways to increase the productivity and provide income stability under limited soil moisture conditions. Some of the promising intercropping system are maize + blackgram at Palampur, Ranchi and Banswara; maize + soybean in Ranchi; maize + cowpea at Karjat; sorghum + soybean at Sehore; sorghum + pigeon pea at Indore; Pigeon pea + green gram at Bichpure and Hunumangarh; rice + soybean at Kalyani and Jabalpur and wheat + rapeseed at Indore. Net profit from these intercropping systems were quite high 15 to 200 percent when compared with sole cropping. Most of these intercropping systems were evaluated on farmers' fields and found to be highly remunerative over the sole cropping (Anonymous, 2002). In these on-farm trials also, the additional benefits over sole crop varied from 9 to 199 percent. In *kandi* area of Punjab comprising 8-9 percent where wheat + gram or wheat + *raya* row are the other promising intercropping system to sustain the productivity under situations where water is a constraint. Among crops, maize-wheat is the major cropping system in soils having medium to high level water retentivity.

Table 3. Evaluation of prominent cropping systems in relation to yield, variable cost, net returns, irrigation water applied and land use efficiency (average of 3 years)

Cropping system	Rice equivalent yield (t/ha)	Total variable cost (Rs/ha)	Net returns (Rs/ha)	Irrigation water applied (cm)	Land use efficiency (%)
Rice-wheat	13.7	34437	40586	205	73.2
Maize-wheat	12.6	32681	36186	84	70.4
Maize-wheat-summer mungbean	15.0	41405	39490	117	82.9
Maize-potato-summer mungbean	18.2	58428	41216	124	80.8
Maize-potato-onion	27.6	76139	71804	127	87.7
Cotton—wheat	10.2	33610	22093	82	88.7
Cotton-African sarson	8.1	29956	14275	74	87.6
Cotton-transplanted *gobhi sarson*	8.4	29956	17230	68	86.1
Summer Groundnut-toria+ *gobhi sarson*	10.3	36367	20016	71	87.4
Summer Groundnut-potato-bajra (fodder)	16.0	55557	31643	109	88.7

Growing of crops as per land capability

The crops perform well in different cropping systems if grown as per soil suitability which determine their productivity make-up in relation to soil type, soil depth, water retention, climatic factors, duration of the crops, source of irrigation, frequency of irrigation water available etc. Growing of maize and wheat in a sequence in loamy sand soil under rainfed condition of sub-montaneous Punjab gives less total productivity (23.8 q/ha) than yield obtained from a sole crop of wheat (25.7 q/ha) in winter seasons. While in sandy loam soil with better water retentivity, maize and wheat crops should be grown in a sequence. The coefficient of variability for maize and wheat grown in sequence in loamy sand soil was 60 and 43 percent, respectively whereas in fallow-wheat, it reduced to 25 percent (Table 4). The lower values of coefficient of variability are a clear indication of better stability (Prihar and Singh, 1983).

Table 4. Suitable crop sequences in different types of soils

Soil	Sequence	No. of years	Treatments	Yield (kg/ha)	CV (%)
Loamy sand	Maize-wheat	6	Maize	945	60
			Wheat	1435	43
			Total	2380	
	Fallow-wheat	6	Fallow	-	-
			Wheat	2565	25
Sandy loam	Maize-wheat	10	Maize	2410	29
			Wheat	2910	14
			Total	5320	

Source: Prihar and Singh (1983).

Selection of crops made on the basis of soil suitability revealed that gram crop which received only one post sowing irrigation produced 17.3 q/ha seed yield (average of 21 on-farm trials) which was very close to the potential yield (17.5 q/ha) in loamy sand soil. Likewise, *gobhi sarson* produced 18.0 q/ha in sandy loam soil (average of 17 on-farm trials) and proved good options for wheat crop in Allowal Command Area. It was further estimated that if 10 percent area is diverted from wheat (34.0 lac ha) to gram crop, it would help to save 76500 ha metre of irrigation water. Similarly, with the diversion of 10 percent area to *gobhi sarson* would save 25500 ha meter of water as compared to wheat grown on the same acreage (Gill *et al.*, 2003).

Integrated nutrient management

To ensure adequate and balanced nutrient supply, integrated approach is an important option and involves more efficient use of chemical fertilizers in conjunction with judicious combination of organic manures without detriment to soil fertility and improving crop productivity. The high cost of fertilizers coupled with relatively greater losses of fertilizer N leading to environmental pollution and yield decline over the years calls for a cheaper and sustainable measures to improve the productivity.

Integrated nutrient supply helps to improve the physical, chemical and biological health of soil and avoids soil degradation and deterioration of water and environmental quality by promoting carbon sequestration and checking the losses of nutrients to water bodies and atmosphere. Besides, organic source of nutrient acts as slow release fertilizers as it synchronizes the nutrient demand set by plants, both in time and space, with supply of the nutrients from the labile soil and applied nutrient pools. Research investigations have further purported that use of green manure before paddy transplanting not only help to save the 50 percent recommended NPK but also improve the soil fertility. Likewise, 50 percent substitution of NPK through farm yard manure also help both the crops in rice-wheat system alongwith fertility improvement (Gill *et al.*, 2000). Another significant investigation for realizing the high yield of paddy the recommended chemical fertilizers should be supplemented with crop residues and green manuring (Bhandari and Walia, 2000).

Inclusion of legumes in different cropping systems

Legumes are known to increase soil fertility through their capacity to fix atmospheric-N and hence the soil fertility can be improved by inclusion of a legume in the cropping system.

Yield of cereals following legumes are reported to be 30 to 35 percent higher than those following a cereal in cropping sequence. Beside N-fixation, legumes also help in solubilization of P, increase in soil microbial activity, organic matter restoration and improvement of physical health of soil (Acharya and Bandyopadhyay, 2002). Results from the All India Coordinated Research Project on Cropping Systems showed consistent better productivity from rice-pulse than rice-wheat systems (Hegde, 1992). The benefits of legumes in rotation are not solely due to biological nitrogen fixation, but reault from improved soil structure, reduced disease incidence and increased mycorrhizal colonization (Wani *et al.*, 1995). Growing of legume as green manure (*Sesbania aculeate* L.) helped to save 60 kg nitrogen for the succeeding paddy crop (Kolar and Grewal, 1988).

Precision agriculture concept

Precision or site-specific crop management refers to a management system of production agriculture, using diverse technologies to increase field productivity and protect the environment. Under precision agriculture, however, inputs are applied in each part of the field according to its unique set of conditions. Moreover, when to apply, how to apply, how much to apply, kind of inputs in relation to water, nutrient, pesticides etc., the residual effect nutrient and crop residue and left over water on the succeeding crop and their behaviour with the environment in time and space are studied from a very close angle so that resources wastages may be reduced to minimum possible. Normally, farmers follow one uniform practice of water, nutrient and pesticides application at their farm while in this concept the variation observed within the field itself is to be taken care of. Each field is to be visualized critically and assured of balanced supply of nutrients in desired amount in each nook and corner to achieve sustainable yield levels of different cropping systems.

Integrated watershed management

Watershed management is an approach of area planning of natural resources especially land, water and plants to sub-serve the socio-economic needs of human society or community based on sustainable eco-system principles. It is divided in to two parts i.e. catchment area-land area contributing water to a given point from where it can be recycled in addition to recharge the profile, and command area - where water is utilized in an effective manner depending upon the catchment area/capacity of reservoir. This is the only approach which can sustain the productivity of different cropping systems under rainfed or under limited irrigation conditions. Upper catchment and foothill regions of several states provide the greatest scope for rain water harvesting and ground water recharge because of favourable hydrological formations and heavy rainfall. An integrated watershed development programme in *kandi* area of Punjab including: (i) forest rehabilitation on 0.045 m ha in upper catchment, (ii) 19 water harvesting dams, (iii) seven medium capacity irrigation dams having cultivatable command area of 9606 ha, and (iv) on-farm development by various departments during the last two decades has already paid dividends by reversing the declining water table as well as increasing the ground water recharge in the lower irrigated area. Such approaches are the only solution to conserve/preserve the natural precious resource "water" for its utilization in a way to restore and maintain the eco-balance ensuring sustainability. The water balance in the study area has increased from (-) 97867 ha-m in 1979-80 to (+) 52075 ha-m during 1997-98 thus reversing the falling trend of water table to a rising water table (Sharma, 2002).

Another study conducted on 16 ha cultivated watershed with 26 farmers at village Boothgarh in Hoshiarpur district revealed that minor land grading, bunding, safe disposal of excess run-off during intense monsoon from each field and drainage of run-off from field to permanent water way were essential to check soil erosion and to conserve moisture. Land treatment with soil and water conservation measures considerably increased the crop yield. The increase in yield was 57 and 25 percent in mixture (wheat + gram) and bajra fodder (Table 5), respectively when grown in a sequence (Verma *et al.*, 1984).

Table 5. Effect of land treatment (grading, bunding and control of surplus water) on wheat + gram – bajra fodder cropping system under rainfed conditions (Av. of 3 years)

Crop	Yield (q/ha)	
	Untreated	Treated
Wheat + Gram mixture	10.5	16.5
Bajra (dry fodder)	48.0	60.0

CONCLUSION

- To make the cropping systems sustainable under assured input conditions, adoption of integrated nutrient supplies and weed management in combination with the selection of crops, genotypes and other agronomic management practices are considered as pre-requisite.
- Under limited irrigation conditions, selection of crops and cropping system should be based on soil type, soil depth, rainfall pattern and matching the use of inputs accordingly.
- Watershed based management is the only approach which not only helps to keep the natural eco-system intact but simultaneously sustains the productivity of different cropping systems with rational use of natural resources.
- Intercropping/mixed cropping and inclusion of legumes in different cropping systems are the other tools for making cropping system profitable and stable alongwith improvement in soil fertility.
- Application of inputs with precision not only reduces the cost of production by ensuring the rational use of resources but also sustains the productivity over longer period of time.

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Resource Conservation Technologies and Cropping System Diversification Opportunities

S.C. Tripathi, A.D. Mongia and Jag Shoran
Directorate of Wheat Research, Karnal 132 001, Haryana, India

ABSTRACT : The scope of bed planting, introduced in India on the pattern of CIMMYT, Mexico, an important resource conservation technology particularly water, was explored for diversification of rice-wheat system. In a system perspective, various crop sequences were studied at the DWR, Karnal during 2001-2003 with the objective to diversify/ intensify the rice-wheat with the help of bed planting and evaluate its effect on succeeding crops. Crops like pigeon pea, maize, soybean, mustard, wheat, vegetable pea and green gram were grown on raised bed whereas rice, berseem and sorghum were grown by conventional planting methods. The experiment was conducted in randomized block design with four replications. Pooled analysis of three years showed that diversification/intensification of rice-wheat system, once in three years, always enhanced the net return, when all crops (except rice) were grown on raised bed in a system approach. Inclusion of oilseed or pulses on beds once in three years or intensification by growing vegetable pea in between rice and wheat or green gram after wheat showed higher return as compared to conventional rice-wheat system. Maximum benefit cost ratio was recorded in pigeon pea-wheat-rice-wheat-rice-wheat (CS8) crop sequence whereas maximum net return (Rs 60952/ha/year) was in rice-mustard-greengram-rice-wheat-greengram-rice-wheat-greengram crop sequence. Growing of berseem crop in the rotation reduced weed population in subsequent wheat cycle. It can be surmised that diversification and/or intensification of rice-wheat system with help of resource conservation technologies like bed planting can play a pivotal role in Indian agriculture. There is need to develop suitable bed planter, which can sow different crops having variable seed size adjustments from mustard to maize. Additionally, the performance of RCTs like zero and reduced tillage were evaluated under non puddled direct seeded and puddled transplanted paddy conditions. It was observed that former production situation recorded conspicuously superior wheat yield over the latter. This showed that resource conservation technologies like zero and bed planting could boost the production to a great extent.

INTRODUCTION

Wheat and rice account for more than 50% of the world cereal production, and in combined they produce grains for about 20% of the world population. In South Asia, rice (*Oryza sativa* L.)- wheat (*Triticum aestivum* L. emend. Fiori and Paol.) crop sequence is the largest agriculture production system and occupies about 13.5 million hectares area including 10 million hectares in India, extending from Indo-Gangetic plain to Himalayan foothills. In India, approximately 23 and 40% of total rice and wheat area, respectively, is represented by rice-wheat system alone (Timsina and Connor, 2001), which requires contrasting edaphic conditions. Rice is generally transplanted in puddled soil and is given continued submergence whereas wheat is grown in upland well-drained soils having good tilth. Rice-wheat system that yields 7t/ha of rice and 4/t/ha of wheat takes up more than 300 kg nitrogen (N), 30 kg phosphorous (P) and 300 kg potassium (K) per hectare from the soil (Sharma and Tiwari, 2005). Continuous adoption of this system has been reported to decline soil and crop productivity (Nambiar and Abrol, 1989). Rice and wheat, both are high water requiring crops, having an evapo-transpiration requirement of more than 1000 mm. In the quest of high production, farmers have to irrigate these crops frequently, especially paddy, through surface water from canals and/or groundwater pumped through shallow tubewells. This led to decline in water table, which is major cause of concerns in some parts of Indo-Gangetic plain. Continuity of this trend will jeopardize the sustainability of rice-wheat system. Analysis of long-term experiments on rice-wheat showed rice yield decline @ 0.02 t ha^{-1} yr^{-1} or 0.5% yr^{-1} (Dawe *et al.*, 2000; Duxbury *et al.*, 2000; Yadav *et al.*, 1998). On the other hand, in India, most of the oilseed and pulse crops are grown on flat by broadcasting with flood irrigation and/or under continental monsoonal type climate resulting in low productivity. Generally, these crops are susceptible to water stagnation, experienced during rainy season or flood irrigation. This prompted to investigate innovative planting techniques for these crops, which could enhance yield per se with lesser water use and also play a catalytic role in diversification of rice-wheat system.

The Resource Conservation Technologies (RCT's), which were evolved with the efforts of scientists, farmers, extension workers and private industry groups gained importance due to increased profit to farmers. The 'Bed Planting', an important input saving planting technique, especially water (20-30%), was introduced in India on the pattern of CIMMYT, Mexico. In this planting method, crop is grown on top of bed (40 cm) and irrigation is applied in furrows (30 cm). There are many additional benefits including lesser seed and nutrient requirement, opportunity for enhancing diversification and intercropping, moving towards conservation agriculture by using same beds for succeeding crops, reducing cost of cultivation, lesser lodging (Tripathi *et al.*, 2002) furrows providing efficient passage for irrigation as well as for drainage (Sayre and Moreno Ramos, 1997), increased surface area for capturing more rainfall, possibility of mechanized interculture operations as well as placement of fertilizer, manual and easy rouging, higher productivity of oilseed and pulses as compared to flat planting, additional window for maximizing yield through interactive effects of RCT's and wheat varieties (Tripathi *et al.*, 2002). Bed planting, sometimes termed as Furrow Irrigated Raised Bed (FIRB) technology works as catalyst for diversification (Tripathi *et al.*, 2001) of rice-wheat system.

Table 1. Yearwise treatment details

Crop sequences (CS)	Year		
	2000-2001	2001-2002	2002-2003
CS1	Rice-wheat	Rice-wheat	Rice-wheat
CS2	Rice-berseem	Rice-wheat	Rice-wheat
CS3	Sorghum(fodder)-wheat (BED)-greengram (BED)	Rice-wheat (BED)	Rice-wheat (BED)
CS4	Rice-mustard (BED)-green gram (BED)	Rice-wheat (BED)-green gram (BED)	Rice-wheat (BED)-green gram (BED)
CS5	Soybean (BED)-wheat (BED)	Rice-wheat (BED)	Rice-wheat (BED)
CS6	Rice-vegetable pea (BED)-wheat (BED)-green gram (BED)	Rice- vegetable pea (BED)-wheat (BED)-green gram (BED)	Rice-vegetable pea (BED)-wheat (BED)-green gram (BED)
CS7	Maize (BED)-vegetable pea (BED)-wheat (BED)	Rice-wheat (BED)-green gram (BED)	Rice-wheat (BED)-green gram (BED)
CS8	Pigeon pea (BED)-wheat (BED)	Rice-wheat (BED)	Rice-wheat (BED)

A field experiment comprising eight crop sequences (Table 1) was conducted at Karnal during 2001-2003 in a randomized block design with four replications. The objective was to diversify/intensify the rice-wheat system and evaluate its effect in subsequent years. In this planting system, crops were grown on 40 cm wide raised beds and irrigation was given in 30 cm wide furrows. Number of rows differed according to the crops. Three rows of wheat, two rows of vegetable pea, green gram, soybean, mustard and one row of maize and pigeon pea were grown on bed whereas other crops were cultivated as recommended. The varieties used for different crops were UPAS 120 (pigeon pea), SL 295 (soybean), PC 9 (sorghum) and Naveen (maize) in *Kharif;* Agrani (mustard), Arkel (vegetable pea), PBW 343 for timely and Raj 3765 for late sown (wheat) in *Rabi;* and Narendra 1 (green gram) in spring/summer season. Wheat after pigeon pea/maize/soybean/vegetable pea and green gram after mustard/ wheat was sown just by reshaping of the beds to reduce the tillage cost. Green gram was incorporated into the soil after picking of mature pods. Irrigation was applied in furrows between two beds under bed planting whereas flood irrigation was given under flat planting.

The cost of cultivation was calculated by taking into account the prevailing price of inputs like fertilizer, seed, herbicides, irrigations, tillage operations, transportation charges, interest on working capital, risk factor, management charges and depreciation cost of implements. The returns were calculated by using the minimum support price of important crops and prevailing market price of vegetable pea, berseem, sorghum fodder and wheat straw etc on yearly basis. Different crop sequences were compared by converting the yield of all the crops in a sequence into equivalent wheat yield on price basis and then averaged. The minimum support prices were used for paddy, wheat, maize, soybean, pigeon pea, green gram and mustard whereas market prices were taken into consideration for wheat straw, berseem and sorghum fodder and green pea pod.

System productivity and profitability rather than individual crop yield play a vital role in determining the most useful and profitable crop sequence. Hence equivalent wheat yield and economics of each cropping sequence was calculated. Three years data of eight crop sequences showed significant differences in equivalent wheat yield in yearly as well as in pooled analysis (Table 2). The crop sequence CS4 (157.7 q/ha) and CS6 (155.9 q/ha) produced non-significant equivalent wheat yield, which was significantly higher than other crop sequences. On the other hand, lowest equivalent wheat yield was recorded in CS5 having soybean as a component crop. During the second year of crop cycle (2001-2002), the equivalent wheat yields of all the crop sequences were high due to high paddy yield compared to previous or subsequent year. Additionally, it was found that wheat grain protein content was higher in the crop sequences where the crop was diversified in previous year or intensified with inclusion of short duration crops.

The economic analysis of different crop sequences showed that crop sequence CS4 recorded maximum total return/ha (Rs 97,860) and net return/ha (Rs 60,952) compared to other crop sequences. Higher return in this crop sequence was due to inclusion of green gram in summer during all the three years and mustard in *rabi* during first year of study. The crop sequences CS7, CS8 and CS6 ranked 2nd, 3rd and 4th in net returns, respectively as compared to other crop sequences. Rice-vegetable pea-wheat crop sequence recorded 2nd highest total return but its highest cost of cultivation (Rs43,640) lead to 4th in net return. On the other hand, lowest total return/ha (Rs 78,796) was in CS5 owing to inclusion of soybean in first year and minimum cost of cultivation (Rs 27,686) in CS8 due to inclusion of pigeon pea. The crop sequence CS8 also recorded maximum benefit cost ratio (2.97) and ranked 3rd in net return (Rs 54,608) after CS4 and CS7. The maximum cost of cultivation incurred in CS6 that led to lowest benefit cost ratio (2.21). In nutshell, the crop sequences CS4, CS7, CS8 and CS6 recorded 23.13, 11.61, 10.31 and 7.16% higher net return, respectively than CS1, rice-wheat system. In this study CS6 recorded 25% higher net return as compared to the finding of Chauhan et al. (2001) where same sequence was practised on flat planting.

Table 2. Equivalent wheat yield and economics (Rs/ha) of crop sequences (mean of three years)

Cropping sequences	Equivalent wheat yield (q/ha)	Total return	Cost of cultivation	Net return	B:C
		<———	Rs./ha	———>	
CS1	133.4	82756	33254	49502	2.49
CS2	134.0	83152	35405	47747	2.35
CS3	134.7	83605	34790	48814	2.40
CS4	157.7	97860	36906	60952	2.65
CS5	126.9	78796	28351	50448	2.78
CS6	155.9	96689	43640	53048	2.21
CS7	142.4	88395	33005	55390	2.68
CS8	132.7	82295	27686	54608	2.97
CD at 5%	4.0				

Prospects of permanent bed

In the context of conservation agriculture, where soil is essentially biologically tilled, bed planting has significant role in enhancing the eco-friendly cultivation with higher productivity and profitability of various cropping systems. The important crop rotations, which virtually can directly go for permanent bed planting, are soybean-wheat, maize-wheat, pigeon pea-wheat, maize-vegetable-wheat, maize-toria/mustard-wheat, pigeon pea+mungbean/urdbean-wheat etc. Even direct seeding of rice in some cases produces similar grain yield with earlier maturity. This provides a chance to grow short duration vegetable pea/potato followed by wheat to enhance the crop and soil productivity as well as cropping intensity. The intercropping of sugarcane and wheat in autumn would enhance the wheat area and production and simultaneously sugarcane productivity. Three years study of eight crop sequences showed that diversification/interruption of rice-wheat system, once in three years, always enhanced the net return, when all crops (except rice) were grown on raised bed in a system approach. Inclusion of oilseed or pulses once in three years or intensification by growing vegetable pea in between rice and wheat or green gram after wheat showed higher return as compared to conventional rice-wheat system.

A huge amount of expenditure on import of agricultural commodities is borne by India. Among the various agricultural commodities the vegetable oils and pulses contribute about million Rs 87448 and Rs 25626, which comes out to be 51.1 and 14.9% of total agricultural imports (2002-03), respectively. Enhancing the productivity of oilseeds and pulses and simultaneously backing by marketing and processing structure could minimize this to a great extent.

Performance of oilseed and pulses under different planting methods

Crops like green gram, vegetable pea, mustard, pigeon pea, maize and wheat were grown on flat and raised bed, and it was observed that bed planting exhibited higher yield as compared to flat planting. Vegetable pea (as a green pod), mustard and green gram recorded up to 34.0, 20.4 and 11.8% higher yield as compared to flat planting, respectively. This

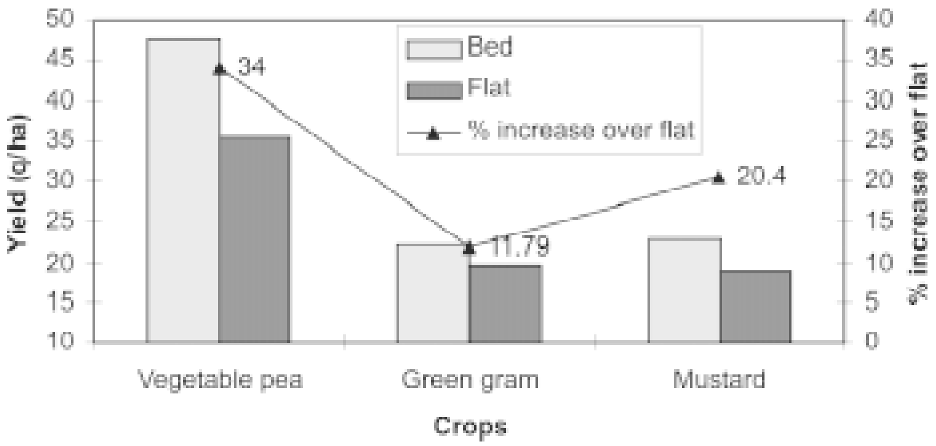

Fig. 1. Performance of various crops under different planting methods.

showed that bed planting could be used for diversification/intensification of rice-wheat system with better returns. Tripathi *et al.* (2003) emphasized that bed planting can be considered a new technique for higher oilseed and pulse production.

RCTs effect on wheat productivity under puddled and non puddled situations

Another field trial was conducted for two consecutive years at DWR where two main plots consist of puddled transplanted and non-puddled direct seeded rice followed by three tillage conditions viz. zero tillage (direct sown by Pantnagar seed drill), reduced tillage (disking, cultivator and planking operation, each one) and conventional tillage (three disking, four cultivator and two planking) during *Rabi* season. Fertilizer was applied @ 120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha in the form of urea, DAP and MOP in both years. Half the dose of nitrogen, full amount of phosphorus and potash were applied as basal. Remaining part of nitrogen was top dressed after first irrigation. Weed control was done through application of Isoguard plus (a chemical blend of isoproturon and 2,4,-D @ (0.5 + 0.125 kg a.i./ha) in 500 litres of water at 30 days after sowing. The wheat sowing for zero-tillage treatment, required higher moisture, was done at 7 days after irrigation. On the other hand reduced and conventional tillage treatments were sown at 14 days after irrigation. However, in dry seeded rice, which matured a week early than transplanted one, sowing of wheat was done at the same time. In all the treatments sowing was done with the help of fertiliser-cum-seed-

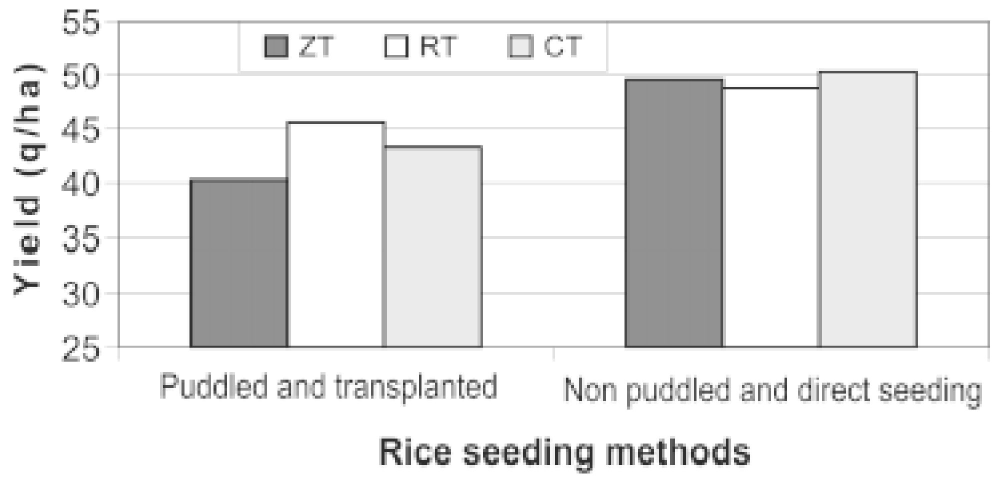

Fig. 2. Performance of different tillage on wheat yield under puddled and non-puddled condition (mean of two years).

drill specially designed for zero-tillage situation by the G.B.P.U.A.& T. at Pantnagar. Before sowing of wheat in non-tilled condition, one spray of Paraquat @ 0.4 kg a.i./ha in 500 litres water by using hand sprayer was done to control weeds left after harvest of paddy.

Combined analysis of two years yield data indicated that maximum wheat yield was recorded in direct seeded condition (49.6 q/ha) which was significantly higher as compared to yield recorded in transplanting condition (43.1 q/ha). The yielding ability of the wheat tested under zero-tillage was at par with reduced or conventional tillage practices. There was a yield gain of 9.3, 3.2 and 7.0 q/ha of wheat under zero-tillage, reduced tillage and conventional tillage, respectively when earlier crop of rice was dry seeded as compared to transplanted one. Wheat yield in non-tilled condition under dry seeded plot of rice recorded 14.3 percent higher yield as compared to yield exhibited in conventional tillage plot of transplanted rice field. The total productivity of rice and wheat annual sequence was similar irrespective of whether rice was dry seeded or transplanted. A similar concern was expressed by Tripathi *et al.* (1999), which pave the way for the popularization of zero till technology.

Limitations of conservation agriculture as well as diversification are many folds. Most of conservation agriculture technologies in developed countries are focused on rain fed and large farm families whereas in Indian sub-continent the agriculture is mostly on small and marginal farmers irrigated or rainfed. Diversification of crops should be ensured by competitive support price, marketing system, short duration and synchronous maturity of pulses, etc. The development of machinery is utmost important for sowing of cereals, oil seed and pulses from seed size of mustard to maize as pure crop as well as in intercrop under the residue retention of flat/bed planted condition.

In brief, the diversification could be possible through innovative approaches like adoption of conservation agriculture, bed planting technique, competitive support price, market establishment, storage and processing facilities. This will ultimately reduce the burgeoning food grain storage problem and import burden of vegetable oils and pulses. Additionally, switching over paddy cultivation practices from puddling to direct seeding could bring a sea change in wheat production with adoption of RCTs.

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Cropping System Options in No/Reduced Till – Surface Residue Managed Systems

*U.P. Singh, Y. Singh, H.P. Singh and Raj K. Gupta**
Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221 005,
Uttar Pradesh, India

ABSTRACT : Zero till is one of the feasible options among the resource conserving technologies (RCT) for advancing the wheat sowing. Direct seeded rice (DSR), unpuddled transplanted rice (UTR), surface seeding (SS) and raised bed planting system (BP) are the other RCT options to optimize the natural resources and inputs for the sustainability of RW cropping system and crop diversification in the eastern region. In this paper an attempt has been made to summarize the result of multi location trials under different thematic areas of tillage and crop establishment/cropping system. The studies have shown that timely crop establishment enhances crop productivity and input use efficiency in rice, wheat, maize, lentil and pigeon pea. It has been found that zero-till technology benefitted the eastern farmers more in terms of higher productivity gains and larger reductions in cost of cultivation. It is for this reason the resource poor, small and marginal farmers of the eastern Gangetic plains have begun adopting resource conserving technologies now. It was observed that benefits of zero-till technology can be further improved by introducing paired-row planting, controlled traffic, single basal deep placement of N (80% of recommended dose and balance 20% on need base using leaf colour charts, LCC), and leaving some crop residues to cover the soil surface. Results of farmer participatory field trials have been very encouraging in effecting a shift from the conventional puddled transplanted rice to unpuddled transplanted rice or direct dry or wet seeded rice in unpuddled soils as potential options for saving in irrigation water and cutting back the cost of cultivation. Zero-till seeding practice has led to improvement in productivity of lentil in low-lying areas of eastern Gangetic plains. Zero-till planting of crop mixtures (crop choices) when based on past flood events (dates, duration and intensity of floods), proved helpful in minimizing risks of floods to farmers and ensure some income during the season. Single basal, deep placement of fertilizer nutrients is likely to improve input use in eastern Gangetic plains (input use not possible otherwise in soils submerged to variable depths). Leaf color charts saved 13-17 percent N and farmers are adopting this practice. Bed planting system has promoted crop diversification through mungbean, pigeon pea and vegetables, and development of more innovative cropping systems (e.g. sugarcane + wheat/chickpea/Indian mustard in north-west; and rice–potato/winter maize/boro rice in eastern Gangetic plains).

INTRODUCTION

In recent years, decline and deterioration of natural resources (NRs) has emerged as a serious concern for sustainable food production in our country. Optimization of NRs, inputs, and diversification/intensification of cropping system through use of fallow lands/rice fallows are the major issues for conservation agriculture and sustainable agriculture development. The rice-wheat (RW) system is labour intensive, less mechanized, uses low inputs and faces serious problem of excessive water during the monsoon in eastern Gangetic plain. No/reduced till-surface residue managed system has benefitted the eastern farmers more in terms of higher productivity gain, good soil health and larger reduction in cost of cultivation. Permanent no till (permanent bed and double zero-till system) through crop residue managed system provided permanent soil cover and minimum soil disturbance which is helpful in

* RWC/CIMMYT India, NASC Complex, Pusa, New Delhi.

minimizing seasonal weed infestation. Due to this reason, the resource poor, small and marginal farmers of eastern Gangetic plain have now begun adopting resource conserving technology (RCTs). It has been realized that benefits of RCTs can be further improved by adopting remunerative cropping system/catch crop.

In the RW cropping system, several temporal and spatial variations in relation to two crops of the system are observed. Rice and wheat may be grown: (i) in the same plot, (ii) in different plots during a year, and/or (iii) in the same plot in different years. While rice and wheat may be the main crops in same plot in the same year, other crops such as maize, Indian mustard, mungbean, linseed, lentil, sesame, black gram, pigeon pea, potato and sugarcane are also replacement or intercrops/catch crops in RW system. Mungbean, cowpea could be better options during the time slot between wheat and rice as a risk management strategy in areas prone to drought and floods. Raising Indian mustard, lentil, chick pea, linseed, coriander, winter maize, garlic, French bean, sugarcane, boro rice may be productive crops in no/reduced till-bed planting/surface residue managed system. Furrow irrigated raised bed (FIRB) system offers an opportunity to diversify and intensify the cropping system. Linseed and coriander may be grown in furrows with bed planted wheat / winter maize / French bean. FIRB system also offers scope for staggered planting (maize + pigeon pea or French bean + garlic or rice + maize / pigeon pea + rice). Table 1 gives major productive cropping system options in eastern Gangetic plains under different ecologies (upland, midland and lowland).

Table 1. Major rice based cropping systems in eastern Indo-Gangetic plains (all ecologies included: uplands, midlands and low lands)

- ❖ Rice-Potato-Wheat
- ❖ Rice-Jute/Rice
- ❖ Rice-Wheat/Boro Rice
- ❖ Rice-Potato-Winter Maize
- ❖ Rice-Potato-Rice (Boro)
- ❖ Pigeon pea + Greengram-Wheat
- ❖ Rice-Potato +Maize/Boro Rice
- ❖ Rice + Sesame + Maize +Mungbean (Spring)- Boro Rice

Current fallow and rice fallow lands constitute a major portion of under utilized lands in the eastern Gangetic plain. Major causal factors for lands to remain fallow include lack of irrigation facilities and rice vacating the fields too late to permit planting of second crop during the winter season. Such conditions are typical of the *tals/chaurs* and *diara* land. In many upland and midland areas where there is no groundwater development for irrigation, lands also remain fallow. These rainfed areas are often planted to rice during the *kharif* season. Rice fallow lands generally belong to poor farmers having no irrigation facilities and they mainly depend on monsoon rains for crop production. The timely seeding that taps the residual moisture of the previous rice crop, relay cropping or surface seeding of cereals (wheat, barley) and legumes (lathyrus, lentil, chickpea, faba bean) and oilseed (linseed, mustard, safflower) could offer potentially good cost effective options for resource poor farmers in areas that lack irrigation facilities. Diara lands adjacent to the river receive fresh sediments on annual basis during the rainy season. The highly fertile soils of the diara lands have good potential for a variety of crops. Many landless farmers take land on lease and develop groundwater on temporary basis to grow vegetables and boro rice. Zero-till/surface seeding of wheat and other dry season crops can be grown in these soils. In cracking soils of diara, boro rice could be a better option with development of appropriate irrigation system.

Opportunities for cropping system intensification/diversification with pulses

Pulses on account of their short duration and ability to thrive better than other crops under harsh climate and fragile ecosystems on one hand and the national agenda to achieve household nutritional security on the other hand have great promise for intensification/ diversification of cropping systems. Pulses can be intercropped, relay cropped or grown as catch crop in multiple sequences. Testing of crop establishment methods under different systems at farmer's participatory sites in eastern IGP clearly reveal that in spite of higher apparent productivity rice-wheat is not as much remunerative as cropping systems with pulses combinations. Significantly, rice or wheat rotated with pulse crop or rice wheat combined with pulse are economically profitable and ecologically harmonious (Table 2). It is important to ensure that crop intensification goes together with crop diversification. The intensification enhances the productivity; the diversification adds strength to the system in terms of sustainability. The options available for diversification in cropping systems through pulses are:

- Inclusion of short duration cultivars of pulses as catch crop in irrigated areas.
- Introduction in new niches.
- Substitution of existing low yielding crops in the prevailing system.
- Pulses as intercrop with wide space planted crops and relay crop.

Results clearly indicated that inclusion of short duration pigeon pea and mungbean in cropping systems under different RCT options is remunerative and both the crops gave the highest yield and net return under bed planting (Table 3). From the data presented (Table 3), it emerges that total annual yield equivalent of the cropping systems in terms of rice and total net returns were in the order that follow:

- Permanent furrow irrigated-bed planting system of rice-wheat-mungbean cropping system gave highest yield equivalent of 12.14 t ha^{-1} and net return of Rs. 33,375/ha.
- Permanent bed planting system of rice-wheat + zero tilled linseed gave yield equivalent and net return of 11.8 t ha^{-1} and Rs. 32,850 ha^{-1}, respectively.
- Unpuddled transplanted rice-ZT wheat-ZT mungbean gave yield equivalent of 11.8 t ha^{-1} and net return of RS. 32,536 ha^{-1}.
- CT maize-ZT lentil and BP maize-ZT wheat recorded a remarkable rice yield equivalent (RYE) of 10.64 t ha^{-1} and net return (NR) Rs. 32,206 ha^{-1} and 9.10 t ha^{-1} and Rs. 23,125 ha^{-1}, respectively.
- UTR-ZT wheat also recorded remarkable RYE of 10.18 t ha^{-1} and NR of Rs. 28,399 ha^{-1} followed by
  - BP rice-BP wheat (10.30 t ha^{-1} and Rs. 26,176 ha^{-1}); and
  - ZT rice-ZT wheat (9.46 t ha^{-1} and Rs. 26,614 ha^{-1}) as against CT rice-CT wheat (8.53 t ha^{-1} and Rs. 13,189 ha^{-1}).

Table 2. Effect of crop establishment methods under different cropping systems in farmers' participatory trials

Sl. No.	Establishment methods/ cropping systems	Yield (t ha^{-1}) 2002-03	Yield (t ha^{-1}) 2003-04	Rice yield equivalent** (t ha^{-1})	Net return (Rs ha^{-1})
1	UTR Rice-ZT Wheat	4.77-3.96 (6)*	4.66-4.32 (5)	10.18	28399
2	BP Rice-BP Wheat	3.88-4.50 (2)	4.47-4.77 (7)	10.30	26176
3	BP Rice-BP Mustard	4.13-2.03 (2)	-	7.84	13030
4	ZT Rice-ZT Wheat	3.48-3.94 (3)	4.45-4.39 (9)	9.46	26614
5	BP Maize-BP Wheat	2.60-4.7 (1)	3.11-4.15 (2)	8.83	15294
6	ZT Maize-ZT Wheat	2.40-4.42 (1)	2.71-3.95 (1)	8.20	19535
7	CT Rice-ZT Maize	3.38-4.88 (2)	3.95-4.00 (1)	8.34	15235
8	CT Rice-BP Maize	3.50-3.89 (1)	3.75-4.57 (2)	8.06	13134
9	BP Maize-ZT Wheat	3.50-4.05 (1)	3.66-4.05 (2)	9.10	23125
10	CT Maize-ZT Lentil	3.00-2.1 (2)	3.41-2.18 (2)	10.64	32206
11	CT Rice-ZT Gram	3.00-2.23 (2)	4.13-1.89 (2)	9.91	27155
12	CT Rice-ZT Pea	3.38-2.08 (2)	3.93-1.85 (2)	8.76	21020
13	CT Rice-ZT Lentil	3.31-1.27 (2)	4.13-1.15 (2)	7.83	17045
14	CT Rice-ZT Lathyrus	3.56-1.25 (2)	3.89-1.15 (8)	6.85	11650
15	CT Rice-ZT Wheat	3.50-4.28 (3)	4.01-4.31 (9)	9.42	21922
16	CT Rice-ZT Barley	3.75-4.18 (1)	3.50-4.11 (2)	8.31	19033
17	BP Rice-BP Wheat-BP Mungbean	3.75-5.2-0.6 (1)	4.20-4.0-0.50 (1)	12.14	33375
18	UTR rice -ZT Wheat-ZT Mungbean	4.15-4.45-.61 (2)	4.25-4.13-.50 (6)	11.80	32536
19	BP Rice-BP Wheat+ Linseed (NT)	-	5.00-2.50+1.0 (1)	11.80	32850
20	ZT Rice-BP Wheat-BP Mungbean	-	3.20-4.6-00.46 (1)	11.00	27108
21	Fallow-Boro Rice (UTR)	F-7.10 (3)	F-6.25 (5)	8.02	23750
22	Fallow-SS Wheat	F-3.25 (2)	F-3.01 (4)	4.13	10958
23	DSR RLR-SS Wheat	3.25-3.32 (2)	2.88-2.99 (2)	7.23	19448
24	DSR DWR-Boro Rice (UTR)	1.88-5.05 (2)	2.0-5.85 (2)	8.50	15535
25	CT Rice-CT Wheat	3.38-3.88 (2)	3.65-3.71 (4)	8.53	13819

* Numbers of participating farmers is given in the bracket.
** Indicates yield equivalent in terms of rough rice on the basis of prevailing market rates.
ZT - Zero tillage; DSR - Direct seeded rice; RT - Reduced tillage; UTR - Unpuddled transplanted rice; TPR - Transplanted rice; ZT - Zero tillage; BP - Bed planting; CT - Conventional tillage; UTR - Unpuddled transplanted rice; SS - Surface seeding; RLR - Rainfed lowland rice; DWR - Deepwater rice; NT - No till.

Zero–till establishment of pulses after rice increased the rice yield equivalent and profitability.

- CT rice-ZT gram registered the RYE of 9.91 ha^{-1} and NR of Rs. 27,155 ha^{-1} followed by
    - CT rice-ZT pea (8.76 t ha^{-1} and Rs. 21,020 ha^{-1}); and
    - CT rice-ZT lentil (7.83 t ha^{-1} and Rs. 17,045 ha^{-1}) as against CT rice-CT wheat (8.53 t ha^{-1} and Rs. 13,815 ha^{-1}).

Diversification and inclusion of pulses in the system contributed to increase the yield equivalent, net return and sustainability of the cropping system. Establishment of pulses (lentil, gram, pea, lathyrus, pigeon pea and mungbean) through zero till/raised bed planting increased the yield equivalent and net return as compared to conventional RW system)

- Under the flood prone (diaralands), highest net return was with fallow – boro rice (UTR) i.e. Rs. 23,750 ha^{-1} with an yield equivalent of 8.02 followed by fallow-surface seeded wheat (Rs. 10,958 ha^{-1} and 4.13 t ha^{-1}).
- Under deepwater/ waterlogged situations, highest net return was obtained by DSR RLR-SS Wheat (Rs. 19,448 ha^{-1}) followed by DSR DWR – Boro rice (Rs.15,535 ha^{-1}).

Yields of crops planted in different cropping and tillage systems given in Table 2 and 3 also clearly revealed that farmers in the region stand to gain by practising the furrow-irrigated raised bed panting system.

Table 3. Average yield and net return of crops under different establishment systems (mean of two years, 2002-2004)

Crops	Grain yield (t ha^{-1})			Net return (Rs ha^{-1})		
	ZT	BP	CT	ZT	BP	CT
Early pigeon pea	1.15 (3) *	1.28 (5)	0.895 (3)	13900	14160	8181
Kharif Maize	2.60 (3)	3.65 (5)	2.35 (2)	2350	6963	358
Rabi Maize	4.25 (4)	4.86 (3)	3.66 (2)	8213	10415	4215
Pea	2.28 (4)	-	1.95 (2)	21840	-	11850
Lentil	1.70 (3)	1.78 (2)	1.50 (3)	21800	22360	17500
Gram	2.00 (3)	1.99 (3)	1.86 (2)	23200	23045	20830
Lathyrus	1.45 (6)	-	1.31 (3)	12050	-	10030
Summer mungbean	0.452(10)	0.475 (3)	0.394 (4)	3738	4300	1401

* Number of participating farmers is given in brackets.
ZT - Zero tillage; BP - Bed planting; CT - Conventional tillage.

Late planting of rice is a common feature in eastern Gangetic plains due to uncertainty of rainwater/ground water irrigation facilities/submergence problems. Photosensitive varieties of rice are preferred in rainfed lowland (submergence/water logged situation) which matures in November end or even December first week. In mid land situations due to poor ground-water irrigation facilities, transplanting is always delayed. All these situations compel for delayed sowing of *rabi* crops.

A sizeable area in the eastern IGP is mono-cropped under medium and long duration varieties of rice. The unavailability of irrigation water and delay in vacating the field after rice does not normally permit the sowing of second crop because the top layer of soil dries up at the time of rice harvesting and therefore, planting of a winter crop is not feasible. Under such conditions CT rice-ZT rice, CT rice-ZT gram. CT rice-ZT pea, CT rice-ZT lathyrus (Table 2) could convert these monocropped areas into double cropped areas and hence increase pulse productivity and sustain productivity of the rice based systems. Expansion of this system urgently requires on farm testing of genotypes especially suited for these situations and matching agro-technology adequate attention.

Opportunities and potential for boro rice in standing water/waterlogged areas

This land type represents the extreme lowland area, which remains inundated with water most of the year, and from which no crop or single short duration crop is generally harvested. Water may stand at variable depths for long periods. In very deep-water situations, farmers often grow floating rice cultivars during *kharif* season. In low lying positions (e. g. fringe areas of permanent water bodies) receding water provides natural niches for cultivation of boro rice in winter season.

These lands could be used for productivity enhancement; one strong potential option in irrigated areas that remain under water until January or February is boro rice. Boro rice is seeded in November- December, germinates and young seedlings undergo chilling treatment in the winter months (January and February) before transplanting in last February/early March. There are two methods for raising nurseries prior to transplanting in water logged soils: conventional and the dapog method. The boro rice crop then matures before the upcoming season's monsoons or floods caused by run-off water from upper catchments. The presence of standing water in fields into February is an additional benefit because it reduces irrigation costs at the time of transplanting and during the growth period. Yield potential of improved boro rice varieties is high (Table 4) and economic returns of the farmer are good, making it an attractive component in the farming system.

Table 4. Average grain yield (mean of three years 2001-02 to 2003-04) of boro rice cultivars at farmers' field

Variety	Days to maturity	Yield (t ha^{-1})
Sarjoo-52	174	6.46 (13) *
Pant-4	190	6.26 (18)
Pant-12	175	636.00 (11)
Prabhat	170	6.11 (21)
Krishna Hansa	185	6.33 (12)
Gautam	185	6.60 (22)
IR 64	183	6.77 (29)
Jyoti Prasad	170	5.83 (16)
Bishnu Prasad	172	6.56 (8)
Ratna	190	6.00 (12)
Saket-4	175	6.27 (15)

* Numbers of participating farmers is given in bracket.

In the low-lying water logged areas, providing supplementary irrigation water is usually not a major problem. This can often be achieved at little cost through the use of bamboo tubes or clay pipes. Realizing the high productivity potential of boro rice, efforts are being made to relocate the crop to irrigated mid and uplands (nontraditional areas for this crop). A good example of this is the development of a very innovative intercropping system-rice (short duration), followed by potato +maize/boro rice-currently undergoing farmers participatory trials in eastern IGP.

In a case study, it is estimated that more than 3000 ha of low lying waterlogged lands located east of Ballia city in eastern Uttar Pradesh remains waterlogged during both *rabi* and *kharif* seasons. On occasion, farmers may plant a short duration rice crop, however, profitable potential alternatives, e.g., boro and deep-water *kharif* rice exists for these areas. Elsewhere in the district, around Surha *Tal*, farmers grow traditional deepwater and floating rice varieties (*Jaisuriya, Tudahiya. Kalanigee*). For wider adoption of these rice technologies, improvement in the land tenure system may need to occur and some financial assistance given to leased land farmers to assist them with cultivation and harvest of these varieties. Deepwater and floating rice are usually harvested using boats. Improvement in deepwater and floating rice and sugarcane landrace named "Bansa" (which is able to withstand a meter of standing water for several months) could be an effective option for productivity enhancement and improving livelihoods of the farmers.

Conservation Agriculture and Opportunities for Sugarcane Based Cropping Systems

R.L. Yadav and T.K. Srivastava
Indian Institute of Sugarcane Research, Lucknow 226 002, Uttar Pradesh, India

ABSTRACT : Conservation agriculture is now being practised worldwide on an area of 58 m ha, however in India only about 40000 to 50000 ha acreage mainly under rice and wheat has been brought to this system of agriculture that mainly relies on reduced tillage, permanent soil cover and crop rotations. Benefits of conservation agriculture namely buildup of soil organic carbon, enhancement of factor productivity of applied inputs, increased nutrient and water use efficiency are needed to be effectively reaped in sugarcane production system that occupies 4 m ha acreage and utilizes more than 5% of country's irrigation resources on merely 2.8% of the net cultivated area. Sugarcane crop removes huge quantities of nutrients from soil and requires a lot of energy in the form of human labour (25 to 30% of total cost of sugarcane production). Since sugarcane plant and ratoon crops occupy the field for more than half of the duration of most of the sugarcane based cropping systems adoption of agro-techniques such as uniform trash mulching in between sugarcane rows, ring pit system of sugarcane planting and cultivation of sugarcane + wheat under furrow-irrigated raised bed (FIRB) system hold promise for bringing sugarcane based cropping systems under conservation agriculture with reduced cost and environment friendly effects.

INTRODUCTION

Conservation agriculture is a management system that maintains a soil cover through surface retention of crop residues, reduced or zero tillage and the use of cover or green manure crops in rotations. World wide it is now being practised over an area of 58 million hectare involving crops like rice, wheat, pulses, sugarcane, vegetables, potato, beets, cassava and fruits. In India this concept of farming has found favour in the states of Punjab, Haryana and western parts of Uttar Pradesh and as estimated about 40000 to 50000 hectares of land particularly under rice-wheat system has been brought under conservation agriculture involving primarily reduced or zero tillage, bed planting and crop residue mulching. As experienced world-wide conservation agriculture leads to the buildup of soil organic carbon and thereby arrests the decline in total factor productivity of the applied inputs; helps saving the top fertile soil from wind and water erosion, enhances the nutrient use efficiency by creating conducive rhizosphere for soil micro-flora and fauna; reduces water requirement of the crops by effectively cutting the evaporation losses; checks non-point pollution of nearby water bodies and helps sequestering the green house gasses in the soil. The farmers adopting this system have reaped good benefits and gained confidence to bring crops other than rice-wheat under this for saving their lands from deterioration and getting higher returns. A positive effect of this system of agriculture has also been reported on saving of inputs like nutrients, water and energy. These benefits of conservation agriculture need to be reaped in other input intensive cropping systems such as sugarcane system.

India is one of the largest sugar producers in the world contributing up to 18 million tonnes of sugar annually. The country shares about 13.25 percent of world sugar and 41.1 percent of Asian sugar production. The sugar industry is among the largest agro-processing industries in the country. Sugar and its by-products play a pivotal role in the agro-industrial economy accounting for nearly 2 percent share in the GDP. During the last fifty years, production of sugarcane and sugar in India has made tremendous strides. However, share of increased acreage (1.7 m ha in 1950-51 to 4.0 m ha during 2003-04) contributed more than that of enhanced productivity of the crop. Similarly achievements in sugar production depend much on enhanced supply of sugarcane for crushing than on recovery of sugar. Presently India is facing a problem of plenty as far as sugar production is concerned as we maintain a carry over stock of almost 13.1 million tonnes of sugar and during the current crushing season we expect to produce another 16 million tonnes against a domestic demand of 15.6 million tonnes. Sugarcane is the only source of sweetener in India which, however, many a times gets soured, because of the slump in sugar prices vis-à-vis sugar glut in the international market. The London Daily Price (LDP) of white sugar has slid down from US $ 316.7 a tonne during 1990 to just $239.5 a tonne in 2004. The situation therefore warrants for options that saves the cost of cultivation of sugarcane as at present sugarcane price our sugar is not able to compete in the international market. India being one of the largest sugar producers of the world and facing surplus sugar production must opt for cost reducing systems such as conservation agriculture.

Characterization of sugarcane based cropping system

In our country sugarcane based cropping systems are followed in an area of 4.0 m ha located in agro-climatic regions like upper-gangetic plains, middle gangetic plains and states of Bihar, Maharashtra, Karnataka, Kerala and Andhra Pradesh. The climatic conditions of these regions vary from tropical humid to semi-arid sub-tropics receiving 600 mm to 2500 mm precipitation annually. The soils range from alluvium, black soils, red and lateritic soils to coastal alluvium. Soils in the gangetic plains gradually assume heavier structure as we move from west to east. In western Uttar Pradesh soils are deep and fertile and have better internal drainage, whereas in central parts of UP soils are sandy loam and occasionally slightly alkaline in reaction. In the eastern regions the soils are of two type *bhat* and *banger*. *Banger* soils are light textured loam to sandy loam with high water table and low lime content as compared to *bhat* soils. The most important areas where sugarcane is grown in Karnataka have medium black soils quite deep, rich in lime fertile and productive. In Tamil Nadu and Andhra Pradesh the soils growing sugarcane are classified as red and lateritic, black and alluvial.

The prevalent sugarcane based sequential cropping systems of sub-tropical India are:

- Rice- wheat- sugarcane- ratoon- wheat
- Rice- mustard- sugarcane- ratoon- wheat
- Rice- potato/ pea/ gram/ coriander- sugarcane- ratoon- wheat
- Maize- potato- sugarcane- ratoon
- Rice- sugarcane- ratoon- wheat

The prevalent sugarcane cropping systems for tropical belt include:

- Cotton- sugarcane- ratoon- wheat
- Cotton- sugarcane- ratoon- rabi sorghum
- Cotton- sugarcane- gram
- Sugarcane- ratoon- *kharif* rice- winter rice
- Rice- groundnut- sorghum- ragi- sugarcane

Intercropping of *rabi* crops like potato, mustard, wheat, pea, coriander, lentil, garlic and other winter vegetables has been found more remunerative as compared to autumn sugarcane grown alone or *rabi* crops followed by cane in sequence. Crops such as urd, moong, and cowpea that mature within a short period (75 to 90 days) are most compatible intercrops with spring cane and sometimes ratoons.

Scope of conservation agriculture in sugarcane system

A cropping system based on sugarcane generally occupies the field for more than 2 years duration and comprises one plant, at least one ratoon and other crops in sequence. Often sugarcane plant and ratoon crops remain in field for more than half of the total period of a particular crop rotation. This indicates that sugarcane based cropping systems automatically do away with the requirement of frequent land preparations (primary tillage), normally done under other cropping systems. Besides, sugarcane being a widely spaced row crop provides ample scope for land maneuoverings through inter-culture and/or otherwise maintaining a residue cover on the soil surface for long duration. These conditions auger well for the application of 3 basic principles of conservation agriculture namely reduced soil disturbance, permanent soil cover and crop rotations.

Cropping systems based on sugarcane are exhaustive as far as nutrients and water consumption is concerned. Sugarcane crop to yield 100 t/ha removes 208, 53,280, 3.4, 1.2, 0.6 and 0.2 kg/ha of N, P, K, Fe, Mn, Zn and Cu respectively from soil (Yadav and Dey, 1998). Replenishing the soil with these nutrients in a judicious and balanced way is imperative to ward-off the ill effects of high analysis fertilizer based approach of nutrient management. An integrated approach involving crop residue recycling, bio-fertilizers and green manuring, as envisaged under conservation agriculture holds promise for not only the build of soil organic carbon but also maintaining the soil ecological balance. Moreover, sugarcane based systems are prevalent in irrigated agro-ecosystems and rice, wheat, sugarcane crops collectively utilize more than two-thirds of our irrigation water resources (Table 1).

Table 1. Water requirement and average nutrient removal by major crops

Crop	Water requirement (mm)	Nutrient removal kg/t		
		N	P_2O_5	K_2O
Rice	490-1290	20.1	11.2	30.0
Wheat	300-520	24.5	8.6	32.8
Sugarcane	600-2000	1.7	0.2	2.0
Cotton	700-1200	44.5	28.3	74.7

Sugarcane alone utilizes more than 5 percent of irrigation resources of the country on a share of just 2.8 percent of net cultivated area by requiring 600 to 2000 mm of water annually for one hectare of crop area. It has been estimated that to produce one kg of sugar 60 to 90 litres of water is required. In the present scenario due to unchecked exploitation of groundwater and resulting poor output of tube-wells the crop suffers badly due to moisture stress during summer months. As estimated only 35% of sugarcane area gets optimum irrigation whereas remaining 65% area is under sub-optimal irrigation and un-irrigated conditions. Irrigation water scarcity in Maharashtra has severely affected the cane productivity and options are being explored to replace sugarcane by a less water requiring crop like sugar-beet. The situation therefore warrants for adoption of conservation agriculture techniques that reduce the water requirement of the crop by cutting the evaporation losses and conserving the moisture in soil.

Cultivation of sugarcane is labour intensive and as estimated in energy terms the operational energy requirement contributes 10-15% to total energy requirement of sugarcane production. Among different operations, seed bed preparation and planting account for more than 50% of operational energy requirement (Srivastava, 2003). However, in terms of cost of cultivation 25-30% of the total cost of sugarcane production is incurred on labour. This could be saved effectively by adoption of reduced/ zero tillage techniques.

Conservation agriculture techniques for sugarcane system

In India conservation agriculture is yet to be popularized among sugarcane growers however in countries like Brazil and Thailand sugarcane is being grown in accordance with the conservation agriculture technologies on sizeable area of land. Research efforts have, however, been made in India to develop agro-techniques which can effectively conserve the physico-chemical and biological properties of soil, irrigation water and reduce the labour requirement to slash down the cost of sugarcane production and maintain the sustainability of sugarcane production system. The prominent agro-techniques are detailed hereunder.

Recycling of sugarcane trash

Sugarcane though occupies only 2.86% of net cultivated area in India, ranks third after rice and wheat crops as far as the production of recyclable wastes are concerned (Table 2). Trash production from sugarcane varies with the variety, season of planting and duration of the crop. However, on an average it is 12-15% of millable cane yield. Among different methods of trash recycling viz. soil incorporation, mulching and burning, trash mulching in between the sugarcane rows maintaining a uniform thickness of 7.5-10 cm, has been found to be the best.

Table 2. Estimates of the crop residue yield and realizable plant nutrient potential from the residues of principal crops in India

Crop	Residue yield ('000 tonnes)	Nutrient concentration (%)			Total N, P, K potential ('000 tonnes)
		N	P	K	
Rice	80744	0.61	0.09	1.15	1493.8
Wheat	44987	0.48	0.07	0.98	688.3
Sorghum	11563	0.52	0.12	1.21	216.2
Maize	6219	0.58	0.09	1.25	119.4
Pearl millet	8283	0.45	0.07	0.95	121.6
Barley	3180	0.52	0.08	1.25	58.8
Sugarcane	15645	0.45	0.08	1.20	270.7
Potato	5062	0.52	0.09	0.85	73.9
Groundnut	9580	1.65	0.12	1.25	277.3

Studies conducted in India and abroad during recent past clearly indicate that burning of trash not only causes irreparable loss of valuable biomass but also adds to the air pollution by producing 4, 35 and 5 kg of particulate matter, carbon monooxide and hydrocarbons respectively upon burning of one tonne of sugarcane trash (Table 3).

Table 3. Emission factors and fuel loading factors for open burning of agricultural materials

Refuse category	EF (kg/tonne)			FLF(t/ha)
	Particulate	CO	Hydrocarbon	
Rice	4	41	5	6.7
Wheat	11	64	9	4.3
Sugarcane	4	35	5	2.4
Cotton	4	88	3	3.4

Source: US Environmental Protection Agency.

On the other hand trash mulching has been found to reduce the emission of green house gasses (N_2O and methane) from sugarcane fields. On productivity front it is almost established that trash mulching @ 10 t/ha enhances the nutrient and water use efficiency and checks the weed growth effectively (Prasad *et al.,* 1988). Trash mulching over one hectare of area adds up to 50, 15 and 60 kg N, P and K, respectively. For the release of these nutrients in soil, decomposition is not required as studies indicated that 28, 42 and 56 percent of available N, P and K in trash becomes available to the plants just by leaching. By reducing evaporation losses of water from soil surface trash mulching increases the water use efficiency. Studies conducted in Cambodia revealed that trash mulching helps maintain the pest population below economic threshold level by maintaining the population of natural enemies of harmful insect-pests. The positive effect of trash mulching has been found to bring about 20-30% increase in plant as well as ratoon cane yields over no mulching or trash burning. Improvement in soil properties due to trash mulching was found significant in terms of soil organic carbon buildup (an increase of 25% from plant crop to third ratoon) and bulk density (decreased from 1.45 to 1.39 from plant crop to third ratoon).

Ring-pit system of sugarcane planting

Under majority of the planting conditions sugarcane is planted in 15 cm deep furrows by placement of three budded setts end to end or bud to bud using 40,000 setts. This method of planting gives rise to 40% mother shoots i.e. first formed shoots and 60% tillers that come after emergence of mother shoots from the underground buds situated on the mother shoots. A drain of nutrients, water and food takes place from mother shoot to tillers as their survival depends on it till their own shoot-roots are in place. However, only one or at the most two, tillers per mother shoot survive till the harvest causing wasteful expenditure of energy on the part of mother shoots and finally reducing the realizable yield. A new method 'ring-pit system' of sugarcane planting was therefore developed to suppress the tillers and attain maximum number of mother shoots in the total population of millable canes (Singh *et al.,* 1984). This has been found to conspicuously increase the yield (by 70 to 90%) over conventional planting methods. In the ring-pit system of sugarcane planting all the nutrients are applied in the pit having 90cm diameter and 45 cm deep where 20 three-budded sugarcane setts are planted. Experimental evidences (Table 4) indicate 262 and 189% increase in nitrogen and water use efficiency under this system over that of conventional planting. In this system of planting the dug up soil is placed back in the pit in three or four installments that cuts the light availability at the base and thereby effectively checks the emergence of tillers.

Table 4. Efficiency of fertilizer N and water requirement of sugarcane under ring-pit and conventional flat planting methods

Method	kg cane/ kg N	kg cane/ ha-cm water	Cane yield (t/ha)
Conventional flat	118	1012	52
Ring-pit	427	2925	152
% increase in RP over CF	262	189	192

Furrow irrigated raised bed system

Cultivation of wheat and sugarcane in sequence is in vogue in more than 28% of sugarcane acreage in western parts of Uttar Pradesh. In this system sugarcane is planted after harvest of wheat in April that is beyond its optimum time of planting between 15th February and March. Delayed planting drastically reduces the tillering span of sugarcane and therefore yield is low. As farmers are not ready to forego wheat crop in autumn season, efforts were made to develop agro-techniques for simultaneous cropping of wheat and sugarcane. In this system 3 rows of wheat is sown on raised beds of 80 cm width in the month of November and sugarcane planting is done in February by placement of three budded setts in the furrows. Experiments conducted at the Indian Institute of Sugarcane Research revealed that wheat + sugarcane cropping under FIRB system resulted in better utilization of resources and out yielded wheat-sugarcane in sequence as the cane equivalent yield under FIRB was 107.8 t/ha as compared to 88.2 t/ha in sequential system. There was a 20% saving in water utilization under FIRB (Fig. 1).

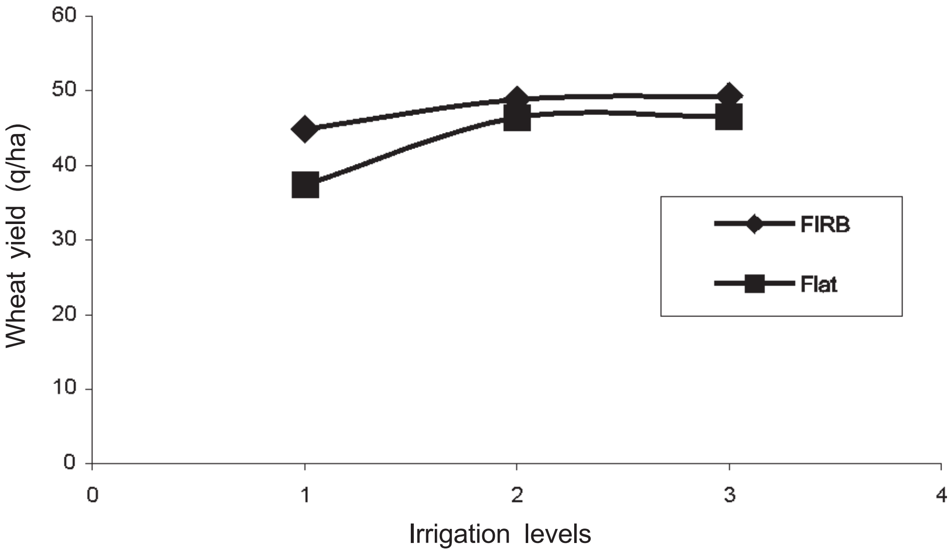

Fig. 1. Water saving in wheat in wheat+sugarcane cropping under FIRB system.

With a view to cutting down the labour requirement and making sugarcane planting convenient a cutter-planter has been developed which performs all the planting related operations viz. cutting and placement of setts, application of fertilizers and agro-chemicals in the furrows, seed treatment, covering and pressing of setts in a single pass. Srivastava (2003) have reported that experiments during 1992-96 showed that tillage before planting which required about one-third (936 MJ/ha) of the total operational energy (2795 MJ/ha) could be saved without adversely affecting the yield (48.5 t/ha compared to 49.4 t/ha for zero and conventional tillage experiments, respectively). The level of tillage did not have any significant effect on the soil, irrigation and crop parameters.

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Water Management Imperatives in Zero/Reduced Till

A.K. Sikka, A.R. Khan, S.S. Singh and N. Subash
ICAR Research Complex for Eastern Region, Patna 801 505, Bihar, India

ABSTRACT : Resource conservation as means of enhancing resource use efficiency assumes high priority for sustainable agriculture. Resource conservation technologies (RCTs) such as zero/reduced tillage, surface seeding and raised bed sowing are emerging as new paradigm shift for enhancing conservation of soil, water, nutrient and energy. The long-term sustainability of zero/reduced tillage under crop residue or bare fields without residue is now a subject of attention. Judicious use and management of water is imperative in zero tillage to improve productivity of land and water. It would be imperative to examine and study the impact of RCTs in water conservation and adopt water management practices to supplement better adoption of RCTs/ZT to improve not only water use efficiency but also overall input use efficiency and water productivity. The paper covers impact of zero-tillage on water use aspects based on our experience at farmers' fields in eastern Indo-Gangetic Plains and concludes with suggested areas of research in view of long-term implications of RCTs.

INTRODUCTION

Conservation and management of water for sustainable agriculture assumes increasing importance, as it is not only the most critical input for enhancing productivity but is becoming more and more scarce with declining per capita water availability. Growing water scarcity and competing water demands are expected to reduce diversion of water for agriculture in the future. It is anticipated that the present level of diversion of water for agriculture in India is likely to reduce from 85 to 69 percent in the future due to other competing demands. The per capita availability of water in India declined from 5300 m^3 in 1955 to 1818 m^3 based on 2001 census and it is projected to be 1235 m^3 by 2050.

The seventies witnessed the era of "Green Revolution" due to increased coverage of high yielding varieties, irrigation development and increased use of inputs. The Indo-Gangetic Plains (IGP) witnessed higher growth rates for food production compared to other regions in India. Most of this area is under rice-wheat cropping systems covering a total of 13.5 million hectares in India, Nepal, Bangladesh and Pakistan. Extensive irrigation infrastructure, mechanization and easy access to production inputs, marketing and grain procurement services have contributed to these increases, especially in the western parts of the IGP. The long-term sustainability of these systems is now a subject of attention.

Conservation tillage is equally important both in rainfed/ dry land and irrigated agriculture for efficient conservation and management of water. Harmonization of water management practices and resource conserving technologies is important for enhancing resource use efficiency. Resource conservation technologies such as zero/reduced tillage, surface seeding and raised bed sowing are emerging as new paradigm shift for enhancing conservation of soil, water, nutrient and energy. The long-term sustainability of zero/reduced tillage under crop residue or bare fields without residue is now a subject of attention. It is an established fact that moisture loss is faster in conventional tillage than from zero/reduced tillage. It is argued that future productivity growth would come from better risk management strategies in the drought/flood prone regions of the eastern Gangetic plains. Resource conserving technologies provide an opportunity for livelihood improvement of the resource poor, small and marginal farmers in highly populated eastern Gangetic plains.

The paper focuses on the impact of zero-tillage on water use aspects, especially water saving based on our experience and experimentation at farmers' fields in Bihar and elsewhere, largely under the RCT project of NATP, RWC-CIMMYT and DFID-NRSP projects. The paper concludes with suggested areas of research and development needs in view of long term implications of RCTs on hydrology and water regime.

TILLAGE AND WATER MANAGEMENT

Tillage is necessary for getting optimum soil tilth for germination and establishment, whereas water is necessary for survival and growth of different crops. Tillage practices adopted in one crop influence the establishment and performance of succeeding crops. Continuous tillage at a particular depth (15-20 cm) results in the formation of plow/ hardpan, which not only affects the distribution and growth of roots but also restricts the movement of water and nutrients below this layer, which adversely affects the growth and yield of crops.

Moisture retention is a combined function of soil adsorptive surface and capillary pores and hence directly dependent on soil texture and organic matter content. But tillage may indirectly enhance moisture retention by soil profile encouraging high infiltration through the larger clods due to higher porosity initially produced by tillage. Tillage operations change the aggregate size distribution or pore size arrangement, and also bulk density, which is accompanied by a change in water holding capacity, and capillary conductivity. This provides a means of changing the water storage characteristics of seed environment and changing the ability of the surrounding soil to replace water loss by evaporation. The movement of soil water in unsaturated conditions is of utmost importance, which depends mostly on soil properties that regulate water content. Faster rate of moisture loss from conventional tillage than from no-tillage treatment are reported.

Appropriate water management technologies together with resource conservation technologies (RCTs) are needed for rational use of water. Development of efficient water-management practices in different cropping systems may reduce the water requirement without significant reduction in crop yields. Reduction of water use in land preparation (zero tilled direct seeded rice and wheat, ZT transplanted rice) and adoption of second generation RCTs (laser land leveling system, residue management, bed planting and crop diversification) are being advocated for conservation of soil, water and energy, and enhancing water productivity. 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. RCTs could very well be supplemented by rainwater conservation, increased bund height, irrigation scheduling, land leveling etc for *in-situ* moisture/water conservation and conjunctive use of rain, surface and groundwater to enhance water productivity.

EFFECT OF RCTS ON WATER USE IN RICE - WHEAT SYSTEM

Conservation tillage has now been gaining importance is the region, with area coverage under ZT alone increasing from 3000 ha (1998-99) to 200,000 ha in 2001 (Gupta, 2001). Besides other benefits, the effect of ZT in water saving has been found at various locations, particularly under rice – wheat system in IGP. Integrating other water management practices together with ZT to capitalize on their synergies could further enhance its scope.

Due to late vacation of land after rice and excessive moisture in the field, especially in the eastern IGP in Bihar, sowing of wheat gets delayed and it affects wheat yield. Zero-tillage helps in advancing the sowing of wheat by about 15 days under such conditions. Double zero-tillage i.e. ZT in rice and wheat has also been demonstrated and adopted by farmers in selected areas in Bihar. Effects of RCTs on water regime under ZT rice and wheat are discussed.

WATER SAVING IN RICE UNDER ZT

Rice is a semi aquatic plant, which thrives best under submerged conditions resulting in high percolation losses. The irrigation water requirement of rice can be minimized by reduced puddling or by resorting to zero tilled direct seeding of rice. For this purpose rice fields are ploughed in dry soil condition after the harvest of winter crops and kept fallow during summer. When the moisture condition becomes favourable after the pre-monsoon rain, the fields are ploughed again, and dry rice seeds are broadcast in ploughed fields and covered by laddering. In clay-rich lowland soils, the laddering is often avoided, as the operation would require high draught to overcome big-size clods. The advantages of dry seeding are earlier and easier crop establishment, saving of labour and efficient use of early monsoon rainwater in sustaining initial crop growth.

Zero-tillage has mostly been accelerated in wheat. We started field demonstration of zero tilled direct seeded rice at small scale in farmers' fields during 2002 in Bihar. The initial results and farmers response has been quite encouraging. Before direct seeding rice through ZT machines, glyphosate is used to control weeds. Zero tilled direct seeded rice in heavy soils of south Bihar was found to save nearly 35 percent of irrigation water against puddled transplanted rice. Saving of water by avoiding puddling was upto 10-12 cm (Table 1). Frequency of irrigation in zero tilled direct seeded rice was 25 days as compared to 10 days in puddled transplanted rice in silty loam soil of Bihar. There was saving of two irrigations upto tillering stage in zero tilled direct seeded rice besides saving of 10-12 cm of water for puddling. Rice cultivation under furrow irrigated raised bed system (FIRB) was found to save water upto 40 percent. In another situation in the farmers' field of Barh, Patna during *kharif* 2004, which was a drought year, 13 irrigations were needed in puddled transplanted

Table 1. Saving of irrigation water in rice establishment in heavy soil of south Bihar (2002 and 2003)

Particulars	Zero tilled direct seeded rice	Puddled transplanted rice
Water requirement in puddling (cm)	00	10-12
Time required to irrigate one ha rice field during dry spell (hrs)	14	20
Irrigation required at flowering under delayed rice establishment due to water crisis for timely transplanting (cm)	00	12-15 (1-2 irrigation)

Table 2. Effect of seeding method of rice on irrigation and water saving

Rice establishment method	Hours required per irrigation by 5.0 HP	Days interval required between two irrigation	Total no. of irrigation applied	Total diesel requirement* @ 1 lit./ha (lit./ha)	Water saving (%)	Grain yield (t/ha)
ZT direct seeded after ploughing	20	30-35	05	100	72	3.8
Puddled transplanted	28	07-08	13	364	-	3.1

Source: S.S Singh (2004). Personal communication.

* It excludes 5.0 litre diesel to irrigate nursery field (500 m^2) required for 01 ha and 40 litres diesel for puddling.

rice while it was reduced to 5 irrigations under zero till direct seeded rice (ZTDSR) (Table 2). There was saving of 72 percent irrigation water in ZTDSR due to cracking of soils and more irrigation water need at less interval in conventional puddled transplanted rice. The yield gain was also 7 q/ha under ZTDSR. Total saving in irrigation was estimated to be Rs. 10,560/ha due to ZTDSR (Singh, 2004).

Farmers in Bihar begin tillage operations for rice nursery after first monsoon shower and go for rice transplanting as late as August due to non-availability of water for puddling. This not only adversely affects yield and delays sowing of *rabi* crops but also looses the opportunity to make effective use of rain water during June and July, which amounts to about 460 mm (40 years average of Patna rainfall). With zero-tillage direct seeded rice besides timely sowing, it enhances rainwater utilization efficiency and reduces need of irrigation water. Practising other water conservation practices such as raising bund height and irrigation scheduling could further enhance efficiency of rainwater and irrigation water in zero-tillage areas. For example raising of bund heights to 25-30 cm in the command of RPC-V in Sone Command of Bihar could save 1-2 irrigations to rice crops through effective utilization of rain water. Intermittent submergence of rice at 3 days after disappearance of ponded water have been found to save more than 40 percent irrigation water without compromising on rice yield.

WATER SAVING IN WHEAT UNDER ZT

In Bihar for conventional tillage, friable moisture content is needed and it takes about 15 to 20 days after irrigation to reach the optimum moisture content. This causes delay in field preparation for sowing wheat. In this situation, zero-tillage may be helpful for early sowing of wheat for higher grain and water use efficiency. The sowing of wheat by zero-tillage is possible at higher moisture content as compared to conventional tillage. This facilitates 10 to 12 percent more utilization of residual soil moisture (Table 3).

Table 3. Soil moisture status at sowing of wheat and water use efficiency under different tillage observations in silty clay loam soil of North Bihar

Particulars	Conventional Tillage	Zero Tillage
Soil moisture status at sowing time (%)	23.67	33.57
Time taken by 5 HP diesel pump (discharge – 12 lts) for irrigating one hectare area (hrs)	20.60	14.50
Depth of applied irrigation water (cm)	08.90	06.30
Charges of each irrigation (Rs./ha)	1236.00	870.00
Total water applied (cm)	17.80	12.50
Wheat yield (t/ha)	03.69	04.21
Water use efficiency (kg/ha-cm)	207.30	336.80

In case of conventional tillage the time taken for irrigation in one-hectare wheat with flooding was observed to be about 20 to 21 hours with 5 h p diesel pump having discharge of 12 litres per second. Whereas, in case of zero till sown wheat it took about 14 to 15 hrs. Due to this lesser irrigation water was used in zero-tillage (6-6.5 cm) and more in conventional tillage (8.5-9 cm). Table 3 shows a net saving of 5 hours of pumping, which will reduce the cost of irrigation for zero tilled farmers (Anonymous, 2003).

Zero till sowing of wheat also gets advantages of earlier sowing like low temperature for longer period and time for more tillering in wheat. This also encourages the healthy growth of crops with less moisture loss. The crop escapes from temporary water stress and gives 10 to 15 percent higher grain yield with lesser depth of irrigation which ultimately gives higher water use efficiency in zero till sown wheat in low lying area.

In a three-year study at the ICAR-RCER, three methods of wheat establishment (conventional, zero-tillage and raised bed planting) and four depths of irrigation (3,5,7,9 cm) were evaluated for determining the effectiveness of zero-tillage on increase in yield, saving in water and cost of cultivation (Table 4). All the treatments were sown on the same date. Whereas zero-tillage gave wheat yields at par with other establishment methods, it saved 27.7 percent water in the first irrigation. Adoption of zero-tillage could save Rs.1850/ha in cost of cultivation (Rs.1400 in land preparation and Rs.450 in irrigation).

Table 4. Effect of tillage method and irrigation water depth on yield attributes and yield of wheat crop in heavy soil of Patna (Bihar)

Treatment	Total dry matter at harvest (gm/m^2)	Earhead (No./m^2)	Earhead length (cm)	Grams per earhead	1000 grain weight (gm)	Grain yield (q/ha)	Straw yield (q/ha)	H.I (%)
Tillage method								
ZT	749.4	311.9	7.99	38.0	50.35	32.60	42.3	43.5
RB	740.0	281.8	8.21	40.15	51.10	32.10	42.35	43.0
CS	742.8	303.0	8.15	38.27	51.9	32.29	42.66	43.5
C.D. (P=0.05)	50.5	59.4	0.88	1.55	NS	1.76	NS	NS
Depth of irrigation (cm)								
3	726.7	280.7	7.92	37.33	50.63	30.87	42.04	42.3
5	748.7	307.4	8.27	40.16	51.63	33.23	42.83	44.0
7	766.3	313.5	8.29	39.80	51.85	33.53	42.89	44.0
9	734.8	293.8	7.99	37.93	50.36	31.69	41.76	43.0
C.D. (P=0.05)	86.3	29.9	0.49	2.10	NS	1.75	NS	NS

Saving in irrigation in different agro-climatic zones of eastern U.P is presented in Table 5. An average saving of Rs. 562/ha under ZT wheat was found in northeastern plain zone. The maximum saving of Rs. 656/ha was in eastern plain zone and only Rs. 312/ha was reported in Vindhyan Zone (Anonymous, 2002). Under farmers' conditions in north Bihar, the farmers obtained highest wheat yield (4.21 t/ha), 14.1 percent higher over conventional tillage besides a saving of 29.5 percent water in first irrigation and Rs. 367/ha in cost of cultivation and registered an increase of 62 percent in water use efficiency (Sikka *et al.*, 2004).

Table 5. Saving on account of irrigation (Rs./ha) in zero over conventional tillage in different agro-climatic zones of eastern Uttar Pradesh for two season of wheat

Agro-climatic zone	Saving in irrigation		Mean
	2001-2002	2002-2003	
North-eastern plain zone	625 (3)	500 (3)	562 (3)
Eastern plain zone	750 (4)	563 (4)	656 (4)
Vindhyan zone	250 (1)	375 (2)	312 (1)

Parenthesis represents number of irrigations.
Source: Eastern UP marching forwards ZT Technology, Directorate of Extension, NDUAT, Faizabad (2002).

RESIDUE/STUBBLE MANAGEMENT FOR IMPROVING THE SOIL EDAPHIC AND FERTILITY LEVELS

Residue management is important in rice-wheat systems because large quantities of crop residues are burnt in the field. Burning of residues can result in upto 80 percent loss of tissue nitrogen by volatization and also pollutes the atmosphere. On the other hand if crop residues are retained, increase of organic carbon and total nitrogen in the top 15 cm of soil is reported. In such fields wheat crop can be sown 20 days earlier and residual moisture in soil saves pre-sowing irrigation. Many crop insects like rice stem borers are depleted and more biodiversity of beneficial insects occur. However, we found that farmers experience difficulty in leaving the residue/stubble in manual harvesting in the eastern plains of Bihar.

ISSUES/IMPLICATIONS OF LONG-TERM USE OF ZERO-TILLAGE ON WATER REGIME

Adoption of RCTs in the eastern IG plains has now picked up. It is suggested that for sustainable development in the future, following R & D issues of RCTs could be worth addressing.

- Increasing the infiltration/percolation of soil under continuous ZT, where no residue is retained in the fields due to harvesting by manual labour especially in heavy soil of eastern Indo-Gangetic plains.
- Reducing the water requirement for submerged condition in ZT direct seeded rice.
- Ensuring optimum moisture status of field under surface seeded wheat just after rice harvest for efficient use of applied fertilizer.
- Timing of first irrigation in zero tilled wheat sown under excess soil moisture vis-a-vis normal conditions, where first irrigation is recommended at 15-16 days after sowing.
- Impact of herbicide application in ZT rice/wheat for weed management on soil, groundwater and environment.
- Effect of herbicide application on microbial populations and micro flora in soil environment
- How to reconcile the zero-tillage with deep summer ploughing for enhancing the water, land and nutrient efficiency, especially for heavy soils of eastern IGP.
- Long term implication of large scale adoption of RCTs on run-off and groundwater recharge under different soil conditions.
- Residue management in manually harvested areas like eastern IGP.

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Conservation Agriculture - IPM issues

Saroj Jaipal, R.K. Malik, Peter Hobbs, A. Yadav and Samar Singh
CCS Haryana Agricultural University, Regional Research Station, Uchani, Karnal 132 001, Haryana, India

ABSTRACT : Conservation Agriculture which mainly entails zero or reduced tillage and surface management of crop residues is emerging as a key strategy to enhance sustainability of intensive production systems. Conservation Agriculture practices cause major changes in crop environment and ecology which, in turn, may influence soil properties as also the species diversity, status, biology and carry over of insects, diseases and beneficials. In collaboration with RWC we focused on to learn about these influences in particular with zero tillage method of wheat sowing. Our studies on species diversity and population density of insects and retention of rice stubble in no-till wheat fields indicated that the method helps to conserve the diversity and population density of natural enemies of rice pests, particularly the predatory crickets, beetles, bugs, ants and spiders. The rice residue providing refuges to a vast number of predators contributes to enriching and maintaining their number in the cropping habitat. This will contribute to greater prediction of the pests. The wild vegetation (weeds, grasses) on the bunds and on surrounding wastelands also seem to serve as refuge to many predators and parasites. Habitat diversification through introduction of plant diversity, crop rotation and cover crops will also improve biological control because diverse agro-ecosystems tend to enhance the abundance of natural enemies due to availability of alternate prey, food and suitable microclimate. Organic soil management and least soil disturbance tillage practices enhance the activity of decomposers and hence are further supportive in improving natural control of pests. This paper deals with the main IPM concerns with regard to conservation tillage as also on the holistic approach to tackle the insects particularly associated with zero or reduced tillage in rice-wheat system.

INTRODUCTION

Conservation Agriculture (CA) is a holistic approach to crop production, which encompasses a range of tillage practices specifically intended to reduce soil disturbance during seedbed preparation. It also seeks to preserve biodiversity in terms of both flora and fauna. Activities such as integrated crop, weed and pest management form part of the conservation agriculture system.

The conservation tillage in the form of zero or reduced tillage is relatively a new concept in rice-wheat cropping sequence (RWCS) in Indo-Gangetic plains of South Asia. In India, this has transformed wheat cultivation across much of north-west states in the recent years. There are several reasons for the current dramatic spur in acreage under the system in states like Haryana, Panjab, Uttar Pradesh and Bihar. The revolution entails widespread adoption of wheat sowing method that involves direct drilling of wheat seeds into rice residues after the harvest of rice crop. This has virtually culminated in major changes in wheat crop environment ranging from minimum soil disturbance to location of rice stubble and weed ecology which, in turn, may influence the soil properties as also the species diversity, status, biology, ecology and carry over of insects, diseases and beneficials.

Many species of arthropods inhabit almost all crops, albeit most are not truly noxious to them. For instance, some 500 species of insects and spiders may appear in a rice field in a particular season. Of these only few are potential threat. The rest are either beneficial in the form of a wide range of predators and parasites that contribute to keeping insect pest organisms in check or innocent immigrants (neutral species) living on weeds or on organisms and under certain conditions serving as general prey for some beneficials. However, the status of these different categories of organisms is not permanent in crops and may shift or change in response to natural or artificial (induced externally) modification of the habitat of cropping systems. The latter mainly entails the alterations in crop environment through cultural practices.

Insects reduce yields substantially depending on their population densities in the crops. Although insects have been a problem since ages, outbreaks have increased and the pest complex has changed with change in agricultural practices. With change in cultural environment of crops, some insects have increased in severity while others have declined in importance. Conservation tillage in forms of minimum tillage, no tillage, stubble mulch, chisel-plant or till-plant bring about a profound change in the cultural environment of crops. The probable shift we have been assuming in the composition of the pest fauna and flora or the associated natural biotic mortality factors as the tillage practices evolve needs to be strictly followed particularly in reference to rising prospects of pests and IPM concerns. In practice, however, such an assessment may not be a simple process as CA systems in themselves are very complex. Moreover, many aspects of the environment typically vary together and their separate effects seem difficult to unravel.

REDUCED TILLAGE IN RWCS AND BIOTIC CHANGES

Under RWCS there seems to be four main ways in which zero/reduced tillage may bring out biotic changes. Firstly, the huge amounts of surface residues over large areas in the region resulting from zero/reduced tillage may ensure survival of a number of insects both destructive and beneficial. Reduced tillage systems particularly under staggered planting system of crops in monoculture may contain comparatively high levels of pest inocula than the conventional system. The cutting height of the crops at harvest may also influence the levels of pest inoculum. Further, the decomposition of residues along with several inter-related factors like climate, crop geometry, irrigation and fertilization, cultural practices and pesticides may affect the survival of insects in crop residues. The decomposition of residues brings out a chemical change in the composition of soil which in turn may affect the host's reaction to pests. Secondly, the reduced or no tillage system may affect the population densities of insects which otherwise become reduced in number with each tillage operation. Thirdly, a change in weed ecology is expected to influence the survival of several of those insects which tend to develop on weeds particularly during fallow and fourthly, since the zero/reduced tillage system reduces the fallow between crops, a change in sowing period of the following crop may result in altered incidence of certain insects.

This paper deals with these four IPM concerns in detail as also on the holistic approach to tackle the insects associated with zero or reduced tillage particularly in reference to rice-wheat system.

Crop residues as survival habitat for insects

An important aspect of pest life history is the strategy for survival in the period in which either host plant is not available or the climatic conditions are unfavourable for their proliferation. Insects generally pass through unsuitable conditions by using different mechanisms. While the oligophagous and the polyphagous species have a range of hosts to survive on, the monophagous ones mainly use the mechanisms of dormancy (Listinger *et al.*, 1987). The ability of many coleopterans and hemipterans to survive for long helps them to overcome the adverse conditions. The adults of several insects particularly the moths are active fliers and thus have little difficulty in locating the alternate hosts. Many lepidopterans pass through unfavourable periods in a restive stage called diapause (aestivation or hibernation). The survival habitat for many of such tissue borers are mostly the post-harvest crop residues. The cropping system also greatly influences the survival of insects in crop residues. For example the stem borers of rice over-winter in the stubble of rice crop. After the harvest of crop, the larvae of pink stem borer (*Sesamia inferens*), yellow stem borer (*Scirpophaga incertulas*), striped stem borer (*Chilo suppresallis*) and white stem borer (*S. innotata*) seek refuse in the stubble. While the last three species undergo hibernation and stay there unnoticed, the larvae of *S. inferens* may damage the wheat crop even up to maturity in subtropical semi-arid region. Hence in rice –wheat cropping sequence this is the only borer species, which damages both the rice and wheat crops.

The major over-wintering sites of rice stem borers are fallow unploughed fields and those of oilseeds, lathyrus, chickpea and berseem when planted with minimal tillage (Rehman and Salim, 1990; Rehman *et al*., 2002). Our studies (Jaipal *et al.,* 2002) have revealed that the larvae of *Scirpophaga* spp. usually overwinter in the basal part of rice stubble. Migration of larvae to underground stems seems to be an adaptation to their specialized feeding. Ploughing/harrowing of fields immediately after harvest of crops kills most of these hibernating/aestivating individuals as also prevents unwanted crop re-growth which helps perpetuate several insect species. Stubble plough down kills the ratoon to stop pest cycles. Turning the soil over crushes insects, buries them, destroys their nests and exposes them to dessication and predators. Tillage can be performed most frequently in irrigated and dryland agriculture. Many soil dwelling pests and those hiding in underground stubble become reduced in number with each tillage operation. Land preparation by ploughing and planking controls dormant tissue borer larvae before they emerge as adults. Hence, tillage practices and the crop following rice greatly influence the survival of these larvae. In Pakistan, Majid (1983) reported on the survival of hibernating rice stem borer larvae under different cultural practices. Though cent percent larvae were not killed in any of the tillage system, maximum survival was noticed in rice stubble remaining intact in following berseem crop.

Table 1. Effect of cultural practices on survival of over-wintering larvae of rice stem borers

Tillage practices	Live larvae	Dead larvae	Mortality (%)
Fallow – unplowed	29.7	2.0	6.3
Fallow – bullock plowed	13.0	3.3	20.4
Wheat – tractor plowed	21.7	4.0	15.6
Wheat – bullock plowed	10.7	2.3	17.9
Berseem – unplowed	35.0	2.0	5.4
Berseem – tractor plowed	17.3	2.7	13.3
Berseem – bullock plowed	20.7	3.7	15.0
Mean	21.1	2.9	13.4

Source: Majid, 1983.

In north-west India, the survival of rice stem borer larvae especially those of yellow stem borer (YSB) was noticed to increase with crop intensification. The fields double cropped with susceptible cultivars like ProAgro hybrid 611 and Traori Basmati in sequence recorded higher YSB population surviving in stubble than those planted with single crop of less susceptible cultivar HKR 126 (Jaipal *et al.,* 2002). The rapid adoption of double cropping without proper fallow and staggered planting of rice in some districts of Haryana during 1997-2003, in fact, has been responsible for the increased incidence of YSB even in non-Basmati rice. The observation gets credence from the reports of Loevinsohn (1984) that in irrigated rice systems around IRRI farms at Los Banos a rise in double cropped area from 39 percent in 1969 to 99 percent two years later resulted in significant increase in yellow stem borer incidence. Similarly, a higher survival of pink stem borer (PSB) is also currently being noticed with planting of cultivar HKR 47 (personal communication) in rice-wheat sequence. Our observations have revealed that the retention of straw of this variety in following wheat crop especially in form of a surface cover or when rice panicles are removed superficially with a combine harvester leaving long stubble has resulted in increased incidence of PSB in wheat crop. Therefore, within the framework of our research, any increase in stem borer survival in rice-wheat cropping sequence was seen to be more related to early planting, crop intensification, cultivar susceptibility, climate and increased use of N fertilizer than the tillage treatment. There is evidence that ecologically specialized (monophagous) species have been favoured by crop intensification that involves changes in cultural practices such as: (a) an increase in the number of crops grown per year, (b) an increase in the use of agricultural chemicals (fertilizer and pesticides), (c) increased area under irrigation, and (d) increased plant densities. The YSB larvae as usual occupy the underground stalks of rice in zero-till wheat fields, but their number has been seldom abundant to become significant in the next crop. With the decay and decomposition of stubbles and fall in winter temperature a large number of the hibernating larvae in the soil perish. Heavy winter rains during January and February in North India have been shown to bring out even cent percent mortality of the yellow stem borer larvae lying in soil around the root zone of wheat hills (Jaipal *et al.,* 2002). The larvae also move to the soil under situation of *in-situ* burning of rice stubble and straw. Destruction of crop residues is, although, considered a subtle way of reducing the survival and carry over of YSB population from one crop to another, our results indicated that no-tillage method of wheat sowing in rice-wheat sequence may not increase the problem of this borer anticipated to arise by a number of field functionaries and farmers. In semi-arid environments of Central Queensland, Robertson *et al.* (1994) and Wilson-Rummerie *et al.* (1999) also did not find any increase in pest density under conservation tillage (CT) system.

Soil dwelling pests under irrigated and dryland agriculture, however, may increase in number under CT. In our studies, sporadic incidences of termites, armyworm (PSB), cutworm (Spodoptera sp.) and rats occurred in a few zero-till wheat fields. With CT, stubble retained in the soil/on the surface ensures food and refuges to these pests. Since termites are major decomposers in forests and agricultural systems, their association with crop residues seems to be quite obvious. The minimum soil disturbances under CT may also be held responsible for their increased incidence. Rats have also shown constant association with crops and crop commodities. Being highly migratory communities under multi-cropping agro-systems, rats keep shifting between crops according to their harvest schedules. Armyworm, cutworm and grasshoppers generally seek refuge in the crop residues forming a surface cover over the soil. In our studies, their problem have been witnessed in those zero-till sown wheat fields where the loose rice straw formed a sort of carpet providing shelter mainly to pink worm larvae which then acted as armyworm, cutting and destroying the young wheat plants. Burning straw and stubble in fields is a common practice with the farmers and is claimed to contain these problems (Alam and Narullah, 1977). Exposing the straw to sun in hot summer or cool nights in winter is targeted to kill stem borer larvae and may prove as effective as burning. This allows natural enemies to seek shelter to survive (Lim, 1970) as well as conserves nutrients which otherwise would be lost in smoke during burning.

The population size of surviving insects in crop residues is also greatly influenced by the cutting height of crops at harvest. Panicle cutting traditionally practised by the farmers ensures maximum survival and carry over of stem borers (FAO, 1979). Stem borer larvae descend to the base of the plants to pass a unfavourable season in a restive stage. How far they descend depends on the pest species. Lowering the cutting height generally results in proportionally more larvae in the removed straw. The highest number is removed when the stubble is cut at the ground level. Therefore, adjusting cutting heights for crops grown under CA would be important in pest survival and carry over. However, cutting of crops with combine harvesters leaves long stubbles and hence may leave a large population of insects in straw/stubble to carry over to the next crop.

Besides providing shelter to destructive insects, the crop residues serve as refugia to a number of beneficials. Recently, our studies conducted in collaboration with the Rice-Wheat Consortium (RWC) on species diversity and population density of macro fauna of rice-wheat cropping habitats in relation to modified tillage practices of wheat sowing have indicated that retention of rice stubble in no-till wheat fields immensely enhances the diversity and population density of natural enemies of rice pests, particularly the predatory crickets, beetles, bugs, ants and spiders. The predators occur in abundance in the rice stubble as also the nearby grasses and weeds in the early stages of the wheat crop which subsequently shift to the bases of wheat hills, their number declining gradually during the cold winter months This fauna, however, is almost absent in wheat fields sown with conventional tillage or on raised beds.

Our results during 1999-2000 indicated that the zero-till fields at all the five sites in Haryana were substantially rich in beneficial fauna as compared to conventional planting. These differences in the two crop establishments have appeared mainly due to difference in tillage operation. In conventional sowing, the preparation of land through a series of ploughing and planking results in killing of benefials as also their shifting to vegetation around. Non-availability of suitable conditions or host or both causes mortality of most of this useful fauna. Therefore, in conventionally sown fields the colonization of natural enemies is always quite low and occurs late in the season when most of the pests have already inflicted the damage to the crop. On the other hand the zero-tillage with stubble intact ensure survival of these organisms and facilitates early colonization of predators in next crop. Early colonization of natural enemies leading to higher and timely parasitism of pests, therefore, is of great significance in keeping pest population densities below the economic thresholds. The increase in predator density in zero-till fields may lead to greater predation of pest larvae (Brust *et al.*, 1986).

The stubble and open furrows in zero-till fields in which straw was not burnt contained the largest number of predators (Table 2). However, their number declined gradually from December through February under low temperature conditions. The fields in which rice straw was burnt had very little number of benefials than those with stubble intact. During 2000-2001, the population of predators seeking refuse in the stubble varied greatly among the sites (7667 to 16333/ha) and at two sites was higher than the previous year (5333- 9000/ ha). These include a wide range of predatory spiders (*Oxypes, Clubiona, Tetragnatha, Lycosa)*, beetles *(Casnoidea, Paederus, Lemnia, Harmonia)*, ants *(Monomorium, Camponotus)*, and some unidentified predatory crickets and bugs. A further substantial increase in natural enemies density (11000 to 19670/ha) particularly of ground beetles was evident in the next year crop. During the early crop season these inhabited the rice stubbles but in the later season with the decomposition of crop residues and fall in temperature shifted to the bases of wheat hills.

Table 2. Most commonly seen predators in rice stubbles during 1999-2003

A. Beetle
a. Lady-bird beetle
(*Lemnia* sp.)
(*Harmonia* sp.)
(*Macropis* sp.)

b. Ground-beetle
Casnoidea indica
Ophionea sp.

c. Rove-beetle
Paederus fuscipes

B. Spiders
Oxypes spp.
Lycosa pseudoannulata
Araneus inustus
Tetragnatha spp.
Clubiona sp.
Unidentified (*Argiope* sp.)

C. Long-horned Grasshopper
Conocephalus longipennis

D. Sword-bearing cricket
Metioche vittaticollis
Anaxipha sp.

E. Bugs
Microvellia sp.
Cyrtorhinus lividipennis
Assassin bug

F. Ants
Monomorium sp.
Camponotus sp.

G. Wasps
Ropalidia sp.

H. Earwigs
Prareus sp.

Differences in population of predators between no-till and conventionally sown wheat fields were also shown at two sites in Pakistan in the recent past (Rehman *et al.*, 2002) Here, the population of predators was comparatively high throughout the study period from 1999-2000 to 2001-2002 in wheat fields sown after rice with a no-till drill (without seedbed preparation) compared to wheat fields sown conventionally after proper seedbed preparation. At both the sites the magnitude of difference in the population of predators between no-tillage and conventional method of sowing wheat increased with the passage of time (Table 3). Such differences were comparatively less during the first year (2000), increased in the second year (2001) and further increased in the third year (2002). The difference in the population of predators between the two crop establishments may widen further in subsequent years.

Table 3. Population of predators in wheat crop sown with zero-tillage (ZT) and conventonal tillage (CT) after the harvest of rice crop

Month	Number/m^2							
	Spiders		Paederus		Coccinellids		Total	
	ZT	CT	ZT	CT	ZT	CT	ZT	CT
2000								
January	2.6	1.4	2.7	1.2	0.5	0.2	5.8	2.7
February	3.8	1.7	3.5	1.4	0.6	0.3	7.8	3.3
March	3.0	1.1	3.2	1.5	1.3	0.8	7.5	3.4
April	2.6	1.4	2.1	1.3	1.2	0.7	5.9	3.3
2001								
January	3.1	1.5	2.8	1.1	0.5	0.3	6.2	2.7
February	3.3	1.3	3.6	1.7	0.7	0.2	7.6	3.2
March	3.5	1.3	3.2	1.6	1.1	0.7	7.8	3.6
April	3.2	1.9	2.8	1.7	1.8	0.9	7.8	4.5
2002								
January	4.7	1.4	4.1	1.3	0.9	0.1	9.7	2.8
February	4.9	1.3	4.5	1.6	1.3	0.5	10.0	3.3
March	4.8	1.7	4.3	1.5	1.7	1.0	10.8	5.3
April	4.3	2.1	4.0	2.0	2.3	1.4	10.6	5.5

Source: Salim *et al.*, 2004.

Tillage operations destroy rice stubbles and the proportion of destruction of stubbles depends on the type of tillage equipment and the number of tillage operations. One operation of a rototiller plus two passes with a cultivator and one of planking cause 99% destruction of rice stubbles (Zafar and Razzaq, 1988). The rototiller destroys rice stubbles completely and kills hibernating stem borer larvae (Table 4). With the conventional cultivator tillage, rice stubbles are not completely destroyed even after several plowings (Inayatullah *et al.,* 1989).

The population of predators in the rice crop planted after wheat sown with zero-tillage was also comparatively higher than when the rice crop was planted after a conventionally sown wheat crop. The availability of natural enemies in the vicinity of rice fields due to their conservation through zero-tillage and their timely immigration provides an explanation to this. Early arrival of predators in newly planted rice fields depends on immigration from local sources (Cook and Perfect, 1985, 1989; Heong *et al.,* 1991). Early arriving predators can quickly overtake and keep population of rice insect pests low (Way and Heong, 1994). It is, therefore, crucially important that key natural enemies should arrive as early as the crop colonizing pests. In conventional system of crop planting there is minimal chance of the presence of any predators in the fields or in the agricultural matrix as a whole.

Table 4. Effect of different tillage practices on the destruction of stubbles and hibernation of rice stem borer larvae (mean of two years)

Treatment	Stubble/ m^2	Tillers/ stubble	Infested stubble		Larvae/ stubble	Stubble destroyed (%)
			No.	%		
No tillage	138	14	119	86.2	4	-
Cultivator (2) + plank (1)	41	13	18	43.9	2	70.3
Cultivator (3) + plank (2)	21	11	2	9.5	1	84.8
Rotavator (1) + cultivator (2) + plank (1)	1	3	0	0	0	99.3

Source: Razzaq *et al.,* 1997.

The increase in the population of predators in rice fields due to no-tillage sowing of wheat is of great importance to enhance the activity of predators in suppressing the population/ infestation of insect pests of rice. Emergence of *Glyptomorpha deesae, Chelonus* sp., *Isotima* sp. and *Bracon chinensis* from the over-wintering larvae generally coincides with the emergence of the pest. This synchronization could be quite advantageous for the management of the stem borer population as the parasitism of stem borer larvae has been generally higher (Beg and Khan, 1982) under such conditions. Almost all the larval and pupal parasitoids of stem borers and other insect pests remain in the stubbles after the harvest of rice (Table 5). On the other hand, in conventional method of sowing wheat due to tillage operations for the preparation of seedbed rice stubbles are destroyed, which result into high mortality of natural enemies.

Effects of weeding on insect survival

Many insects, both harmful and beneficial can develop on weeds on bunds, in fallows or that occur in association with crops. Several weeds serve as alternate hosts to a number of insects and diseases. For example rice fields infested densely with wild vegetation may contain higher populations of leaf folders (Kalshoven 1981), planthoppers (Oka, 1979), root weevils (Ishly, 1975). Rice Hispa (Prakasa Rao and Israel, 1970), armyworms and grasshoppers

Table 5. Insect pests and their natural enemies commonly seen in rice crop sown after zero till wheat crop during 2000-2001

Insect Pests	Predators	Parasitoids
Stem borers	Long-horned grasshopper, (*Conocephalus longipennis*) Cricket (*Metioche vittaticollis)* (Anaxipha longipennis)	Wasp (*Telenomus rowani*) (Trichogramma japonicum) (*Tetrastichus* sp.) (*Cotesia flavipes*) (Sturmiopsis inferens) (Stenobracon nicevillei)
Leaf hoppers and Plant hoppers	Cricket (*Metioche vittaticollis*) (*Anaxipha longipennis*) Damselflies and Dragon flies Bug (*Cyrtorhinus lividipennis*) (*Microvellia* sp.) Long-horned grasshopper (*Conocephalus longipennis*) Lady-bird beetle (*Harmonia octomaculata*) Micraspis sp.) Wolf spider (*Lycosa pseudoannulata*)	Wasp (*Gonatocerus* sp.) Big-headed fly (*Tomosvaryella* sp.)
Leaf folders and	Ground beetle (*Ophionea* sp.)	Wasp (*Cotesia flavipes*)
Whorl maggot	Damselflies and Cricket (*Metioche vittaticollis*) (*Anaxipha longipennis*)	
Hispa beetle	Orbweb spider (*Argiope* sp.)	Wasp, (*Trichogramma* sp.) (*Bracon* sp.)
Rice bug	Assassin bug (*Rhinocoris* sp.) Long-horned grasshopper (*Conocephalus longipennis*)	Wasp (*Gryon* sp.)

(Grigarick, 1984) dwell on grasses or around the bunds and in fallow fields and shift to crops after border areas are cleaned of grasses. Wild vegetation around crop fields and on bunds also shelter many beneficial species. Vegetation in areas adjunct to crop fields provide food and shelter to natural enemies the same way as it do to harmful insects. Abundance and diversity of parasites and predators within a field are closely related to the nature of surrounding vegetation (Altieri, 1994). Several factors determine the importance of bunds as key sources of natural enemies (Way and Javier Jr., 2001). The wild vegetation (weeds, grasses) of the bunds and of surrounding wastelands also serves as refuges to many predators and parasites. Biocontrol agents and species diversity are most abundant in weedy fields and not all weeds harbour all pests. Paddies with weeds on the bunds have the most abundant natural enemies and they are least abundant in paddies without weeds on bunds. Marcos *et al.* (2001) observed natural enemies in close association with broadleaf weeds. Of the 36 weed species recorded on bunds, only 7 had insect pests while, all weed species except *Alysicarpus vaginalis* harboured natural enemies among them. Of the grass species, two contained pest insects. Sedges did not contain any pest insects. The most common predators inhabiting weeds were ants, spiders and beetles. Ants inhabited all the 30 species of weeds, spiders 14 and coccinellids 3 species.

The levees with grass weeds tend to be an important source of natural enemies of rice pests (Lan *et al.*, 2001). The bunds around tropical irrigated rice fields usually support an abundant and diverse ant community with nesting populations limited to the dry land bunds when fields are flooded. Many ants prey on insects in rice fields, both on the canopy and during fallows (Way *et al.*, 1998). Narrow vegetation-covered bunds surrounding each field are important for early arriving species such as spiders and are also an immense source of some predators like *Cyrtorhinus lividipennis* and gryllids that seasonally gather in rice (Way and Heong, 1994).

Certain weeds are important components of agro-ecosystems because they positively affect the biology and dynamics of beneficial insects by way of meeting out their important requisites in form of alternative prey/hosts, pollen, or nectar as well as microhabitats that are not available in weed-free monocultures (Marcos *et al.*, 2001). Herbivore-natural enemy interactions occurring in a cropping system can be influenced by the presence of herbivores on associated weed plants (Altieri and Letourneau, 1982). In our studies, it was observed that soon upon the harvesting of rice crop, several predators migrated to the wild vegetation on the bunds and nearby wasteland apart from their occupying the rice stubbles from where these were seen shifting to the bases of wheat hills during winter months. On these grounds a clean weeding may not be recommended.

Planting time shifts and insect survival

The basis for planting time shifts is in the cyclical occurrence of insect stages, as not all stages injure the crop plant. Shifting the planting date will disadvantage the pest when prevalent insect stage is vulnerable to air or water temperature extremes, heavy rainfall, a non-preferred crop growth stage or the abundance of natural enemies (Teetes, 1981). Although there are exceptions, often early plantings escape pest colonization (Pimentel and Goodman, 1978) while late plantings of a crop are benefited by high level of natural enemies and delayed planting by suicidal flights. Planting time interactions are greatest if carried out over large areas and against monophagous pests that attack one crop stage or are highly seasonal in appearance . Shifting planting time also means growing the crop under unfavourable weather conditions for the pest to proliferate. An early planted crop may also take the advantage of flush of mineralized nitrogen which could either mean greater tolerance to pest damage due to active crop growth or make the crop more susceptible to stem borers. Shifting planting time in an asynchronous area has little effect. Delayed planting until the moths emerged and died termed as 'suicidal stubble flight'- suppresses the stem borer for the entire crop season. Late planting likewise also minimizes incidence of many pests like gall midge, leaf beetles, root weevils, leafhoppers, planthoppers etc in rice crop. Pests for which early wheat planting due to zero tillage resulted in low populations are shootfly, *Atherigona oryzae*, aphid, *Macrosiphum miscanthi*, and *Rhopalosiphum maidis.*

Effect of decomposition of residues on insect survival

Plant residues in one form or another and in all stages of decomposition are always present in/on field soil. During the decomposition process of these residues, various organic compounds are produced which exhibit a wide range of properties and may directly or indirectly be involved in insect development. The decomposition of plant residues may produce phytotoxic substances particularly during early stages of decomposition (Patrick *et al.*, 1963). The effects might be severe in reduced tillage systems which incorporate huge amount of residues in to the soil and extra application of nitrogen is made to cause quick decomposition of residues. In our studies, the latter situation at some of the farmer fields forced pink stem borer larvae to immediately leave the stubble and shift to wheat during early crop stage where these acted as armyworm, cutting and destroying sporadically the young wheat plants. With decomposition of residues, certain nutritional substances in favour of plant health are also released into the soil e.g. silica known to impart resistance to plants against insects and diseases is continuously added in the soil under zero or reduced tillage system.

Management of pest insects under conservation tillage systems

There is every indication that innovative cultural practices involving conservation tillage systems will continue to be developed because of a host of benefits these are expected to result in. These practices will be refined and may possibly, replace conventional tillage practices of crop production in large areas in the near future. The rapid changeover to reduced tillage systems is exemplified by wheat crop. The significance of the relationship between some insects and abundant plant residues resulting from the reduced tillage operations in rice-wheat signals both benefits and risk which are listed as under:

Benefits	Risks
Rice crop	
• Conserves natural enemies • Reduces the pest risks by enhancing natural control • Makes the ecosystem more stable • Creates species diversity • Reduces the cost of pest control • Environmentally friendly and ecologically sustainable	• Rice stubble inhabit pest stages the incipient opulations of which survive and may shift to wheat crop (pink borer, Chilo sp.) or to early sown rice nurseries, ratoon sprout, etc. (monophagous species)
Wheat crop	
Timely sowing reduces the risks of shootfly and aphid damage	Sporadic damage occurrences by pink borer, termites, cutworm or armyworm may be encountered depending on the agricultural matrix, cultivar susceptibility, climate, cultural practices, carry over

Our recent observations in wheat crop established in rice residues have indicated that the cutworms, armyworms, grasshoppers and termites specially under conditions where straw is cut to form a surface cover may sporadically damage wheat crop. The point is that the surface residue here provide shelter to these extremely polyphagous species. Thus the role of residues in the damage occurrences by such insects must be considered and studies made in formulating control measures against pests associated with conservation tillage. Based on the understanding of the effects, a preventive pest management programme that provided conditions to avoid or prevent pest outbreaks or helps maintain pest below economic threshold level or an ecologically sound biointensive management programme focussing mainly on ecological and biological principles be developed and used. Recently, Landis *et al.* (2000) suggested a more holistic conservation biological control which should fit in the requirements of pest control under "CA". Integrated biodiversity management (Kiritani, 2000) is another similar option which also looks into the needs for conservation and aims to make the agricultural systems sustainable with a strong ecological base. Following tactics may form an important component of such a pest control programme:

- Host plant resistance.
- Cultural, mechanical and physical control.
- Biological control.
- Behavioural control.
- Use of biopesticides.
- Need based use of safer insecticides in low doses, at early pest stage and preferably through spot applications and seed treatment.

For management of destructive insects in CA systems, a combination of varied control tactics instead of relying on just one tactic should be the approach to plant protection. Under this IPM approach, the use of resistant cultivars, where ever possible, is to be encouraged. However, the absence of resistant cultivars due to polygenic nature of inheritance and the poor plant type of donors has made pest control tedious. The current integrated management strategy in crops, hence, relies mainly on cultural, biological, behavioural and chemical means, the judicious blending of which has shown promise in keeping the population density of pests below economics threshold levels. A wide range of mechanical, physical and cultural methods are potential practices and their use in conservation agriculture will depend on existing alternatives and local conditions.

The cultural practices advocated for use on campaign basis include timely and synchronous planting, straw/stubble management, balanced fertilization and application of optimal rates of nitrogen fertilizer in split doses. Short crop rotation particularly in areas where contiguous cropping is in practice may be an effective means of controlling insects in conservation tillage system. Ecofallow is an example of controlling some of the pest and disease problems resulting from a monoculture system. Machine or animal drawn rollers can be used to mechanically kill the over-wintering population in stubbles or to crush the cutworms, armyworms, grasshoppers, crickets hiding under the surface residues. However, this will also kill the predators seeking refuse in the stubble.

Use of biocontrol agents is another important component of IPM system. This entails liberation of some natural enemies and their conservation. In general, most crop fields have rich communities of beneficial that help keep stem borer population densities at economically insignificant levels. Without these beneficials the insect pests would multiply so quickly, they would completely consume the rice crops. In rice, for each group of insect pests there are hundreds of natural enemies in the form of parasitoids, predators and pathogens. However the principal enemies include several parasitoids and predators apart from a few pathogens.

Predators are often the most important group of biocontrol agents in crop fields. In fact, these occur in almost every part of the crop environment. In rice crop, the long-horned grasshopper, *Conocephalus longipennis* (de Hann) is recorded to feed voraciously on the eggs of *S. incertulas*. The predatory crickets *Metioche vittaticollis* Stal. and *Anaxipha longipennis* Sew and the mired bug, *Cyrtorhinus lividipenis* prefer to feed on the eggs of *Chilo* species. The coccinellid beetles, *Micraspis* and *Harmonia* spp. and the carabid *Ophinea* devour young larvae of the borers. While water bug, *Microvellia* sp. and ants are considered good predators of stem borer larvae, the spiders, birds, dragonflies are also seen to prey on adult moths.

Natural enemies also have enemies of their own. For example, predators tend to be generalist feeders and several of them are cannibalistic in the absence of host insects. Hence, to maintain populations of beneficials it is essential that populations of pest insects at levels below which they cause no economic damage are also maintained in the fields. The augmentation of most natural enemies particularly the predators is quite uneconomical because it is extremely costly to mass rear predators. Since there are already many natural enemies in the rice fields, they should be conserved firstly by avoiding indiscriminate use of pesticides. Although insecticides may be needed in some cases, these must be used judiciously and selectively in order to maximize the effect of the natural control agents. Provision of refugia and natural (pollen, nectar, host insects) and artificial (sprays of mixtures containing protein and sugar source) foods in agroecosystems help colonise and conserve natural enemies. Habitat diversification through introduction of plant diversity, crop rotation, cover crops etc also improves biological control because diverse agroecosystems tend to enhance abundance of natural enemies due to availability of alternate prey, food and suitable microclimate. Organic soil management and low soil disturbance tillage practices enhance the activity of decomposers and hence are also supportive in improving biological control. Other important interventions and manipulations required to conserve beneficials are:

- Burning of crop residues *in-situ* in the field should be abandoned.
- Growing alternate crops at appropriate sites.
- Strip cutting of crops.
- Creating shelter for natural enemies during unfavourable season.
- Wild vegetation during off season be left to grow around crop fields.

Sampling, survey and surveillance are basic to maximizing the impact of predators and parasitoids. Recognition of pests and the natural enemies and maintaining their inventory is the first step. Sampling for the composition of pest and natural enemies and their seasonal and relative abundance is the next step which is very important in decision making. Field studies of both pests and natural enemies may lead to the development of practical pest surveillance and forecasting techniques. After going through the procedures of sampling, survey and surveillance the next step should be demonstrating the impact to the farmers.

Need based application of safer pesticides is the most crucial component of IPM. The economic threshold levels should be precisely considered before making pesticide applications. Neem derived pesticides have been shown to offer moderate control of a number of insects. This botanical, in different formulations, has also been reported safe to the predominant natural enemies. There is need to introduce microbial biopesticides because of a number of advantages associated with their usage.

For integrated management of pest insects, behavioural tactic has also shown vast potential as pest monitoring tool or as attractant/ mating disruption tactic. The behaviour modifying chemicals, identified from *S. incertulas, C. suppressalis* and *S. inferens*, are non-toxic, biologically active and specific in action and have been found effective in managing yellow stem borer through mating disruption. A mixture of yellow stem borer pheromones when used in different proportions in polyvinyl formulation, reduces its damage by disrupting communication in male moths.

For making IPM technology workable in conservation agriculture, a holistic approach based on pest and crop ecology has to be rigorously followed by integrating appropriate and yet safer and environment-friendly alternatives to insecticides. It would also require the active co-ordination and co-operation between research organisations, Government agencies, extension linkages and NGO's to promote the preventive IPM concepts under CA, disseminate the technologies and educate the masses on campaign basis regarding the objectives of IPM. A policy environment conducive to IPM, which discourages use of pesticides, is very important under CA systems. Human resource development is also a very crucial aspect and should receive special consideration. Funding for IPM projects from national and international agencies is crucial and needs immediate attention. There are nearly always exceptions so local conditions and knowledge have to be considered. The practicality of different practices must also be considered in light of the farmers circumstances and the effect of the practice on farmer's profit and lifestyle. The future research and development issues for pest management in CA systems should involve:

- Regular monitoring of the system through survey, surveillance and sampling.
- Developing GIS based systems of monitoring.
- Minimizing use of hazardous pesticides and promoting need based use of safe and selective pesticides in low doses and more as spot application and seed treatment.
- Promoting use of biopesticides, bioagents, lures, botanicals, etc.
- Developing cultivars suited to CA systems.
- Increasing diversification.
- Emphasising conservation of natural enemies and enhancing biological control.
- Development of location based IPM packages for a host of pests.
- Empowerment of farmers through farmers participatory approach, travel workshops, trainings on IPM, biodiversity conservation and preventive control.

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Zero/Reduced Tillage/Bed Planting/Surface Managed Crop Residue Systems-Opportunities for Crop Genetic Enhancement

A.K. Joshi, B. Arun, R. Chand, V.K. Chandola, K. Ram Krishna[1]*, L.C. Prasad, C.P. Srivastava, P. Raha and R. Tripathi*
Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221 005, Uttar Pradesh, India
[1]College of Agriculture, RAU, Jobner, Rajasthan, India

ABSTRACT : Reduced tillage, which generally carries substantial crop residue, is different than conventional in several ways. Some of the important differences are in soil structure, shift in the host–weed competition, availability of different moisture regime if sown deep or under stubbles, emergence of a new pathogen population that survive on crop residues and shift in insect-pest scenario. There could be requirement for a different plant type suiting to a specific mechanization, agronomical initiatives such as allelopathy and specific issues related to the problem soils. Further, there could be greater scope of crop diversification and need for adopting a different breeding approach targeting a specific location or environment. Hence, new breeding initiatives need to be taken for the identification and introgression of favourable traits in the crops being grown in areas where conservation technologies are expected to grow. In this direction, special care has to be taken to develop genotypes that have faster emergence, better decomposition and that are able to germinate even if placed deeper. This will enable the crop to compete with weeds and utilize available moisture more efficiently. Enhancement of resistance to new pathogens and insect-pests surviving on crop residue or bunds must also be paid full attention. This would be possible if germplasm and breeding populations are evaluated under reduced tillage practices and suitable traits/genotypes are identified for their inclusion in the breeding programme. Farmers participatory research may also be followed for identification and development of varieties suiting to specific environment or location.

INTRODUCTION

Reduced tillage is a way back to evolutionary process just like Darwinian philosophy was evolved. Plants in their niche grow under zero tillage, but the philosophy of such plants is to complete their life cycle and produce enough offspring for the next generation. In our present day agriculture, we may not like to compromise with the yield. However, we can take idea from the environments that represent the regions where different crops have originated and survived for long under no till situation.

Conventionally, tillage operations used to have three broad objectives: (i) to place the seed in the soil, (ii) to break the capillaries and aerate the soil, and (iii) to check the weed growth. Zero till or reduced tillage does not involve these operations. Hence, reduced tillage system that generally carries substantial crop residue, is different than the conventional tillage in many ways for a growing plant. The differences between two systems warrant for a shift in our focus to traits that either were not so important or were ignored due to different priorities. Further, the change in crop breeding approaches based on what were the missing links could be employed to find better answers. In addition, we can think of new strategies based on ecological niches and farmers requirements to breed varieties that can enhance their profitability under such systems.

HOW REDUCED TILLAGE IS DIFFERENT THAN CONVENTIONAL TILLAGE?

Reduced tillage having crop residue is different than conventional in several ways: (i) the micro environment, viz., soil structure and texture, moisture available to a seed, seedling or the growing plant is different than a ploughed field; (ii) there could be emergence of a different panorama of host–weed competition over years; (iii) seed may get different moisture regime if sown deep or under stubbles; (iv) host-pathogen interaction may be different due to substantial presence of crop residues or raised bed. The insect scenario may change due to presence of substantial crop residues/stubbles; (v) residue decomposition may become an issue and needs to be taken as a trait; (vi) plants may face abiotic stresses in a different manner; (vii) there could be requirement for a different plant type suiting to a specific mechanization; (viii) certain agronomical issues such as allelopathy may be desired which are probably not so important in conventional system; (ix) there could be specific issues related to the problem soils such as greater tolerance to salinity where salt deposits on the earth curst; (x) crop diversification may be possible and needs to be promoted for sustainability and profitability of farmers; and (xi) there could be need for following an altogether different breeding approach such as participatory research to develop varieties suiting to specific location or environment. These issues are discussed in detail as under.

Tillage requirement

Conservation tillage requires varieties suiting to a particular resource conservation practice. For instance, the genotypes required for zero tillage and surface seeding would be having different characteristics than those required for the raised bed. For surface seeding and zero till planting, the variety should possess faster root development for quick establishment of the crop; this would provide safety from the harsh environment during the crop establishment and could also utilize the available moisture in the soil. Since, early sowing is being promoted and has greater possibility under reduced tillage; there should be greater tolerance to early high temperature (greater than the optimum of 17 ^{0}C) in winter crops such as wheat (Dr. Raj K. Gupta, CIMMYT, personal communication). It is regularly observed that short duration wheat cultivars perform poor, if grown early. Tillering and accumulation of biomass are drastically reduced. However, it is not the case with the late maturing cultivars. Therefore, there is need to produce high biomass varieties producing higher yields with same nutrient usage. This genetic improvement must come through both photosynthetic assimilation capacity and partitioning of assimilates to promote high grain number and growth rate (Richards, 1996). Another way to increase grain number in crops like wheat is breeding for multi-ovary florets having up to six kernels per flower (Chen *et al.*, 1998).

In raised bed cultivation, it has been demonstrated that all varieties of wheat do not perform well and there is genotype x tillage interaction (Sayre, 1998). Therefore, varietal development programme should be specially targeted to the tillage requirements.

Soil factors

In reduced tillage, soil may be more compact and unfavourable for root growth. For example, when wheat is followed by rice, the soil is more compacted, but enriched with anaerobic bacteria and physical properties may not be congenial to wheat growth. In contrast to ploughed field which has loose soil around the seed but compact soil below the ploughing zone, a zero till field has compact soil structure all along the roots. Reduced root growth in high strength soils is responsible for patchy growth and losses in yield of wheat under direct drill with surface straw retained (Cornish and Lymberg, 1987). For wheat, it has been suggested that increasing yield under direct drilling may require more disturbances around the seed to enable it to get a narrow zone of low soil strength for better growth (Chan and

Mead, 1990). A plant breeders answer to this issue would be to develop a variety having greater root mass. A higher root mass in the soil may take care of the physical condition of the soil and harvest the nutrients even from the deeper layers of the soil. Although the root of a plant is the first and most important organ that nourishes the plant, but has been neglected from the plant breeders view point (Manske *et al.*, 2001). We need to pay greater attention to this issue.

In reduced tillage, soil is less disturbed therefore, it has been suggested that the soil-root contact would be better and more favourable for the release of root exudates such as organic acids, carbohydrates, amino acids, enzymes, alkaloids, flavonoids, steroids and terpenoids (Hocking, 2001). These root exudates promote the micro flora of rhizosphere and promote competition among microbes and may be helpful in getting protection from pathogens. Therefore, there is need to screen varieties for better release of favourable root exudates.

Water requirements

Crops are often grown in environments where water is a limiting factor. For example, in around 70% of the irrigated wheat area of North-Eastern Plains Zone (NEPZ) of India, farmers are able to provide one or two irrigations and mostly the sowing is done on residual moisture. Hence, taking advantage of available moisture and reducing evaporation from the soil is important. Any increase in early seedling vigour should reduce evaporative losses from the soil surface (Richards, 1992). If crop duration is short, greater vigour is likely to increase final biomass and yield. Furthermore greater crop vigour may be an effective way to reduce weed growth and hence herbicide use in most environments. The available information on the variation and genetics of seedling emergence of wheat (Singh *et al.*, 1998) and oats (Radford and Key, 1993) can be exploited for such purposes.

Among traits that contribute to increase seedlings vigour, coleoptile length is most important (Fick and Qualset, 1976). Short coleoptile results in poor emergence, which leads to poor crop establishment. This is true particularly when seeds of semi-dwarf wheat are sown deeply to seek moisture or are sown into stubble (Richards *et al.*, 2001). In dry environments, farmers sowing into a receding moisture profile following rainfall will often sow at greater depth (8-12 cm) to ensure seed contact with available soil moisture. Better emergence is achieved by sowing wheat with long coleoptiles. The presence of dwarfing genes is associated with a significant reduction in coleoptile length (Fick and Qualset, 1976) and poor emergence under deep sowing. Allan (1980) suggested that the accumulation of modifier genes that favour emergence could be important in breeding for better emerging semi-dwarf wheats. Increased coleoptile length can be achieved by selection within semi-dwarf germplasm, but greater progress can be made using parents that are sensitive to gibberellic acid (GA), although short stature also needs to be selected (Rebetzke and Richards, 1999). Wheats with long coleoptile also tend to have large early leaves and more rapid rates of emergence, which together contribute to faster leaf area development (Richards *et al.*, 2001). Trethowan *et al.* (2001) suggested that wheat breeders should be able to select short statured, non-*Rht1* or non-*Rht2* hexaploid bread wheat with better emergence characteristics suitable for environments where deep sowing into stored soil moisture is practised; they identified non-*Rht* genotypes developed from Seri 82 and Cauliacan 89 as meeting these criteria.

Phenology is a major determinant of drought independent harvest index (HI) as it can determine the amount of pre-anthesis and post-anthesis water use. If flowering occurs a few days earlier, this may mean an extra 5-10 mm of soil water for post-anthesis use and hence a higher HI. Therefore, for water limited areas, we need to focus on early flowering (Richards *et al.*, 2001).

Host-pathogen interaction

Although the increase in the organic matter content of soils under reduced tillage may favour friendly fungi like *Trichoderma*, *Aspergillus*, *Penicillium*, etc. there could be a shift in the host-pathogen interaction. The effects of tillage on the development and severity of crop diseases are variable, depending on the disease, the specific type of tillage system used, and the effectiveness of the other disease management practices applied (Felton *et al.*, 1987). A summary of the effect of crop residues on the growth and reproduction of pathogens is given in Table 1. Conservation tillage usually maintains optimum soil temperatures, conserves soil moisture, and leaves crop residue on the soil surface which serves as a mulch. Of particular concern are crop diseases that are favoured by wet soils. Diseases most troublesome in high-residue tillage systems are those that have inoculum associated with crop residues left on the soil surface (Evans *et al.*, 2002). In reduced tillage system, there could be more favour to facultative parasites as well as saprophytes. Crop residue may promote such pathogens that survive and multiply on crop residues. However, all pathogens do not have broad host range. Also, all do not survive on all types of crop residue. Many of them survive on their own residues. For instance, *Fusarium* spp. of pulses survive on the residues of their host crops and not on rice or wheat. Some of the diseases such as spot blotch of wheat caused by *Bipolaris sorokiniana* which is considered the most important disease of eastern India (Joshi *et al.*, 2004b), have actually shown a decline after the use of zero tillage in eastern Uttar Pradesh where planting is mostly done under late sown conditions. However, we must be vigilant on these issues and our breeding programmes must target to strengthen pre-breeding as well as breeding populations using suitable resistance sources. In this

Table 1. Effect of crop residues on the growth and reproduction of pathogens of different crops grown in rice-wheat cropping system areas of India

Disease	Pathogen & its nature	Host range variability	Incidence	Spatial variability	Temporal	Effect of crop residue
1. Soil borne (seedling diseases, collar rot, damping-off etc)	Facultative parasites: *Phythium, Phytopthora, Rhizoctonia, Scelerotium, Macrophomina*	Broad	Locally high	Very high depending on scale and habitat	Periodic cyclics of disease	May promote disease up to 15 November
2. Wilt	Facultative saprophyte:		High	Depended on scale and habitat	Periodic cyclics of disease	Survive on own residue for 2 to 4 years. No chance of multiplication on other crops residue. If multiplies on other residue, will not be virulent
	Fusarium udam	Pigeon pea				
	F. oxysporum fs. Ciceri	Chick pea,				
	F. oxysporum fs. Pisi	Pea				
	F. oxysporum fs. Lini	Lentil				
3. Necrotroph (Foliar diseases)	Facultative saprophyte	Restricted except, sheath blight pathogen	Very high	Very high. Depends on the scale and habitat	Periodic cyclics of disease	Survival not detected on the residue of wheat and paddy. All pathogens survive on residue for a limited period. Most pathogens are host specific. Hence, can not shift to other hosts
Sheath blight of rice	*Rhizoctonia solani,*					
Bacterial blight of rice	*Xanthomonas oryzae pv. Oryzae,*					
Spot blotch of wheat and barley	*Bipolaris sorokiniana*					

direction, identification of simple morpho-physiological markers such as erect leaf (Joshi and Chand, 2002) and leaf tip necrosis for spot blotch (Joshi *et al.*, 2004a), and *Lr34* gene of leaf rust of wheat (Singh *et al.*, 1992a, b) can simplify the efforts of breeders.

In addition to disease, conservation tillage may have variable effects on insects**.** Summer deep ploughing destroys many overwintering insects by exposing them to high temperature and birds. This does not happen in conservation tillage. There could be more favour to some of the insect pests due to more biota in the soil. The insect pests that are expected to gain are shoot borers. The stem borer like *Sesamia inferens* (which is common in Punjab) is polyphagous while, yellow stem borer (*Scirpophaga incertulus*) (which is common in eastern Uttar Pradesh) occurs only on paddy. This yellow stem borer has also been reported from the residue treated plots in the Andhra Pradesh (Surekha *et al.*, 2003).

Raised bed cultivation may also promote different insect pests such as grasshopper which lay eggs mainly on bunds. The problem was observed during 2003-04 *Rabi* season, when the early sown (November sown) wheat crop in many parts of the rice-wheat cropping areas of eastern Uttar Pradesh was severely attacked by grasshoppers at seedling stage. It was particularly severe in canal-irrigated areas of different districts viz. Varanasi, Mirzapur, Chandouli, Ghazipur, Azamgarh, Jaunpur etc. where long duration paddy dominates. This attack was caused by the grasshopper species viz. *Oxya nitidula* and *Hieroglyphus* species, but the major loss was caused by *Oxya nitidula.* These two species of grasshoppers are of common occurrence in eastern Uttar Pradesh. The *Hierogylphus* is common in *Kharif* season, whereas *Oxya nitidula* is prevalent in *Rabi* season. Both these species are polyphagous in nature. Although this problem was largely due to favourable temperature for grasshoppers, this may get aggravated if raised bed paddy is promoted because *Hieroglyphus* is common on paddy and it lays its eggs in the bunds of the field (Nayar *et al.*, 1985). Hence, we need to follow measures to manage grasshopper population. Tolerant varieties could be one of the options in the integrated management of grasshoppers.

Residue decomposition as a trait

Crop residues are a tremendous natural resource-not a waste (Kumar and Goh, 2000). Disposal of crop residues is based on decomposition, which is primarily influenced by environment and management factors with secondary influences including the species and cultivar type (Summerell and Burgess, 1989). Several workers have reported differences in residue decomposition due to difference in N, C/N, lignin/N, and polyphenol/N ratios even for the same species (Kumar and Goh, 2000). Thus the selection of crop genotype which could promote micro-climate more favourable for the growth and reproduction for the saprophyte would be better. Summerell and Burgees (1989) reported varietal differences in the decomposition of wheat and barley straw. This also suggests possibility for selection of such cultivars in cereals.

Ecological/environmental factors

In a reduced tillage field having plenty of crop residues, there could be less sunshine available to the early seedlings emerging out of soil and also resistance to their growth is also expected to be higher than the conventionally tilled field. The reduced tillage also affects soil temperature (Unger and McCalla, 1980). In comparison to conventional tillage, the reduced tillage field would be cooler during summers (Hatfield and Prueger, 1996). Indirectly, it may benefit early sowing (October or early November sowing) of wheat in environments such as NEPZ of India, where optimal temperature is attained in the second fortnight of November. However, this may not be beneficial for summer urd, mung, vegetables and even for paddy.

Hence, for these crops, varieties that germinate well and produce vigorous seedlings under relatively lower temperature would be more desirable.

The crop residue present under reduced tillage may create the problem of phytotoxicity for various crops (Cochrane *et al.,* 1977; Lynch, 1981). Under anaerobic conditions phtyotoxic compounds such as acetic acid and butyric acid may be formed which influence germination of seeds (Mc Calla and Haskins, 1964; Wallace and Elliott, 1979). This phytotoxicity is reported within as well as between crops. Therefore, the traits related to seedling resistance to organic acids may also be taken care of while breeding for crops to be grown under crop residue and conservation tillage.

Agronomic requirements

Tillage is widely used to control weeds directly and by burying their seeds. Germination of many weed seeds is stimulated by exposure to light. In the presence of crop residue, only those weeds would flourish which can grow under diffused light. Thus, the variation in the occurrence of weed, both at species and temporal level, may shift in the reduced tillage. Therefore, as mentioned earlier, varieties having faster early emergence or those displaying better competition would be more desirable. In view of greater use of herbicides, breeders also need to look for herbicide tolerant varieties.

Another agronomic aspect needs consideration. Generally, thinning is to be done at a particular time to maintain an optimum plant to plant distance. In other words, thinning at late stage is relatively useless. Since under zero till conditions, plant canopy at early stage may become restricted, there would be more plants (including weeds) per unit area as compared to ploughed field crop. The genotypes of crops which exhibit favourable allelopathy (Weston, 1996) to suppress the weeds may be identified. For example, the residue of rye and other small grains have been shown to inhibit weed emergence and growth (Shilling *et al.,* 1986), probably due to phytotoxic effects (Kumar and Goh, 2000). Such traits need to be identified in case of all the crops of the target zone.

Mechanization issues

The sowing depth of seeds might vary under reduced tillage. In surface seeding, seeds are dispersed on the soil surface, while a machine performing sowing under crop residue system may place the seed at lesser depth than recommended in tilled sowing. Hence, varieties displaying better germination and growth under shallow or surface seeding would be more desirable. However, in drier condition, drying of surface soil contributes to increased mechanical impedance which may affect seedling emergence; seeds planted 1-2 cm deep may have trouble in germination for lack of water (Benoit and Kirkham, 1963). The presence of mulch on the upper part of the soil keeps it wetter and in most situations, this is desirable because it is beneficial to germination and plant growth. In case of use of Star (Punch) Planter, planting in the presence of residue would be easier for crops like rice, pulses, maize, etc. However, wheat which shows better performance under drill sown condition may not respond to this machine due to inadequate plant population. For making wheat adjust to punch sowing, we need to either modify punch machine to deliver appropriate amount of seed or develop varieties having profuse tillering with many effective tillers. Variability of synthetic wheats (Mujeeb *et al.,* 2001) may be utilized for developing such varieties. In future, enhanced use of mechanization is expected in most of the parts of the world adopting RCTs. Hence, erect growth habit along with synchronized flowering and maturity, especially in pulses would be important for machine harvesting.

Problem soils

Under increasing population pressure, many of the problem soils are being exploited for crop cultivation. In such areas, reduced tillage is expected to be greater due to economic reasons. Many of these areas suffer from one or the other stresses such as high pH, micronutrient deficiency, high or low moisture, undulating land, etc. Zero till sown wheat performs better in saline soils. However, in case of alkali soils, contact of seed with alkali crust may be harmful for seed germination. Therefore, development of tolerant varieties for saline conditions is an important requirement. For situations such as direct seeded rice (DSR), we need cultivars that do not suffer from iron chlorosis, Zn and P deficiency and are able to germinate when seeds are placed deeper in moist zones (Dr. Raj K. Gupta, personal communication). It has been demonstrated that there is genetic diversity for micronutrient characters within wheat (Graham, 1984). Inheritance of micronutrient traits have been reported in many crops including wheat (Majumdar *et al.,* 1990; Graham *et al.,* 1992) and barley (Graham, 1984). Such information must be utilized for evaluation and introgression of favourable genes in different crops under RCTs.

Issues related to crop diversification

Sustainable crop production through crop diversification is an important issue in rice-wheat cropping areas adopting resource conservation technologies. The crop diversification is likely to be more profitable and beneficial to eco-system. The common crop rotations involving pulse crops in such areas are rice-pea-wheat, rice-lentil and rice-gram. Due to instable and poor yield of pulse crops, the area under diversification is not growing. In case of pea, the pea variety HUDP 15 developed by Banaras Hindu University which has high yield potential (30 q/ha) and performs better under conventional as well as RCTs such as surface seeding and zero tillage, the area of pea has shown better growth due to wider adoption. Development of such type of genotypes in lentil and gram is also expected to promote crop diversification and profitability of farmers. Similarly, there is ample scope to promote mung bean cultivation after the harvest of wheat. A mung bean genotype having maturity duration of 60-65 days and resistance to mung bean yellow mosaic virus is the demand of the farmers.

Breeding approaches

Genetic enhancement, up to now, has utilized standard hybridization, segregation, and whole plant selection techniques at research stations. However, pre-breeding of crop plants has also become necessary in recent years to broaden the relatively narrow genetic base of modern crop cultivars. Such broadening is needed to supply new kinds of traits, to bring in new levels of productivity and stability of performance, and to provide useful new qualities to food and feed products (Duvick, 1990).

In self-pollinated crops like wheat, a modified bulk population breeding method and limited back cross based on few smart crosses would be more logical for the recovery of transgressive segregants (Witcombe and Virk, 2001). Due to a multitude of environments occurring at farmers fields, especially in a country like India, participatory approach such as Participatory Varietal Selection (PVS) (Witcombe *et al.,* 2001) would be immensely beneficial. In PVS, varietal trials for selection are conducted on the farmers' field. This exposes the lines to the real environment and gives a better scope for selection. Since, farmers choice plays key role in selection, it ensures desired trade of traits of different crops. Following one such approach at Banaras Hindu University, farmers of district Mirzapur were able to select varieties providing better profitability (Ortiz-Ferrara, 2001). A new wheat genotype HUW 516 that was selected by the farmers of district Mirzapur for timely sowing in 1998-99 under Farmers-participatory research programme has gained significant area under reduced/zero tillage. This variety has higher yield, higher biomass and good grains and provides farmers, good quality grain as well as substantial soft straw.

Non-conventional approaches

The new scientific approaches of molecular tools could also be applied for developing improved varieties and crops that enable producers to maximize yields and quality but minimize chemical input and other production costs. These new methods will include more effective breeding strategies, and more comprehensive knowledge of microbial, insect, and crop genomic structures. Using somaclonal approach, the wheat team at Banaras Hindu University (Arun *et al.,* 2003) was able to obtain higher yield, earliness and resistance to spot blotch in wheat under conventional tillage. More cost-effective molecular markers must be developed, so as to improve the efficiency of gene identification and mapping.

CONCLUSION

In view of the increasing coverage under RCT's, crop improvement programmes need to be reoriented according to the demand of the changing situation. There is strong case for new breeding objectives, as in many environments under reduced tillage, suitable alternative are scanty. An efficient genotype having traits that could give added advantage to the growing plant can solve many of the problems and thereby enhance the chance of achieving greater profitability and sustainability. A clear understanding of the traits that need priority in breeding programmes of different crops is required to harvest the advantages of upcoming resource conservation technologies. Suitable amalgamation of both conventional and non-conventional approaches of breeding can help us to meet this challenge.

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Wheat Cultivars in Relation to Resource Conservation Technologies

Jag Shoran, Ravish Chatrath and A.S. Kharub
Directorate of Wheat Research, Karnal 132 001, Haryana, India

ABSTRACT : Zero-tillage has emerged as a successful resource conservation technology (RCT) for growing wheat in the rice-wheat cropping system. The technology is gaining repid acceptance by the farmers and currently some 1.5 million ha are grown adopting this practice. Questions have been raised as to the suitability of currently recommended cultivars developed for conventional tillage conditions for the zero-tillage system. Field evaluation of superior genotypes showed variable performance under conventional and zero-tillage conditions clearly indicating genotype x tillage interactions. Results of initial evaluation experiments raise a number of questions on the strategies for genetic enhancement in relation to resource conservation technologies and the need for an aggresive research program to take into account altered microenvironment.

INTRODUCTION

Sustainability of the rice-wheat cropping system is one of the most vital issues in Indian agriculture and in view of the increasing cost of inputs, stagnating yields, it is pertinent to reduce the cost of cultivation so that the farmers can get competent rates in the local as well as world markets. Zero-tillage has now emerged as one of the most successful resource conservation technology (RCT) and is presently spread to about 1.5 mha in the rice-wheat cropping system. There are two main components in the zero-tillage technology, the first and the foremost that has been taken care of is the perfected zero-tillage machine. The second one that warrants immediate attention is the the adaptability of a variety to zero-tillage. At present the popular wheat variety of the area is being tilled by zero-tillage machines. To harvest the gains from this technology it is important that an integrated rice-wheat research approach be adopted towards development of specific varieties suitable for zero tillage conditions.

SCREENING WHEAT GENOTYPES UNDER ZERO-TILLAGE CONDITIONS

To address these issues, a NATP funded project entitled "Evaluation of basmati rice and wheat genotypes for their response to tillage options and thermal tolerance in a system perspective" was undertaken at the Directorate of Wheat Research to evaluate and develop genotypes suitable for the rice-wheat system of Eastern India. In this project, over a period of three years approximately 800 advance bulks were evaluated in site-specific trials at over five locations. The superior genotypes identified from these trials were again evaluated in a network mode under zero-tillage conditions. It was observed that most of the genotypes gave variable performance under normal as well as zero-tillage conditions giving a clear cut indications of the presence of genotype x tillage. Approximately 40 genotypes were found suitable for zero-tillage in comparison to the best check over different locations (Table 1). Similarly, in a pooled trial under zero-tillage over five locations cultivar BW 1485 (61.3 q/ha) was the only entry that out yielded the best check PBW 343 (57.2 q/ha) in the north-western plain zone. In the north eastern plains zone entries NWZ-5 (51.8 q/ha), RAU 1 (51.4 q/ha), RAU 2 (49.2q/ha) and BW 1485 (48.1 q/ha) were at par to the best check HP 1731 (47.8 q/ha).

Table 1. Evaluation of wheat genotypes under normal and zero-tillage conditions at various locations

Location	Tillage	2001-02		2002-03		2003-04	
	options	Superior performing genotypes	Best check	Superior performing genotypes	Best check	Superior performing genotypes	Best check
PAU, Ludhiana	Normal	PAU 29 (60.87*), PAU 31 (59.06*), PAU 21 (58.15*), PAU 28 (58.15*) and PAU 36 (58.15*)	PBW 343 (53.77)	PAU 118 (63.4), PAU 117 (58.0) and PAU 115 (57.1)	PBW 343 (46.2)		
	Zero	PAU 64 (61.59*), PAU 31 (57.97*), PAU 67 (56.16*), PAU 28 (52.53) and PAU 50 (52.53)	PBW 343 (51.30)	PAU 118 (59.8), PAU 115 (56.2) and PAU 117 (53.4)	PBW 343 (45.3)		
RAU, Pusa	Normal	RAU-1, RAU-2, RAU-3, RW-127, RW-1 28	NW 1014	RW 11 (53.4), RW 9 (52.5), RW 16 (52.5) and RW 10 (50.7)	NW 1014 (43.7)	RW 16 (50.72), RW 46 (43.48), RW 43 (39.85), RW 10 (39.85), and RW 44 (36.23).	NW 1014 (26.74)
	Zero	19th ESWYT 36 (58.6), 31st IBWSN – 122 (56.8) and 31st IBWSN-29 (54.4)	NW 1014 (49.1)	RW 10 (54.0), RW 26 (53.6), RW 23 (53.4) and RW 46 (52.5)	NW 1014 (42.1)	RW-33 (54.35), RW-35 (50.72), RW-14 (43.48), RW-17 (43.48) and RW-22 (39.85)	HUW-234 (38.04)
IARI, New Delhi	Normal	DL 186(64.77*), DL 139(64.05*), DL 138(56.17), DL 265(55.71), DL 290 (54.26)	PBW 343 (41.12)	DL 266 (73.9), DL 265 (63.9) and DL 328 (59.5)	HD 2687 (57.2)	DL-535 (55.12*), DL-480 (53.85*), DL-509 (53.85*), DL-531 (52.76*) and DL-476 (52.40*)	HD2687 (46.83)
	Zero	DL 313 (49.51*), DL 297 (47.52*), DL 182 (45.16), DL 220 (44.98), DL 292 (43.52)	HD 2687 (35.09)	DL 266 (59.2), DL 265 (52.6) and DL 328 (52.3)	PBW 343 (46.3)	DL-535 (49.77*), DL-529 (48.96*), DL-480 (48.69*), DL-475 (48.23*), DL-476 (47.60*), DL-531 (47.14*)	PBW 343 (42.12)
NDUA&T, Faizabad	Normal	Entry 6 (60.22), Entry 23 (59.90), Entry 22 (59.63), Entry 47 (58.73) Entry 68 (58.73)	HP 1731 (50.23)	NWL 02-1 (56.33), NWL 02-9 (48.06), NWL 02-20 (46.14), NWL 02-15 (44.33) and NWL 02-37 (44.35)	HP 1731 (38.95)	NWL 03-7 (68.56), NWL 03-12 (66.75), and NWL 03-24 (66.52)	PBW 343 (65.67)
	Zero	Entry 38 (54.49), Entry 68 (52.23), Entry 29 (50.87), Entry 47 (50.19) Entry 62 (50.19)	K 9107 (45.29)	NWL 02-14 (43.8) and NWL 02-2 (39.8)	K 9107 (38.7)	NWL 03-7(55.99), NWL03-6 (54.86), NWL 03-12 (54.18), NWL 03-40 (54.18), NWL 03-18 (52.37)	PBW 343 (49.59)
DWR, Karnal	Normal	RWP 39 (77.61*), RWP 14 (76.81*), RWP 43 (61.59*), RWP 19 (58.41*) RWP 11 (52.90)	PBW 343 (51.88)	RWP 2170 (66.81), RWP 2391(54.86), RWP 2663 (52.32), RWP 2245 (49.78) and RWP 2463 (49.42)	PBW 343 (44.8 0)	RWP 2170 (61.52), RWP 2228 (57.31), RWP 2587 (53.27), RWP 2080 (50.33), RWP 2063 (50.12)	PBW 343 (49.96)
	Zero	RWP 36 (69.06*), RWP 63 (59.93*), RWP 39 (56.88*), RWP 18 (51.30*), RWP 5 (50.94*)	PBW 343 (45.22)	RWP 2170 (64.91), RWP 1705 (63.72), RWP 2991(54.61), RWP 1909 (53.72), RWP 1750 (52.49)	PBW 343 (46.3)	RWP 1849 (55.52), RWP 2040 (55.16), RWP 2245 (54.77), RWP 2068 (54.51), RWP 2467 (51.92)	PBW 343 (50.45)

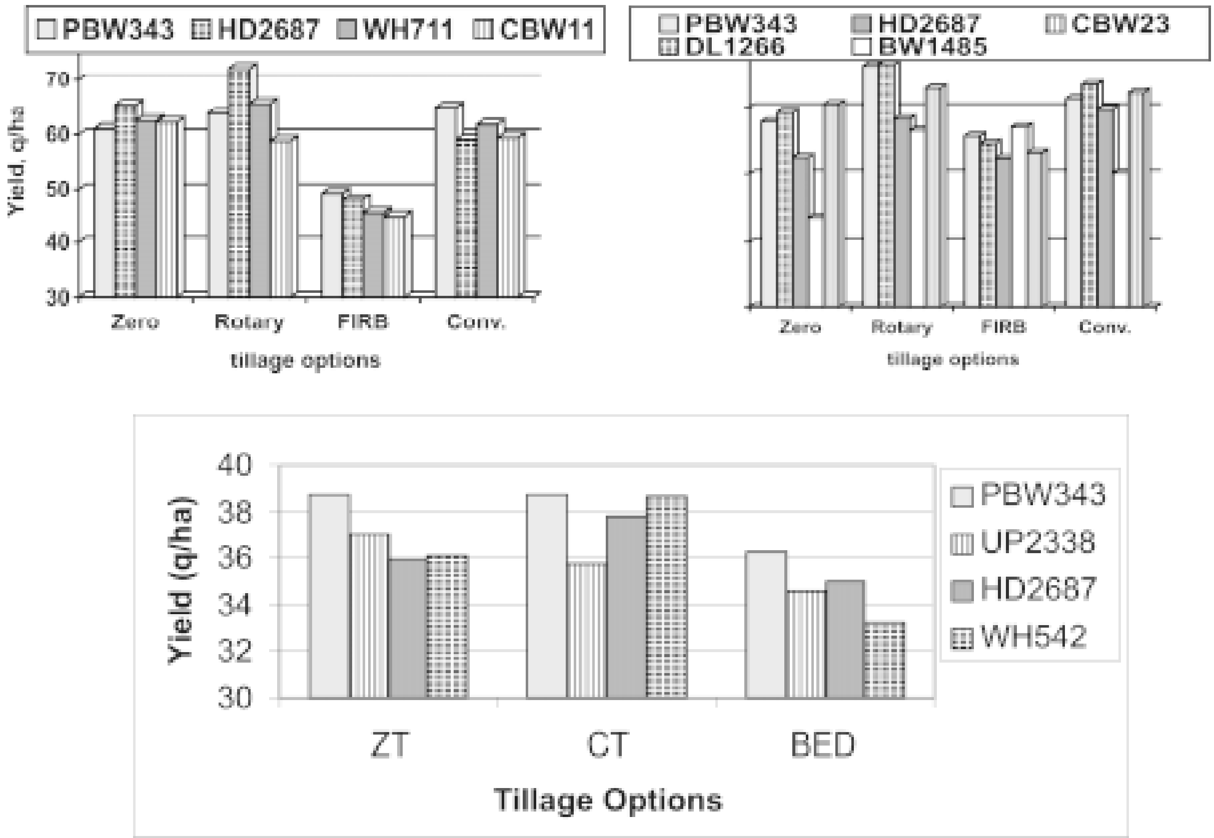

Fig. 1. Performance of varieties under different tillage options.

GENOTYPE X TILLAGE INTERACTION STUDIES

In an agronomical trial four varieties in 2001-02 and five varieties in 2002-03 were evaluated under four tillage options viz., zero, rotary, furrow irrigated raised bed system (FIRBS) and conventional tillage at the DWR, Karnal. There was significant difference in yield of different varieties under various tillage options. In 2001-02, wheat variety HD2687 performed better in zero and rotary tillage and PBW 343 in FIRB and conventional tillage as compared to other tillage options. The grain:straw ratio was high under rotary tillage conditions as it converted more biomass into grain compared to straw. On an average, root biomass was higher in raised bed and rotary tillage at different intervals but statistically all were at par. All the tillage options were at par in water storage capacity at different intervals.

In 2002-03 also, variety x tillage interaction was significant. BW1485, PBW 343, HD 2687 were at par and produced higher in zero and conventional, while PBW343, HD 2687 produced higher grain yield under rotary and DL 1266 was superior in FIRBS. On an average, root biomass was higher in rotary and raised bed. Varieties like BW 1485 which produced higher grain yield in zero tillage also had higher root biomass. Significant positive correlation was obtained between yield versus earheads/m^2, yield versus biomass, leaf area versus grains/earhead, root biomass vs grains/earhead and root vs shoot biomass at tillering, leaf area versus root weight.

It is believed that wheat genotypes with early vigour and better root system would perform better under zero-tillage conditions. Variability for root biomass accumulation and positive correlations between root length, root weight, biomass with grain yield have been observed.

Genotype x tillage interaction studies were also carried out in farmers' field where four wheat genotypes (PBW 343, HD 2687, UP 2338 and WH 542) were evaluated under zero and conventional tillage along with FIRBS. Experimentation over a period of two years has also confirmed the presence of genotype x tillage interactions.

In general, it was observed that PBW 343 did exceedingly well across the tillage methods whereas WH 542 and HD 2687 performed better under conventional tillage. It was also observed that the RCTs had a direct influence on the severity of disease, especially powdery mildew in wheat and as a result the powder mildew incidence was highest under FIRBS followed by conventional and was least under zero-tillage.

Thus, based on the research conducted in the last 2-3 years it seems imperative that breeding wheat genotypes for specific RCT will be very much required. It is necessary that selection for suitable plant type be initiated under zero tillage conditions from F_2 onwards. There is also a need to study the association of related parameters like root morphology, spread and their penetration with yield performance under zero tilled soils. Genotypic differences amongst wheat germplasm needs to be evaluated for root parameters and growth vigour for subsequent use in the breeding programme.

ISSUES ON BREEDING SPECIFIC GENOTYPES FOR TILLAGE OPTIONS

Some of the issues that need to be addressed in our future research are:

- Is it merely high yielding potential of a variety which makes it fit for growing under any RCTs?
- Validation for tillage x genotype interaction at multilocation testing
- Identification of traits including rooting pattern favouring specific RCTs.
- Need for testing diverse materials under different RCTs
- Need to develop suitable machinery for planting segregating generations under different RCTs?
- New emerging weeds, diseases and pest dynamics under different RCTs have to be looked while breeding suitable varieties.

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Transfer of Resource Conserving Technologies through Krishi Vigyan Kendras

A.K. Mehta and Randhir Singh
Zonal Coordinating Unit, TOT Projects (ICAR), PAU Campus, Ludhiana 141 004, Punjab, India

ABSTRACT : Rice-wheat cropping system made tremendous contribution in the food production of the country and economy of agrarian states of Punjab and Haryana. The productivity rate of this system have slowed down along with the associated damage to agro-ecosystem in the form of increasing problem of insect pest and disease, declining soil fertility and infestation of weed flora. Despite all efforts, it is not possible to wean the farmers away from this system because of high & stable profit and support price system. To sustain this cropping system, the Krishi Vigyan Kendras in these states conducted trials on some resource conservation technologies like zero-tillage sowing of wheat, bed planting, paddy straw management and use of Leaf Colour Chart for nitrogen management in paddy. The zero-till-seed-cum-fertiliser drill sowing of wheat gave a weighted average increase in yield of 6.4 percent in Haryana and 2.6 percent in Punjab over conventional method of sowing. It reduces the *phalaris minor* (a menacing weed of wheat) population by 30 percent and cost of tillage operations from Rs. 2,000 to 500/ha. The sowing of wheat and gram on beds also increased a weighted average yield of 2.7 and 23.1 percent, respectively, with a saving of irrigation water in Kaithal and Sonipat districts of Haryana state. Application of nitrogen by using Leaf Colour Chart at number 4 in paddy with recommended plant population saved 10 kg nitrogen/ha over recommended level of nitrogen without affecting the yield of the crop in Kaithal district. The incorporation of paddy straw in the succeeding crop of wheat saved 62.5 kg of nitrogen/ha without any reduction in yield of wheat in Gurdaspur district of Punjab state.

INTRODUCTION

Rice-wheat system is critical to the South Asian food security. Over a billion people depend on this system for their food. This system is practised on 13.5 million ha of land in Indo-Gangatic plains. Despite its more or less assured yield and comparative profitability over other competing crops/crop rotations, continuance of paddy-wheat cultivation over the years has resulted in severe implications for resources. The most common consequences of this are:

- Deficiencies of nutrients in the soil.
- Depletion of water resources in areas of good quality underground water.
- Salinity and sodicity buildup in canal irrigated areas.
- Hard pan formation and reduced organic matter content in the soil.
- Increased use and reliance on inorganic fertilizers and chemicals.
- Increased cost of cultivation especially tillage cost.
- Late sowing of *rabi* crops.
- Degradation of ecosystem.

As a result of these factors, the sustainability of paddy-wheat over a longer period is in question. Keeping in view the importance of this sequence for food security and livelihood of larger number of growers, there is an urgent need to develop and adopt some resources conservation techniques for its sustainability. KVKs of Punjab and Haryana have identified some technologies, such as zero-tillage, bed planting, paddy-straw composting, use of Leaf Colour Chart in paddy to overcome the problems. The KVKs are making efforts to make these techniques popular among the farmers for their adoption.

ZERO-TILLAGE

Zero-tillage is the direct placement of seed into the soil without any land preparation. In areas where the soils are fine textured, poorly drained and land preparation is difficult, it often results in a cloddy tilth. The seed germinates into the moist soil and the roots follow the saturation fringe as it drains down the soil profile. Moisture level must not be too high as oxygen is needed for healthy root growth (Mehta and Singh, 2002).

Use of zero-tillage in wheat was promoted to overcome the problem of resistance of *phalaris minor* against the herbicides. In zero-tillage system, inter-row space is not disturbed and germination of *phalaris minor* is comparatively less. Weed management and crop establishment are high priority thrust areas for wheat cultivation. *Phalaris minor* is an important weed of wheat crop. The germination of *phalaris minor* depends on two factors: (i) time of sowing of wheat; and (ii) tillage disturbance of soils. Zero till drill not only disturbs the soil least but also advances the sowing of wheat, which is beneficial for wheat crop. Zero-tillage not only reduces the weed population and cost of cultivation but also reduces lodging of the crop.

Due to resistance in *phalaris minor* against popularly used weedicide Isoproturon, the population of this grassy weed increased tremendously. For enhancing the productivity and sustainability of the rice-wheat system without affecting the natural resources, zero-tillage is becoming popular amongst the farmers. The increasing cost of cultivation is continuously making the farming business less profitable as there is a little scope to further increase the yield of wheat to a substantial extent. Only way to increase profitability is by reducing the cost of cultivation. The land preparation after paddy for wheat sowing involves huge expenditure as 5-6 cultural operations are to be performed for seedbed preparation. In zero-tillage, wheat is directly sown without disturbing the soil, which increases yield and lowers the cost by saving fuel, water, herbicides and labour.

Zero-tillage trials were conducted by 16 KVKs (6 of Haryana and 10 of Punjab) with the objective to make farmers aware of the use of zero till drill for sowing of wheat. The weighted average yield of wheat indicated that the wheat sown by zero-tillage registered an increase in yield by 6.4 percent in Haryana and 2.6 percent in Punjab over conventional method of sowing (Table 1).

Reduced Weed Population

Data was recorded by KVK Kurukshetra, Kaithal, Panipat, Ferozepur, Kapurthala, Nawanshahar and Gurdaspur on the population of *phalaris minor* as affected by adoption of zero-tillage technology in wheat. The data given in Table 2 indicates that there was 30 percent less population of *phalaris minor* in wheat sown by zero-tillage machine as compared to traditional sowing of wheat.

Economic analysis of zero-till seed-cum-fertilizer drill sowing of wheat

In Punjab, the increase in yield was less but the cost incurred on sowing operation was reduced by 70 percent with sowing of wheat with zero-tillage machine. It was further observed that under heavy soils, if the last irrigation to Basmati is applied about one week before its harvest during early November, the wheat crop can be sown with zero-till drill even without applying pre-sowing irrigation and by this way expenditure on pre-sowing irrigation can also be saved.

Table 1. Performance of zero-tillage in wheat at different locations

District	Year	No. of farmers	Area (ha)	Av. Yield (q/ha)		Percent increase over conventional tillage
				Zero-tillage	Conventional tillage	
HARYANA						
Kurukshetra	1998-02	215	110.2	51.3	46.8	9.6
Kaithal	1997-04	108	115.3	45.8	42.8	7.0
Panipat	1999-04	133	62.5	49.7	46.1	7.8
Faridabad	2001-03	72	124.0	47.3	43.9	7.7
Rohtak	2002-03	18	56.0	47.2	46.7	1.1
Sonipat	2002-04	16	22.0	46.7	45.1	3.5
Total/Wt. Av.		562	490.0	48.1	45.2	6.4
PUNJAB						
Abohar	2002-03	92	36.8	44.5	42.4	5.0
Bathinda	2002-04	26	77.4	45.4	44.5	2.0
Faridkot	2002-03	35	79.0	40.8	41.3	-
Ferozepur	2000-03	41	108.4	45.4	45.1	0.7
Gurdaspur	2000-03	52	47.7	46.0	45.8	0.4
Kapurthala	1999-04	57	179.7	49.9	48.3	3.3
Nawanshahar	2001-03	38	59.6	45.8	44.5	2.9
Patiala	1999-04	76	225.0	45.9	45.3	1.3
Sangrur	2002-03	176	144.8	51.1	49.8	2.6
Hoshiarpur	2003-04	10	20.0	50.5	50.3	0.4
Total/Wt. Av.		603	978.4	46.9	45.7	2.6

Table 2. Average population density of *phalaris minor* in wheat at different locations

District	Year	Population of weeds/m^2		Low weed density over conventional method (%)
		Zero-tillage	Conventional method	
Kurukshetra	1998-01	504	709	28.9
Kaithal	2002-03	122	171	28.1
Panipat	1999-01	826	1052	21.5
Ferozepur	2000-02	110	264	58.3
Kapurthala	1999-02	11	70	84.3
Nawanshahar	2001-02	41	59	30.5
Gurdaspur	2001-02	39	42	7.1
Mean		**236**	**338**	**30.2**

KVK Nawanshahar worked out the cost of tillage operations of wheat crop sown by zero-till-seed-cum-fertilizer drill. It is inferred from the result that the saving in tillage operation was found to the extent of Rs. 2,300/ha (Table 3). The saving was not only in cost of tillage operation but also obtained some additional yield and weed suppression. These results are very encouraging and farmers are now convinced of the benefits of this technology.

Table 3. Saving in land preparation and sowing operation – Nawanshahar

Operation	Conventional method		Zero-till Drill		Saving over conventional (Rs./ha)
	Tillage operation (no.)	Expenditure (Rs.)	Tillage operation (no.)	Expenditure (Rs.)	
Harrowing @ Rs.525/ha	2	1,050	-	-	1,050
Ploughing @ Rs.375/ha	2	750	-	-	750
Planking @ Rs.250/ha	2	500	-	-	500
Sowing @ Rs.375/ha	1	375	1	375	-
Total	7	2,675	1	375	2,300

BED PLANTING

To reduce water use, conserve rain water and improve productivity, the system of raised bed planting of crops may be advantageous in up and low land situations. Raised bed planting is reported to be beneficial in the fields where herbicide resistant weeds are becoming a problem. This crop establishment system also facilitates crop diversification and inter-cropping such as wheat with chickpea, mustard with sugarcane, pigeonpea with sorghum or green gram, etc. Weeds between the beds can be controlled mechanically in early stage of crop, thereby reducing herbicides dependence.

The farmers participatory trials on bed planting were conducted on wheat (Cv PBW-343) in Kaithal and Sonipat districts of Haryana and Una district of Himachal Pradesh state on twenty nine farmer's fields. The result indicates that there was an increase in weighted average yield of wheat by 2.7 percent in bed planting over conventional method of sowing (Table 4). Though the cost of cultivation is higher in bed planting of wheat but there was a saving of 10 to 40 percent in irrigation water depending upon the soil type.

Table 4. Performance of bed planting in wheat during *rabi* 2002-03

District/KVK	No. of farmers	Area (ha)	Av. yield (q/ha)		Percent increase over conventional tillage
			Bed planting	Conventional tillage	
Kaithal	20	8.0	47.0	42.5	10.6
Sonipat	4	4.0	48.6	47.8	1.7
Una	5	11.3	33.0	28.0	17.9
Total/Wt. Av.	29	23.3	40.5	39.4	2.7

Another trial on gram was laid out with three planting methods i.e. flat bed sowing (2 rows/bed) and bed sowing (three rows/bed) and two irrigation levels i.e. no irrigation and one irrigation in Nawanshahar district. It is revealed from Table 5 that bed sowing method in gram significantly improved the grain yield whereas one irrigation applied to the crop significantly reduced the grain yield in rice-gram system. The crop sown on beds (2 rows or 3 rows) gave significantly more grain yield than flat sowing. The crop grown on bed with 3 rows and with no irrigation gave the highest yield of 25.7 q/ha. Whereas interaction between method of sowing and irrigation level was found to be non-significant (Mehta and Singh, 2003). This clearly established that bed sowing has a definite advantage over flat sowing.

Table 5. Grain yield (q/ha) of gram as influenced by planting method and irrigation level

Sowing Method	Irrigation Level		Mean
	No irrigation	One irrigation	
Flat (row to row 30cm)	20.6	16.0	18.3
Bed (2 rows) (37.5 cm bed + 30cm furrow)	23.7	22.2	22.9
Bed (3 rows) (37.5 cm bed + 30cm furrow)	25.7	22.3	24.0
Mean	23.3	20.2	-

LSD (P=0.05) Sowing Method = 1.4 ; Irrigation = 1.1; Interaction - NS.

PADDY STRAW MANAGEMENT IN RICE-WHEAT CROPPING SYSTEM

The practice of burning of left over paddy stubble is most commonly followed with the sole objective to reduce the cost of seed bed preparation for sowing the succeeding wheat crop. On the other hand, this practice not only reprieve the soil of recycling of left over crop residues but also causes environmental pollution. The paddy and wheat residues amount to as much as 7-8 tons per ha per year. The residues, when burnt during land preparation, generate CO_2, which pollutes the air, deprives organic matter of soils and reduces supply of fodder for livestock (Rathee *et al.,* 2004).

An on-farm trial was, therefore, conducted to determine the beneficial effects of left-over rice straw over its burning on the yield of succeeding wheat crop at Gurdaspur by the KVK. The incorporated paddy straw had an edge over the burning of straw at all levels of nitrogen in respect of grain yield of succeeding wheat crop. It was interesting to note that grain yield of wheat with the application of 125 kg N/ha supplemented with incorporation of paddy straw was at par when paddy straw was burnt along with application of 187.5 kg N/ha. So, with the help of incorporation of paddy straw, the additional nitrogen of 62.5 kg/ha in comparison to when it was burnt can be saved (Table 6).

Table 6. Effect of rice straw on succeeding crop of wheat at Gurdaspur during 2001-02

Nitrogen rates (kg/ha)	Wheat grain yield (q/ha)	
	Incorporation of paddy straw	Burning of paddy straw
62.5	51.7	45.1
125.0	53.8	50.2
187.5	54.1	53.7

LEAF COLOUR CHART BASED NITROGEN MANAGEMENT IN PADDY

Nitrogen (N) fertilizer is one of the major input in rice production. Inadequate or excessive amount or improper timing of nitrogen application may lead to large nitrogen losses and poor nitrogen-use-efficiency in rice fields. New tools are needed to synchronize N application with crop demand and minimize nitrogen losses to the environment. Leaf Colour Chart is simple and inexpensive tool that could improve farmers decision making process in nitrogen management for rice. Leaf Colour Chart is a tool that helps farmers in deciding the right time of N application to paddy crop. It measures leaf colour intensity, which is related to leaf N status. The rice crop is transplanted with a basal dose of 20 kg. urea per acre. The reading is taken from 14th day after transplanting till panicle initiation. The last reading is taken when the crop just starts to flower. Select at least 10 disease free rice plants or hills in a field with uniform plant population. Under shade, compare the colour of the youngest fully expanded leaf of the selected plant or hill with the colour strips of the chart. If more than five leaves read below a set critical value (LCC4), apply 25 kg urea/acre. Repeat the process every 7-10 days and apply N as needed.

The on-farm trials were conducted at three locations in Kaithal district to introduce and promote Leaf Colour Chart based nitrogen application in paddy (Cv HKR-126) during *kharif* 2002.

Table 7. LCC based N management in paddy at Kaithal

Treatments	N used through fert. (kg/ha)	Grain yield (q/ha)			
		Kaithal	Seewan	Bhuna	Average
LCC_4 based N + basal N with 33 pl/m^2 (LCC-60-60-25)	140	47.5	67.0	65.0	59.8
Recommended fertilizer (150-60-60-25)	150	45.0	70.0	65.0	60.0
LCC_4 based N + basal N with 20 pl/m^2 (LCC-60-60-25)	140	43.0	68.5	62.0	57.8
LCC_4 based N without basal N and with 33 pl/m^2 (LCC-60-60-25)	120	43.0	66.0	62.0	57.0

LCC_4:60:60:25 – NPK and Zn kg/ha.

The results indicated that the application of nitrogen based on Leaf Colour Chart at number 4 with recommended plant population (N-33 pl/m^2) gave the average yield of 59.8 q/ha which is at par with the recommended dose of fertilizer (60.0 q/ha) but there was a saving of 10 kg N/ha in the former treatment. It was also observed from the data that there was no additional effect of basal application of nitrogen fertilizer in paddy.

Feedback from farmers:

- Presence of loose paddy straw after combine harvesting of paddy, create obstacle in smooth running of zero-tillage machine.
- Moisture is a limiting factor for zero-tillage. If the moisture is low at sowing time, the germination of wheat will not be optimum.
- Continuous sowing of wheat over the years by zero-tillage reduced the grain yield of wheat.

- The seed rate of wheat sown under zero-tillage should be on higher side (45-50 kg/acre) as compared to conventional tillage.
- Broad leave weeds like *jangli palak, metha* etc are more under zero-tillage sowing of wheat.
- Bed sowing method of wheat is less profitable than zero-tillage sowing of wheat.

FUTURE RESEARCH NEEDED

Studies are required to be continued to evaluate the effects of zero-tillage in change of weed flora, soil health, physical properties of soil, attack of insect pest, incidence of nematode, presence or absence of other bio-agent which are very important to see its long term effect on paddy-wheat cropping system.

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Ripples of Changes Through Zero-Tillage Technology for Enhancement of Productivity and Conservation of Resources: Experiences of K.V.K. Bahraich

M.P. Singh and Vinay Kumar
Krishi Vigyan Kendra, Bahraich 271 801, Uttar Pradesh, India

ABSTRACT : Eastern Uttar Pradesh has an area of 2.9 million ha under rice-wheat cropping system within 25 districts of the state. The productivity of the system is only 3.5 to 4.5 t ha^{-1} against the potential of 8.0 to 10.0 t ha^{-1}. Further, the yield of wheat is either stagnating or showing downward trend mainly because of delayed sowing after harvest of rice. Bahraich , a district of U.P., is no exception and has its productivity below state average. Wheat is grown in nearly 62 percent of total cropped area of 3,05,000 ha i.e. nearly 1,90,000 ha with an average productivity of 2.50 t ha^{-1} against the state average of 2.76 t ha^{-1}. Wheat is mainly grown in paddy harvested fields. This paddy crop is grown in heavy and low-lying soil, where either water stagnates for a long period or tilth condition is not achieved at appropriate time of wheat sowing. Farmers also grow long duration crop of paddy which is harvested in late November or even some times in December. This delay hampers the sowing of wheat and the yield reduces significantly. This low yield can be made up with the use of zero-tillage technology (ZT) by advancing the time of planting at a little higher moisture content without waiting for optimum tilth condition required for conventional tillage.

It has been demonstrated on 22 participating farmers' field through field trials on zero-tillage technology in 52.2 ha during *rabi* 2001-2002, on 39 farmers field in 159.8 ha during 2002-2003 and on 121 farmers field in 410 ha during 2003-2004 that wheat can be successfully grown without tillage using zero-till-ferti-drill. The findings have established that wheat sowing can be advanced 8-15 days in timely sown and 15-20 days in late sown condition over conventional tillage with increase in yield ranging from 2.30 to 4.15 q ha^{-1} in addition to saving in field preparation cost to the tune of Rs 424 to 1635 ha^{-1}, economising seed rate 20-30 kg ha^{-1} worth Rs 400-600 with 20-27% less irrigation. Besides, reduction of *phalaris minor* intensity from 14.2% to 32.73% is recorded as inherent advantage of ZT.

INTRODUCTION

Resource conservation technologies are being practised over the whole world since time immemorial which were basically limited to broadcasting of seed in rainfed condition but the yield from this technique was not enough to feed the increasing population over the time. During recent past the increasing pressure of population compelled the scientists to increase food production per unit of inputs. This required better and timely management of improved agricultural practices. The scientists analyzed various factors and constraints responsible for low yield. Placement of seed and fertilizer is one of the causes. Pantnagar University took the initiatives and developed zero-tillage technology to place seed and fertilizer at proper depths in a little higher moisture content without tilling the field. This technique was supposed to increase the yield and reduce the cost of cultivation.

Directorate of Extension of Narendra Deva University of Agriculture and Technology Narendranagar (Kumarganj), Faizabad (NDUAT) sharing the responsibility of dissemination of improved technology in 25 districts of Eastern Uttar Pradesh, analyzed the constraints of low productivity of various crops and found that eastern U.P. is mainly a rice-wheat (R-W) growing belt, where productivity is below 6 t ha^{-1} against the potential of 18 t ha^{-1}. The Directorate held a meeting of scientists working in Krishi Vigyan Kendra (K.V.K.) and Krishi

Gyan Kendra (K.G.K.) and finalized a strategy to disseminate the technology through K.V.Ks and K.G.Ks. Bahraich is one of the extension centre of the NDUAT which is responsible for the implementation of the programme.

BACKGROUND OF BAHRAICH DISTRICT

Location

Bahraich lies in the NE Plain and Tarai belt of U.P. from 27^{o} 24' to 28 ^{o} 24' N and 81^{o} 30' to 83^{o} 13" E with MSL 123.2 m and has rice-wheat, arhar, and rice-lentil as dominant crop production systems. It has 19 blocks and 7 tehsils and 1238 gram sabhas. Its boundaries touch Nepal in north, district-Gonda in east-south, Barabanki in south and Lakhimpur-Kheri and Sitapur in west. District economy is based on agriculture. Farmers' holdings are small (90% small farmers (3,37,726) occupy 65% of land (2,16,245 ha with less than 0.65 ha) of holding size. Ten percent farmers (33,876) have 35% of land with an average holding of 3.46 ha.

Temperature and Relative Humidity

Temperature ranges from 45^{o}C in June to 3^{o}C in January with yearly maximum average of 35^{o}C and minimum average of 15^{o}C. Relative humidity varies from 43-60% during dry months of April and May to 99% during monsoon.

Rainfall and Irrigation

Irrigation facilities of district are very poor (31% during *Rabi* and 0.5% during *Kharif* is irrigated). The average rainfall of the district is about 1100 mm out of which 72% occurs during 45 days of July and August each year. Most of the irrigation in the district is done by diesel pumping sets owned by the farmers. Water table ranges from few metres to ten metres. Generally, tubewells are shallow in nature and installed in sand strata with sand strainer.

Cropping pattern

Total geographical area of the district is 6,87,700 ha, out of which 5,46,077 ha is actually cultivable. Crop intensity is 168. Paddy is grown in 65.5% area followed by maize and arhar in *Kharif*. During *Rabi*, wheat occupies 62.5% of area which is mostly grown in paddy harvested fields. Lentil, next to wheat, is also an important crop sown in paddy harvested fields and occupies nearly 15% of cropped area.

Agro-eco situations

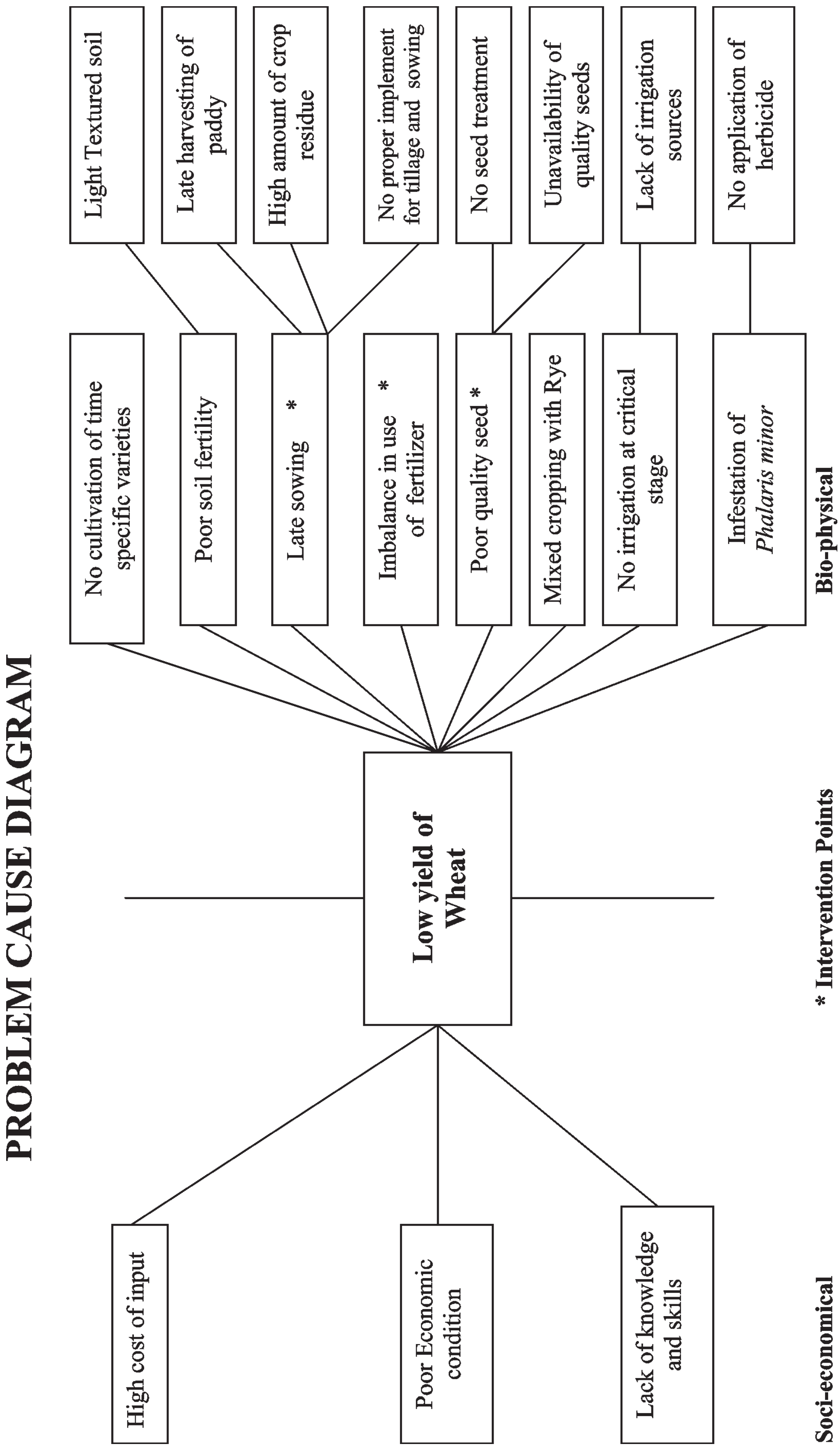
Mainly three agro-climatic situations prevail in the district which are flood-prone condition, dry and rainfed and water logging conditions. These all are scattered in different pockets of the district.

Soils

The soils are loam and sandy-loam but suitable for growing almost all significant crops. In general, soil is new and deep but lacks in organic content (0.2%).The availability of nutrients like nitrogen and phosphorous is low but for potash it is medium. Soils are deficient in micronutrients like zinc, copper, sulphur, iron, manganese, etc.

The problems

Bahraich is considered a low wheat productivity district of U.P. The scientists of K.V.K. analyzed the problems and their causes which are presented.



Among the various causes, late sowing of wheat is prominent for which farmers are helpless due to non-availability of tilling condition of the field, late harvesting of preceding paddy crop or high moisture content for longer period at the time of sowing wheat, long time taking process of land preparation due to 30-45 cm high anchored stubble amounting to 5-6 t ha^{-1} in combine harvested field, etc.

Solution

Introduction of 2T technology was considered as a way to overcome many of the problems faced by farmers in enhancing productivity.

Strategies

A strategy was formulated according to which every extension centre i.e. Krishi Vigyan Kendra (K.V.K) and Krishi Gyan Kendra (K.G.K.) working under the Directorate of Extension in different 25 districts of Eastern U.P. will work as a resource link and centre for transfer of technology for the farmers. At each centre, a team of scientists was constituted consisting of agronomist, agricultural engineer, plant protection and weed expert to implement the programme. This team was given the responsibilities for speedy transfer of Z.T. technology, its popularization and adoption among the farmers. The team accordingly short-listed steps for this task which included introduction of technology, sensitization and convincing of farmers for adoption, repeated persuasion, training, demonstration, trials on farmers field, organization of exposure visits, camp, meetings, *Gosthies,* zero-tillage-fair and imparting skills.

Implementation

During first year the programme was implemented within 10 km, during second year within 30 km and during third year full district and nearby area.

During *Rabi* 2001-2002 the technology was tried for introduction among the farmers. The farmers were not convinced with the technology and they wondered how it would be possible to grow wheat without good field preparation. It became very difficult to convince them that it is possible to grow wheat crop without land preparation. During the first stage team had prompted the farmers to divide their field in two parts. The first part for opting zero-tillage and the second one for their own conventional practices. A MOU was framed with the condition that if the yield in Z.T. is less than C.T. yield then the team will meet out short-fall.

The second problem scientists faced was the lack of operational skills in the farmers to use the machine as well as its calibration. To resolve the problem and to acquaint farmers with new technology a plan was devised through which live demonstrations and trainings were given to the farmers on operational skill, hitching skills and calibration of Z.T. machine, etc.

Demonstrations

At the start inspite of all efforts and continuous persuasion only one farmer agreed to sow his field without land preparation in the first fortnight of November and that too to sow in reduced tillage (R.T.) condition i.e. after two passes of harrowing and planking. When ten days elapsed and germination was completed, rest of the farmers started coming forward without much hesitation to sow their field without any preparatory tillage. With all efforts, energy and resources the team was able to sow 50.2 ha wheat crop on 22 farmers fields. This was a great success of the team and laid foundation for the next coming year.

During 2002-03 two more Z.T. machines were engaged for sowing of wheat. But this year more wide range of farmers and area was adopted. In all, 39 farmers participated as experimented in 159.8 ha. The range further increased in 2003-04 to the remote places as K.V.K. scientists approached them. The farmers also themselves started approaching K.V.K. The rush increased and K.V.K. was compelled to refuse the farmers to supply the machines. Ultimately farmers started purchasing this machine. Some of the big farmers came forward and purchased their own machine. Farmers at remote places transported machine up to 90 km and sowed their crop. The average distance that farmers covered to come to K.V.K. for the transportation of machine was 35 km during 2003-04. Farmers from the nearby district also came and transported machine to their villages for sowing of wheat.

The change was revolutionary. Many farmers purchased the machine from U.P. State Agro Industrial Corporation, some from private manufactures and others from private sellers in Bahraich.

It was observed that some unemployed rural youth belonging to Punjab come every year in Bahraich to seek employment opportunities here. They come with tractor and its implements, do agricultural operations like combine harvesting and preparatory tillage during harvesting season of paddy and the sowing season of wheat, earn money and go back. During 2003-2004 they came with Z.T. machine and combine harvester and did harvesting of paddy with combine harvester followed by sowing of wheat with Z.T. thus created lot of employment opportunities for the young in Bahraich. In all 410 ha area was sown on 121 farmers field (Table 1).

Impact of the Technology

With persistent efforts the team of scientists could get success in convincing 22 farmers for zero-tillage sowing of wheat during *Rabi* 2001-2002 and only 50.2 ha could be sown. Gradually, viewing the success, next year it gained momentum and more and more farmers came forward for the adoption of technology during *Rabi* as well as during *Kharif*. The results are presented in Table 1 and Following important impacts are worth mentioning.

Advancement of wheat sowing

It was recorded that with the use of Z.T. machine 10-15 days make-up was possible by preponing the sowing of wheat. The average yield recorded was 10.67, 6.10 and 8.69% higher in 2001-02, 2002-03 and 2003-04 which was 3.68, 2.35 and 3.8 q ha^{-1} higher than C.T. respectively.

Increase in number of participating farmers and area

During the implementation period of three year it was recorded that number of participating farmers increased 5.5 times over the first year (nearly 450%) and the area increased by 716%.

Seed Saving

During the three years of implementation of the Z.T. programme participating farmers reported that they were using 125 kg ha^{-1} seed in normal seeding time and up to 150 kg ha^{-1} in late sown field with conventional tillage practice but with Z.T. they used only 100 and 120 kg ha^{-1} seed in both the conditions respectively. Thus a saving of 20-30 kg ha^{-1} seed was recorded with the use of Z.T. In 620 ha a total of 155.0 q seed was saved which costs about Rs. 1,86,000. Similar observations were recorded for fertilizer up-take efficiency.

Saving of Irrigation water

Participating farmers reported that 20-25% of irrigation water in terms of pumping set hours was saved in first irrigation and also upto some extent in the subsequent irrigations. Thus during three years of programme 6231 diesel-pumping set hours were saved worth Rs. 3,11,550.

Saving in preparatory tillage cost

The direct saving of the participating farmers out of the wheat crop, during 3 years sowing of 620 ha ZT, recorded about 6665 tractor-hours or 31.82 liters of diesel ha^{-1} worth about Rs. 4,53,753. This is a huge saving and has direct bearing on the economic condition of the farmers.

Control of weeds

The most notorious weed that created havoc to the farmers is *phalaris minor*. It has been observed by participating farmers that there was sharp decrease in the population of this weed in wheat crop which was sown with Z.T. During three years of demonstration, the population decrease observed was about 36.61%. It was also observed that the fields which were late sown (after December 15) with conventional tillage practice were having less population of *phalaris minor* than Z.T field because during field preparation most of the weeds are destroyed in CT methods while it was not so in ZT, but removal of weeds was easier in ZT as compared to CT because of the advantage of line sowing. The plants which were similar in features to that of wheat but were standing out of lines and in the unplanted location between two rows were easily identified as *phalaris minor* and their uprooting was found easier. Thus, this weed was identified and removed very easily without much efforts within 25-30 days after sowing. It was also observed that women farmers were happy with Z.T. sowing as they do mostly intercultural operation for up-rooting of this weed. They were found having no difficulties in the identification of this weed. It was considered a great achievement of the technology.

Adoption of technology for crops other than wheat

During the three years of implementation farmers viewed the progress of wheat and adopted the technology for other crop also. Farmers adopted the technology for pigeon pea, lentil, paddy, maize, okra, and urdbean.

Benefit-Cost (B:C) ratio

The performance of Z.T. demonstrations revealed that benefit-cost ratio for wheat varied from 1.02 to 1.86 depending on sowing time and field condition while for conventional tillage practices it varied 0.93 to 1.56 which is a fair indicator for the superiority of the technology. This also confirmed that in late sowing condition (first fort-night of January) Z.T. farmers did not suffer loss while C.T. farmers suffered a loss of about 7%. Over all average B:C of Z.T. recorded was 30% higher than C.T.

Unit cost of production

The participating farmers reported that the 'unit' (Rs q^{-1}) cost of wheat production increased if the sowing of wheat was done after 30th November each year in both the methods but it recorded always higher for C.T. The unit cost of production for November sown was recorded lowest i.e. Rs 307 and Rs 360 for Z.T. and C.T. respectively while same was higher for January sown wheat i.e. Rs 537and Rs 665 q^{-1} for Z.T. and C.T. respectively. Thus Z.T. demonstration recorded 16.4% less unit cost of wheat production which established the trust of farmers in ZT.

Higher yield gain

The yield recorded by participatory farmers revealed that during three years Z.T. planted crop performed better than C.T. On an average yield gain was 10.67 (3.68 q ha^{-1}), 6.10 (2.35 q ha^{-1}), and 8.69% (3.8 q ha^{-1}) higher over C.T. during 2001-02, 2002-03 and 2003-04 respectively.

Table 1. Activities covered for dissemination of Z.T. technology in Bahraich district

Particulars		2001-02	2002-03	2003-04
No. of participating farmers		22	39	121
Area (ha) sown by Z.T.		50.2	159.8	410
No. of farmers who adopted the technology in the following years too.		-	21	53
No. of farmers who adopted ZT for *Kharif* season (paddy, maize, etc)		-	7	13
No. of farmers who adopted technology as profession (entrepreneurship)		-		15
Availability of machine		1	3	18
Demonstrations conducted by KVK, Bahraich in nearby districts				
Crop Wheat	Barabanki		6(18.0)	19 (33.0)
	Gonda		-	7 (25.0)
	Shravasti		-	7 (25.0)
Crop Soybean	Barabanki		-	2 (6.4)
Employment opportunity generated within district. (15 machines have been purchased by the farmers so far. Each machine generates 600 mandays each year. Total mandays = 600x15=9000)		600	1800	9000
Saving of the farmers (Rs.)		2,00,800	6,39,200	11,20,000
Sowing of crops other than wheat (ha)				
Paddy			7.1	2.4
Arhar			4.4	2.2
Okra			1.0	1.0
Urd bean			0.4	0.8
Maize			2.4	7.0

Future prospects of Z.T. Technology

Bahraich is mainly agricultural district having 1340 revenue villages. Rice-wheat is main cropping system which occupies nearly 1,90,000 ha. If farmers adopt Z.T. in 50% area i.e. nearly 95,000 ha for sowing of wheat through ZT then nearly 1000 machines will be required creating employment opportunity of nearly 88000 mandays for farmers and rural youth.

Besides, manufacturer, paint-industries, transportation industries, mechanic/repairer and dealers will get employment opportunities.

Attitude of farmers

A questionnaire prepared by NDUAT was used to find out attitude, level of satisfaction, constraints faced by the farmers in adoption of the Z.T. technology, and knowledge level of farmers after adoption of technology.

Six sites were purposefully selected randomly where farmers have used Z.T. technology. A total of 100 respondents (farmers) belonging to these sites constituted the sample for this study. A scale consisting 20 attitude statements, 23 knowledge statement, 22 constraints statements and 20 statements for level of satisfaction was used for this study. Half of statements were for favourable (positive) and half for unfavorable (negative) response. The five columns represent continuum of 'agreement' to 'disagreement'. The five points on the continuum were 'strongly agree', 'agree', 'undecided', 'disagree' and 'strongly disagree' and with weightage of 5,4,3,2 and 1 for positive and with 1,2,3,4, and 5 for negative statements respectively.

The scale for finding out the mentioned factors towards Z.T. technology was then administered to the respondents to obtain their response to each of the statement in term of their own degree of agreement or dis-agreement

The brief results of the study are presented and discussed below.

Attitude

Table 2 shows that a majority, 49.92 percent of the respondents expressed highly favourable attitude towards Z.T. followed by favourable attitude (34.64%). Only 12.20% of farmers were neutral followed by 2.82% unfavourable farmers. Highly unfavourable farmers were negligible with a magnitude of 0.42%. Thus it is clear that Z.T. has a bright future in Bahraich as 84.56% were found in favour.

Table 2. Distribution of respondents based on of selected attributes scores towards zero tillage technology

Category of respondents	Respondents attribute			
	Attitude	Knowledge	Constraints	Level of satisfaction
Highly favourable	49.92	57.54	46.14	50.06
Favourable	34.64	28.64	17.43	32.19
Neutral	12.20	12.55	17.45	11.51
Unfavorable	2.82	1.05	8.53	3.26
Highly unfavorable	0.42	0.22	10.45	2.98
Total	100	100	100	100

Status of knowledge of Z.T. farmers

Study revealed that 57.54% of the farmers became almost perfect in handling and operational skills of Z.T. while 28.64% gained workable knowledge. 12.55 percent of the farmers were recorded as neutral about Z.T. It is also revealed that 1.27 percent of the farmers responded negatively regarding knowledge status. Probably these were farmers who neither operated Z.T. nor had seen its working in the field and got sown their field by other operators.

Constraints faced by Z.T. farmers

Out of 100 farmers interviewed for 20 constraints listed in questionnaires, 63.57 percent of the farmers viewed that these constraints were not serious or so serious. 17.45 percent of the farmers opined that these were serious while remaining 8.53 percent viewed as very serious and rest 10.45 disclosed that these constraints were most serious for the adoption of Z.T. technology.

Level of satisfaction

It is observed that 50.86 percent of the Z.T. users were highly satisfied, 32.19 percent were satisfied, 11.51 percent neither satisfied nor dissatisfied, 3.26 percent dissatisfied and 2.98 percent highly dissatisfied.

It could be concluded that Z.T. technology is making positive impression, 84.56% of the farmers have positive attitude to adopt the technology, 86.18 percent of farmers have upgraded their knowledge level, 63.57 percent of the farmers have no major constraints for the adoption of technology and 82.25 percent of the farmers are satisfied with the performance of technology.

FUTURE RESEARCH NEEDS

Resource conservation technologies undoubtly have proved a boon for the farmers especially in R-W cropping system but we still find that farmers are fully or partially burning crop residue in the field as they find it quickest method of safe disposal without considering its ill effects on the nutrient loss and environmental pollution. Why they do so is the matter of concern. We have to analyze the problem from the farmers point of view. RCT is a broad base issue and requires multidisciplinary involvement of experts of different disciplines, NGO, Government and farmers.

Following research issues are of major concern:

1. Crop residue management.
   We have to find out ways and means for:
   a. Value addition to crop residue for alternate fodder for milch animals.
   b. Quickest composting alternative such as aerobic, bio-physical and chemical for recycling.
   c. Use as animal litter and then recycling for fast decomposition.
   d Alternative for domestic fuel with mechanical, chemical and physical treatment.
2. Genetic potentialities: Crops and their varieties suitable for different conditions and crop establishment alternatives.
3. Development of machine and equipment for *in-situ* and *ex-situ* process such as baling, haulage, transportation, harvesting of stubbles, etc.
4. Improvement in the existing R.C.T. machine for fertilizer placement and metering devices, use of corrosion resistant material such as plastic. Development of low cost multi-crop seed-cum-ferti-drill and different alternatives for crop establishment
5. Mulching: Research is needed to develop technologies which utilize crop residue as mulches.
6. Irrigation management: There is a need to develop energy and cost effective irrigation technologies with incorporation of R.C.T. This may need development of feasible water metering device for field level use.

7. Soil health: Soil health is a major concern and will require strategies in place to monitor soil health
8. Participatory approach: All above issues need participation of farmers. Without their involvement, research and efforts being done by experts, will go in vane.

CONCLUSION

The case study revealed that Z.T. technology is beneficial in many ways. It has not only recorded the yield enhancement but also saved time, labour-cost, diesel, environment pollution, wear and tear of tractors and agricultural implements, drudgery and labour-days and irrigation water. It has opened a way to use mulching practices for the establishment of crops. The technology was not limited only to wheat but farmers also planted many other crops like paddy, okra, pigeon pea, field pea, maize, urdbean, sesamum, etc.

Farmers attitude is positive toward its adoption. More than 82% are satisfied with the technology the constraints faced by farmers are no obstacles in the adoption of technology as their knowledge and skills have been upgraded and is being improved. Farmers have come forward to purchase the machine. Private dealers have started its selling business. Rural youths have started taking interest to adopt technology as own enterprise. The technology has sense of full advancement, merit for promotion, technical feasibility, and economical viability.

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Laser Land Leveling- The Precursor Technology for Resource Conservation in Irrigated Eco-system of India

M.L. Jat, S.K. Sharma, Raj K. Gupta, Kuldeep Sirohi and Parvesh Chandna**
Project Directorate for Cropping Systems Research, Modipuram 250 110, Meerut, UP, India
* RWC-CIMMYT, NASC Complex, Pusa, New Delhi 110 012, India

ABSTRACT : Land Leveling is one of the few mechanical inputs in intensively irrigated farming that meets the objective of achieving better crop stand, saving irrigation water and improving the use efficiency of inputs. In recent year considerable efforts have gone in developing and promoting resource conservation technology (RCTs) e.g. Zero tillage, bed planting etc. The performance of RCTs can be greatly enhanced through final land leveling. This paper describes our experience with laser land leveling and the opportunities it offers for enhanced inputs use efficiency productivity and overall profitable farming.

INTRODUCTION

Application of science and technology in agriculture through which self-sufficiency in food grain production has been achieved is the most successful story of the post independent India. Development of crop management technologies and irrigation infrastructure in post independence India has boosted the production of crops. The varietal breakthrough in crops provided opportunities for enhancing cropping intensity at farm level and food security at national level due to which the impending crisis of food was successfully averted. But, the ever increasing population pressure and shrinking land resources has proved to be another turning point in the history of agricultural research and development especially in the irrigated eco-regions of India. The demand for food grains in India will be 238.5 and 268.8 million tonnes respectively by 2010 and 2020 (Kumar, 1998). In the projected food demand by 2020, the combined share of rice (41.07 %) and wheat (33.89 %) will be 75.96 %, which covers about 87.5 % of the irrigated area of the country. This shows that the productivity growth of the rice and wheat has been mainly attributed to the varietal breakthrough coupled with irrigation and over exploitation of natural resource base. For further productivity growth of rice and wheat and keeping pace with natural resource base, more emphasis is needed on precursor technologies. In this respect, Hill et al (1991) rated the development of laser technology for precision land leveling as second only to breeding of high yielding varieties.

Several reports bring out that productivity of wheat decrease by 1.5% per day if the crop is planted after the first fortnight of November in Punjab, Haryana and western UP and by 2-3% after third week of November in the Gangetic plains of eastern Uttar Pradesh and Bihar. It appears that modern agriculture depends heavily on timeliness of the farming operation for enhanced crop yields and profits. Short turn around time and excessive tillage often attributes to late planting of wheat for the consequent yield losses. Recent evidences clearly bring out that the problem of late planting of wheat can be overcome by reduced or minimum tillage coupled with mechanization of the planting operation. Thus, appropriate choice of conservation agriculture practices and mechanization of farming operations has great importance in improving farm gate incomes and in opening up avenues for another green revolution in the country.

Unevenness of the soil surface influences the farming operations, energy use, aeration, crop stand and yield mainly through nutrient-water interactions. The general, practices of land leveling used by the farmers in India is either through use of plankers drawn by draft animals or by small tractors. Farmers in Indo–Gangatic Plains especially Punjab, Haryana and Uttar Pradesh are using iron scrappers/ leveling boards drawn by 4-wheel tractors. But, these leveling practices are not so perfect even after best effort for leveling which results in less input use efficiencies and low yield at the cost of more water. High crop yields depend on optimum seedling emergence, better crop stand and early crop vigor. Laser land leveling is one of the few mechanical inputs in intensively cultivated irrigated farming that meets the twin objectives of achieving a better crop stand, save irrigation water and improves the input use efficiencies.

Land leveling – the precursor technology to other farming operations:

Land leveling is a precursor to good agronomic, soil and crop management practices and the levelness of the land surface has significant influence on all the farming operations. The soil moisture status throughout the field governed by its levelness has great influence not only on farming operations but also the yield and input use efficiency. The leveling of land for achieving higher resource use efficiency is not a new technique but the way in which it is done is not up to the mark as frequent patches of dikes and ditches stretched over a minimum workable distance are created even with best effort by conventional leveling practices (Fig 1). Undulated land hampers the seedbed preparation, seed placement, germination and also requires heavy draught for machines, which leads to consumption of more energy, and ultimately to more cost of production and low productivity levels. The performance of resource conservation technologies (RCTs) can be improved on well level fields (Jat, *et al,* 2003). Zero-till seedling performs better on a well-leveled field compared to unleveled or fairly leveled field due to better seed placement, germination and uniform distribution of irrigation water and plant nutrients. The other resource conserving technologies seems to perform better on laser leveled field as the successfulness of RCTs mainly depends on the crop establishment, which directly influenced due to soil moisture status. Uniform and better soil moisture status at sowing leads to better germination and crop stand, which is possible through precision land leveling. The general practice of N application in India is through broadcasting of Urea. Under uneven soil surface, the applied N is either washed away from higher elevating points to lower elevating points or leached down in low lying points which results in low use efficiency. If field is perfectly leveled, the uniform distribution of N will leads to better use efficiency and higher yield levels.

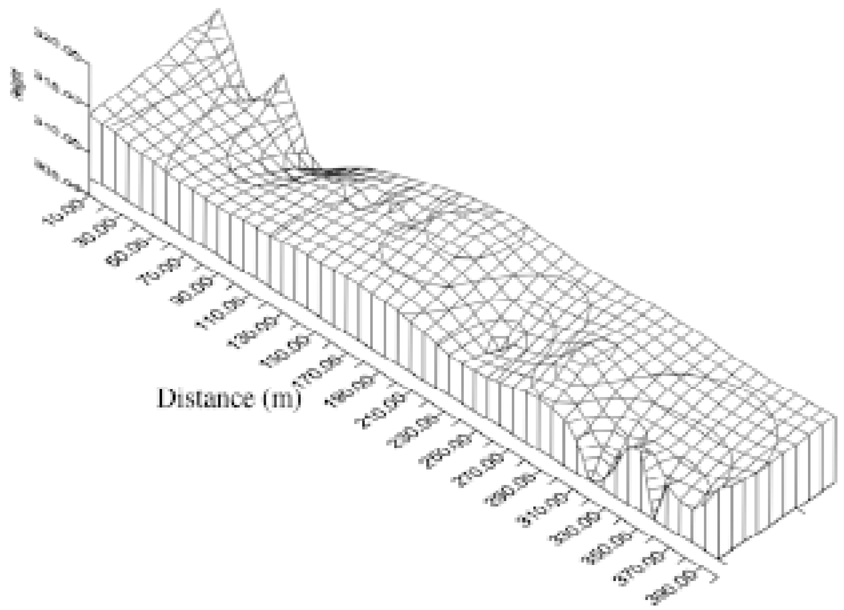

Fig. 1. Elevations of a field after leveling with traditional methods.

Standards for laser land-leveling system

The quality of the land leveling depends mainly on the compatibility of the laser, bucket/ scrapper and the tractor. The land leveling lasers are standard specifications but their performance depends on the scrapper/bucket size and the power of the tractor to drag them. For précised and efficient operation of the laser land levelers the scrapper size should be as per the standards of the tractors (Table 1) as their availability various regionally.

Table 1. Standards for size of tractor and scrapper for precision land leveling

S.No.	Tractor size (HP)	Scrapper width (m)
1	30-50	2.0
2	50-100	2.0-3.0
3	100-125	3.0-3.5
4	125-150	3.5-4.0
5	>150	4.0-4.5

Comparative performance of different land leveling systems

The working efficiency and quality of land leveling depends on the leveling systems. The working efficiency of the land levelers varies from 0.08 ha to 2.0 ha per day. The accuracy of land leveling in animal drawn and tractor drawn bucket and scrappers even with the best efforts is ± 4-5 cm whereas it is ± 1 cm in laser-operated bucket (Table 2).

Table 2. Comparative performance of different leveling systems

S.No.	Leveling system	Working efficiency (ha per day)	Accuracy
1	Animal	0.08	± 4-5 cm
2	Hand tractor	0.12	± 4-5 cm
3	Blade	0.5-1.0	± 4-5 cm
4	Bucket	0.5-1.0	± 4-5 cm
5	Laser	Up to 2	± 1 cm

Laser land leveling and resource conservation

Cultivable land area: Evenness of the land surface due to laser land leveling helps in use of larger fields for irrigation in food crops. Increase in plot size for irrigation leads to reduction in number of buds and channels in the field and brings more area under cultivation. Rickman (2002) reported 5 to 7 % increase in farming area due to precision land leveling. In Punjab and Sind province of Pakistan, 2 to 3 % addition in cultivable area was reported due to precision land leveling (Khan, 1986). Through RRA in western Uttar Pradesh (ML Jat, Personal Communication, 2004), it has been estimated that about 3 and 6 % additional land area can be brought under cultivation in canal and tube well irrigated areas respectively (Table 3) due reduction in number of bunds and channels mediated by laser land leveling. Jat and Chandana (2004) reported an addition of 4.39 % area under cultivation due to precision land leveling on a tube well irrigated farm of western Uttar Pradesh (Fig 2).

Operational efficiency: Precision land leveling requires larger fields, which increases the farming area and improves operational efficiency. In on-farm investigations, Rajput and Patel (2003) reported that, the plot size of wheat was increased from 50 x 12 before leveling to 50 x 20 m after precision leveling and in rice it was increased from 50 x 25 to 50 x 50 m.

Table 3. Estimated additional land area which can be brought under cultivation due to precision land leveling under rice-wheat cropping system in Western Uttar Pradesh

Parameters	Traditional land leveling		Precision land Leveling	
	Canal irrigated	Tube well irrigated	Canal irrigated	Tube well irrigated
Plot size (m x m)	40 x 30	30 x 20	50 x 50	40 x 30
Total Plot area (m^2)	1200	600	2500	1200
Area under bunds & channel (m^2 ha^{-1})	600	1200	300	600
Additional land area brought under cultivation (%)	-	-	3	6

Source: ML Jat, Personal Communication (2004).

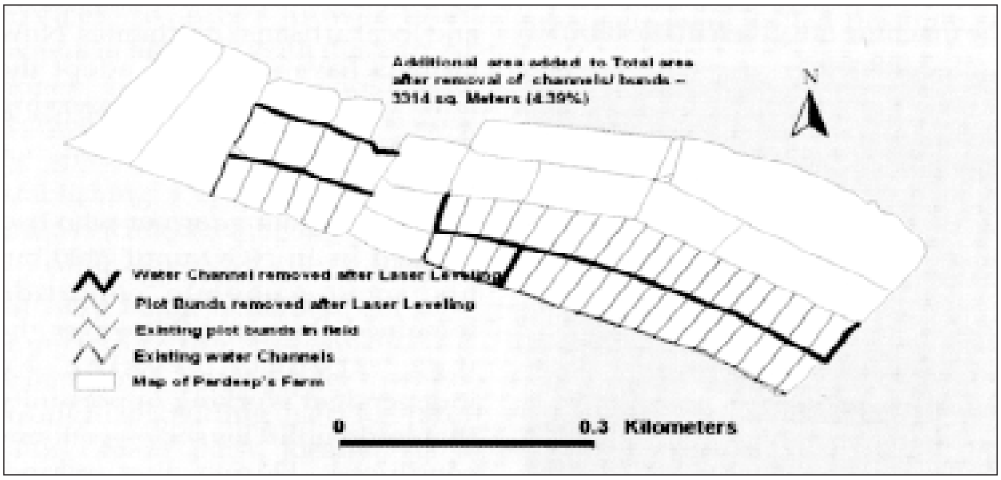

Fig. 2. Addition in cultivable land area of a farm due to laser land leveling
Source: Jat and Chandna (2004).

Increasing field size from 0.1 hectare to 0.5 hectare increases the farming area between 5% and 7%. This increase in farming area gives the farmer the option to reshape the farming area that can reduce operating time by 10 to 15 % (Rickman, 2002). The operational efficiency of tillage operations of a tube well irrigated farm in western Uttar Pradesh was increased by about 23 % (Table 4) after precision land leveling (Jat, 2004).

Table 4. Effect of land leveling on operational efficiency and fuel consumption of tractor

Levelness of the field	Time in tillage operation(min ha^{-1})		Fuel consumption* (Lit ha^{-1})	
	Cultivator	Harrowing	Cultivator	Harrowing
Laser leveled	80.00	87.50	5.33	5.83
Traditionally leveled	105.00	115.00	7.00	7.67
Difference	25.00	27.50	1.67	1.84
% Savings	23.81	23.91	23.86	23.99

*Average diesel consumption of the tractor @ 4.0 lit hr^{-1}
Source: ML Jat, Personal Communication (2004)

Weed management: Reduction in weed population is also most likely in laser land leveling, which creates almost uniform seedbed with ample storage of moisture and nutrients that helps in uniform germination of crops. Unleveled fields on the other hand, frequently exhibit patchy growth. The areas with sparse plant population are zones of higher weed population because weeds are mostly C_4 plants and posses the inherent genetic capability to suppress the crop growth. Reports on suppression of weed population by laser land leveling, though meager, convincingly prove its beneficial effects. Reduction in weed population up to 40 % was reported due to smothering effect from land leveling. This reduction in weed population results in improvement in weed management efficiency as removal of less number of weeds manually requires less time as well as better distribution of weedicides leads to higher efficiency of weed control. A reduction of 75 % in labour requirement for weeding was noticed due to precision land leveling (Rickman, 2002). A marked reduction in weed population in wheat at 30 days after sowing (Fig. 3) was recorded under precision leveling compared to traditional leveling (Jat *et al.,* 2003).

Crop productivity: There is a strong correlation between the levelness of the land and crop yield (Rickman, 2002) and considerable increase in yield of crops is possible due to precision land leveling. Results of the experiment carried out at Modipuram, India showed a significant yield advantage of Laser Land Leveling over traditional leveling (Jat *et al*., 2003). The grain yield of wheat was increased from 4.3 t ha^{-1} under traditional leveling to 4.6 t ha^{-1} through precision leveling (Table 5). The crop yield was further increased by 0.4 t ha^{-1} when grown on raised beds on a laser-leveled field compared to planted on beds on traditionally leveled field. They further reported that the yield advantage of laser land leveling in upland paddy (0.67 t ha^{-1}) was more compared to wheat (Table 5). The results of on-farm investigations in western Uttar Pradesh (Jat, 2005) showed an average increase of 5.45 % in rice productivity in the first year of the laser land leveling compared to traditional leveling (Table 6). Findings of a long-term study (Rickman, 2002) showed 24 % increase in yield of rice due to precision land leveling over traditional land leveling at the same level of variety and fertilizer use. Sattar *et al*. (2003) reported a reduction in the yield of seed cotton up to 20.1 per cent on traditionally leveled (TL) fields compared to precision leveling (PL) due to (i) low plant population in TL, (ii) greater variation in plant height from average plant height, (iii) late crop maturity or prolonged vegetative growth due to excessive water applied to the TL fields. Choudhary *et al*. (2002) demonstrated the effect of laser land leveling on the productivity of wheat sown on different dates. In general, as the time of sowing delayed, the yield decreased. But, the marginal decrease in the yield due to delayed seeding (from 1st to 2nd and 2nd to 3rd date of seeding) was much higher in traditionally sown wheat (774.5 and 1425.5

Table 5. Effect of laser land leveling and land configurations on grain yield (t ha^{-1}) of tube well irrigated upland rice and wheat crops

Treatment	Grain yield (t/ha)	
	Rice	Wheat
LLRB + N_{120} + P_{26} + K_{50}	–	5.0^a
TLRB + N_{120} + P_{26} + K_{50}	–	4.6^b
LLFB + N_{120} + P_{26} + K_{50}	6.33^a	4.6^b
TLFB + N_{120} + P_{26} + K_{50}	5.00^b	4.3^b
TLFB + N_0 + P_0 + K_0	4.08^c	2.7^c

Means with the same letters are not significantly different at P= 0.05LLRB- planting on raised beds with laser land leveling; TLRB- planting on raised beds with traditional land leveling; LLFB- planting on flat beds with laser land leveling; TLFB- planting on flat beds with traditional land leveling
Source: Jat *et al.* (2003)

kg ha^{-1}) compared to seeding under laser land leveling (346 and 581 kg ha^{-1}). Tyagi (1984) reported that the yields were higher by 50% in precision-leveled plots compared to traditional leveled plots. In a similar study Khepar (1982) observed a decrease of 270 kg ha^{-1} for each unit increase in topographic index from 0.5 to 2.82 cm. It can therefore, be concluded that precision leveling is the most effective technique to improve productivity of surface irrigated crops.

Table 6. Effect of laser land leveling on total water use and rice yield

Land leveling practice	Total water use (m^3 ha^{-1})	% Saving in water	Rice yield (kg ha^{-1})	% Increase in yield
Laser leveling	6900	31.16	5800	5.45
Traditional leveling	9050	-	5500	-

Source: Jat and Sharma, 2005

Water productivity: The foremost objective of the laser land leveling is to improve application and distribution efficiency of irrigation water, which ultimately leads to higher water productivity. Tyagi (1984) reported the application depth values of 3.9 and 9.7 cm at leveling index (LI) of 0.75 cm. and 6.75 cm, respectively in wheat crop under sodic soils Haryana. Further, the distribution efficiency obtained with various depths of application (4 cm to 12 cm) showed that distribution was more uniform (> 90%) in plots with an average LI of 0.75 cm and poor (< 50%) in plots with an average LI of 6.75 cm. However, as the depth of application increased, the distribution improved in poorly leveled plots as well. The distribution efficiency of applied water in wheat in a sandy loam soil at Modipuram, India was remarkably higher (Fig 4) under precision land leveling compared to traditional leveling (Jat *et al*., 2003). The remarkable improvement in application and distribution efficiency of applied water was also reported (Sattar *et al*., 2003) under precision land leveling compared to traditional leveling (Fig 5). Due to improved water application and distribution efficiency, Jat *et al* (2003) reported a drastic reduction in water use in wheat from 5270 m^3 ha^{-1} in traditional land leveling (TL) to 3525 m^3 ha^{-1} in laser land leveling (LL) and an increase in water productivity (WP) from 0.82 in traditional leveling to 1.31 g wheat grain l^{-1} water in precision leveling under flat bed planting technique. The WP of raised bed planted wheat improved further from 1.38 in TLRB to 1.90 LLRB (Fig 6). They further reported that the WP of rice was increased from 0.55 under TL to 0.91 g rice grain l^{-1} water under LL (Table 7).

Table 7. Effect of land leveling and configuration on water use (m^3 ha^{-1}) and productivity (kg grain m^{-3} water) in tube well irrigated upland rice and wheat grown on a 20 x 20 m.

Treatment	Total water use (m^3 ha^{-1})		Water productivity (kg grain m^{-3} water)	
	Rice	Wheat	Rice	Wheat
LLRB	–	2635^d	–	1. 90^a
TLRB	–	3335^c	–	1.38^b
LLFB	6950.00^a	3525^b	0.91^a	1.31^b
TLFB	9150.00^b	5270^a	0.55^b	0.82^c

*Means with the same letters are not significantly different at P= 0.05*LLRB- planting on raised beds with laser land leveling; TLRB- planting on raised beds with traditional land leveling; LLFB- planting on flat beds with laser land leveling; TLFB- planting on flat beds with traditional land leveling
Source: Jat *et al.* (2003)

Under on-farm trials in western Uttar Pradesh, Jat (2005) reported a remarkable increase in water productivity of rice from 0.60 under TL to 0.90 under LL (Fig 7). A significant increase in water use efficiency of seed cotton from 36.9 under TL to 63.1% in LL was noticed by Sattar *et al.*, (2003). The increase in WUE was attributed to less requirement of total water depth under precision leveling (54.80 cm) compared to traditional leveling (74.65 cm) and more storage of water in the soil profile under precision land leveling. Choudhary *et al* (2002) also reported higher water use efficiency (1.67) under precision leveling compared to conventional leveling (1.10) under on-farm investigations.

Nutrient use efficiency: Improved use efficiency of the applied nutrients under laser land leveling is an obvious consequence. During land leveling, cut and fill of the soil in the field are done several times wherein, the soil attains near homogeneity particularly up to rooting depth. Therefore, application of nutrients under irrigated condition creates a condition for uniform distribution of nutrients in the soil water in the supposedly uniform field. In homogeneous seedbed, uniform distribution of nutrients invariably improves crop growth. As higher quantum of water and nutrients are available over the entire field, use efficiency of applied nutrients is also improved. The information on increased nutrient use efficiency as mediated by laser land leveling, though scanty, convincingly demonstrated its beneficial effects. The uptake of applied nutrients in a sandy loam soil was increased significantly under precision land leveling compared to traditional land leveling (Pal *et al,* 2004). They reported a significant increase in the agronomic and uptake efficiency as well as apparent recovery fraction of the applied N, P and K in a typic *Ustochrept* in rice (Table 8) and wheat (Fig 8) due to precision land leveling compared to traditional leveling. In on-farm investigations in western Uttar Pradesh, marked improvement in nitrogen use efficiency in rice-wheat cropping system has been recorded and the NUE was increased from 45.11 to 48.37 and 34.71 to 36.90 kg grain kg^{-1} applied nitrogen in rice and wheat respectively. Choudhary *et al* (2002) noticed higher fertilizer use efficiency (26.91) under laser land leveling compared to conventional leveling (21.67) in wheat crop.

Table 8. Agronomic efficiency (kg kg^{-1}) of N (AE-N), P (AE-P) and K (AE-K) under different land leveling systems in rice

Treatment	AE-N		AE-P		AE-K	
	2003	2004	2003	2004	2003	2004
LL+NPK*	18.75	20.00	86.54	92.31	56.25	60.00
TL+NPK*	7.67	9.17	35.38	42.31	23.00	27.50
TL+NPK#	-	-	-	-	-	-

LL-Laser leveling, TL-Traditional leveling, * N @120 kg, P@ 26 kg and K @ 40 kg ha^{-1}
\# - NPK (Control)
Source: Pal *et al.* (2004)

Economic benefits: It is of the opinion of the people that precision land leveling is a costly preposition. Rickman, (2002) reported that although the initial cost of land leveling is convincingly high, a cash flow over a period shows that financial benefits do result from land leveling. The additional cost and benefits of precision land leveling over an eight-year period reveal that there are major economic benefits to be gained through land leveling. The costs allow for an extra fertilizer in the first and second years. The benefits include reduced weeding costs of 40 %. Contrary to that Rajput and Patel (2003) reported that on custom hiring basis laser land leveling for wheat production was found beneficial even in the first year (Table 9). Jat *et al* (2004) evaluated the economics of laser land leveling in wheat for two consecutive years and found that during the first year of cropping though the returns were slightly less compared to traditional leveling but in the succeeding year there was remarkable increase in the monetary advantage compared to traditional leveling practice (Table 10). Choudhary *et al* (2002) reported an increase in net return of Rs. 5125 ha^{-1} from wheat grown under laser-leveled field compared to conventional leveling. The respective B/C ratio of 2.71 and 2.04 with a difference of 0.67 was recorded under laser leveling and conventional leveling (Table 11). The cost analysis of on-farm investigation in western Uttar Pradesh showed that the cost per ton of cut-fill work varied from rupees 0.26 to 18.96 with an average of 2.24.

Table 9. Net profit in the first year of laser land leveling on custom hiring

Village	Plot no.	Additional amount of wheat produced due to laser land leveling (Rs.)	Expenditure in laser land leveling (Rs.)	Net profit (Rs.)	Saving in irrigation water (m^3)
Lakhan	516	1750	945	805	584.6
	456	2000	945	1055	406.8
	745	1750	945	805	338.4
Masauta	364	2125	2025	100	807.6

Source: Rajput and Patel (2003).

Table 10. Economic evaluation of laser land leveling in wheat for two consecutive years

Treatments	Gross Return (Rs ha^{-1})		Additional Cost for laser leveling (Rs. ha^{-1})		Gross Returns after subtracting cost of leveling (Rs ha^{-1})	
	Ist Year	*IInd Year*	*Ist Year*	*IInd Year*	*Ist Year*	*IInd Year*
LLRB	37000	38927	5000	0	32000	38927
TLRB	33820	35302	1000	800	32820	34502
LLFB	34720	36524	5000	0	29720	36524
TLFB	31160	32446	1000	800	30160	31646

LLRB - planting on raised beds with laser land leveling; TLRB - planting on raised beds with traditional land leveling; LLFB - planting on flat beds with laser land leveling; TLFB - planting on flat beds with traditional land leveling
Source: Jat *et al* (2004)

Table 11. Comparative economics (per ha) of wheat production under different land leveling techniques

Land leveling	Mona				OFWM			
	Cost (Rs.)	Gross return (Rs.)	Net return (Rs.)	B/C return	Cost (Rs.)	Gross return (Rs.)	Net return (Rs.)	B/C return
Laser leveling	11243	41685	30442	2.71	12779	38596	25817	2.02
Conventional leveling	12413	37730	25317	2.04	12114	31482	19368	1.60
Difference	1170	3955	5125	0.67	665	7114	6449	0.42

Source: Choudhary *et al.* (2002)

In the post green revolution era, declining factor productivity, degradation of natural resource base and high cost of production in the irrigated farming systems of the country are the major issues of concern. Use of laser technology being rated second to breeding high yielding crop varieties for increased yield and resource use efficiency has showed tremendous potential in the irrigated intensively cultivated areas of the country. Laser assisted precision land leveling has been shown to improve water management, crop stand and productivity. With laser leveling, significant savings in irrigation water, improved efficiency of inputs, higher yields, increase in cultivated area, reduced cost of weeding and better operational efficiency can be achieved. Acceleration of laser land leveling technology and assessing its log-term impact needs immediate attention.

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Socio-Economic Impact Assessment of Bed Planting Technology in Punjab

D.K. Grover, Joginder Singh, Ranjeet Singh and S.S. Dhillon
Punjab Agricultural University, Ludhiana 141 004, Punjab, India

ABSTRACT : During the last few years serious efforts have been made to evolve resource conservation technologies. Development of the bed planting system for increasing the yield and input use efficiencies under different cropping systems is one of these efforts. To asses the impact of this technique on various socio-economic parameters along with sustainability and environment, the study was carried out. The comparative analysis has been based on the information collected from fifteen respondent farmers using 'with' and 'without' technology approach during 2002-03. The study highlighted that most of the adopters of this technology were in the age group of 50 to 60 years and educated from sixth to tenth and above. Majority of the adopters belonged to families' sized 5 - 8 members. They were following paddy-wheat crop rotations. As far as the farmers' perceptions about the technology is concerned it was yield enhancement, saving of inputs and natural resources and some positive impacts on sustainability and environmental parameters. The major constraints/ problems highlighted by the farmers in the adoption of the new technology were non-availability/repair of relevant machinery, and difficulty in harvesting the crop sown with new technology. The results revealed that the new technology was not only helpful in the reduction of input use but also increased the yield and net returns to the farmers. The use of inputs like seed, irrigation, and fertilizers was reduced by 20.45, 32.71 and 5.64 percent respectively, which is statistically significantly different from the traditional technology. Almost 32 percent saving in water requirements of wheat crop has enormous impact in reducing sustainability problem apart from reduction in cost; fall in water table in the state, which has been viewed as a very serious problem. The present technology would help in mitigating it to some extent. The consumption of plant protection chemicals was reduced by 34.30 percent that is highly desirable in the sanitary and phytosanitary context of WTO requirements. This would be helpful not only in lowering the cost but also would improve the quality of produce, and may reduce human and animal health hazard. The overall cost of cultivation was reduced by 8.56 percent. The use of human labour was increased by 12.21 percent creating more employment opportunities under new technology. The yield and net returns increased under new technology were 3.79 and 12.24 percent respectively. At present, area under wheat in the Punjab state is about 34.2 lakh hectares. If we assume 10 percent adoption level of the technology then the saving of various inputs like seed, fertilizers and chemicals will be of Rs.5.39, 4.8 and 20.5 crores respectively. The overall saving in cost of cultivation will be Rs. 40.9 crores. The improvement in the yield will be of worth Rs. 36.21 crores and thus an improvement of Rs. 77.6 crores in net returns to the state will be realized. The other impacts of the new technology are conservation of natural resources; improve the agro-industrial base, diversification of agriculture through intercropping sugarcane/mentha in wheat on beds etc. Preliminary research findings on the growing of crops (wheat, maize, cotton, soybean and rice) on permanent (renovated) beds have shown encouraging results and the use of permanent beds would thus help reduce tillage costs and green house gas emissions from burning diesel and stubble retention system.

INTRODUCTION

There is no doubt that intensive agriculture in irrigated areas has brought about substantial enhancement in the production of food grains and other agricultural commodities but this type of farming has threatened the environmental safety and promoted the degradation and inefficient use of basic resources of land and water and various production inputs. Thus it is a matter of universal concern to sustain the productivity of agricultural system concomitant with friendly environment and efficient utilization of production resources especially soil, water and nutrients. The research activities initiated about 2 decades ago on broad beds (120-150 cm) and furrow (BBF) system by ICRISAT scientists showed that this system works best in areas with dependable annual rainfall averaging 750-1250 mm per year. The results also revealed that raised bed and furrow (BBF) system in comparison to flat bed system induced good root development, good nodulation, better crop growth, better pod filling and early maturity in groundnut besides considerable saving of time and cost of cultivation.

The research activities under irrigated conditions over the past many years in North-West Mexico by CIMMYT scientists and preliminary research findings at PAU (unpublished data) have shown that wheat could be grown on beds varying in size from 65-90 cm. However, there is a wide range of genetic variation in bread and durum wheat and triticale and some genotypes could be successfully grown on beds (Sayre, 1992). In the Yaqui Valley of Sonora State in NW Mexico which has about 2.25 lakh ha and wheat is grown on about 65 percent of the area under irrigated conditions. About 90 percent of the farmers in 1996 as compared to 6 percent in 1981 have adapted to the system of growing wheat on beds (Sayre and Moreno Ramos, 1997). Numerous advantages were cited for adoption of bed planting system including, better irrigation management, better plant establishment, the ability to use inter-bed cultivation for weed control, lowering seedling rate, less crop lodging and increased compatibility of farming equipment used for wheat as well as other crops (Meisner *et al.*, 1992)

The literature suggests that there is a large possibility of mitigating the adverse effects if the conventional planting is replaced by the more innovative bed planting system for wheat. As water, fertilizer nutrients, energy etc. are getting scarce and costly there is an urgent need to develop and refine planting practices (such as bed), which ensure enhanced utilization efficiencies of inputs and are environmental friendly. Keeping in view its multi benefits, the bed planting technology has been developed by the scientists and recommended recently to farmers for adoption in Punjab. The present study has been designed to assess the socio-economic impact of this technology in terms of input saving, yield enhancement (if any) and environment upgradation. The specific objectives were to study:

- the agro-socio economic profile of the adopters of bed planting in Punjab.
- farmer's perception about the new technology and constraints thereof.
- the changes in input use, yield, costs and returns under new technology.

METHODOLOGY

In order to study the socio–economic impact of the technology under study, data/information have been collected from the adopters. The methodology followed for the same has been discussed here:

Sampling and data collection

The study was conducted in Punjab state. All the 15 farmers who adopted the practice of bed planting in the four districts i.e. Ludhiana, Amritsar, Mukatsar and Moga, were taken for the impact analysis. Impact assessment of the bed planting technique was done using 'with' and 'without' technology approach. The primary data were collected on the especially designed questionnaire. The information was collected on the socio-economic profile of the respondents along with various indicators of impact assessment, with and without technology pertaining to 2002-03. The various indicators involved were seed rate, fertilizers use, human and machine labour use, plant protection measures, yield, quality, sustainability and environmental protections

Analysis

The interpretation of the results was based on the simple averages and percentages. The cost of cultivation and gross returns under these two conditions were calculated for the impact assessment. T-test was applied to see whether the changes in the level of inputs used and yield/returns 'with' and 'without' technology are significantly different from zero or not.

RESULTS AND DISCUSSION

The results have been discussed in the following sub-heads:

- Agro-socio-economic profile of adopters.
- The changes in input use, yield, costs and returns under new technology.
- Farmer's perception about new technology and constraints.

Agro-socio-economic profile of adopters

Various socio-economic characteristics of the respondents were studied and the same are given in Table 1.

Table 1. Agro-socio-economic profile of the sample respondents

Particulars	Distribution of respondents based on agro-socio-economic characteristics			
Age (Years)	Up to 50	51-60	Above 60	Overall
Number	7(46.67)	7(46.67)	1(6.66)	15(100.00)
Education (Standard)	0-5	6-10	Above 10	Overall
Number	3(20.00)	7(46.67)	5(33.33)	15(100.00)
Family size (Persons)	0-4	5-8	Above 8	Overall
Number	3(20.00)	9(60.00)	3(20.00)	15(100.00)
Type of soil	Light	Medium	Heavy	Overall
Number (Multiple Response)	0	13(86.67)	6(40.00)	15(100.00)
Source of irrigation	Tube well	Canal	Others	Overall
Number (Multiple Response)	15(100.00)	7(46.67)	0	15(100.00)

Note: Figures in the bracket indicate percentage to the total.

Age

The total number of respondents were 15 from which the number of farmers with less than 50 years of age and between 50 to 60 years were equal i.e. 7. Only one respondent was of age more than 60 years.

Education

Education of the farmers indicate that the majority of the farmers (80 percent) were educated from sixth to tenth standard and above and only 20 percent were under sixth standard of education.

Family size

Majority of the farmers belonged to family with 5-8 members each i.e. 60 percent of the total respondents, whereas, only 20 percent farmers having less than 4 family members and also the equal number with family size of above 8 members.

Size of holding

The overall average size of holding of the selected farmers was 11.87 hectares with 6.24 hectares leased-in and 0.27 hectares as leased-out. The average size of owned area was 5.9 hectares i.e. about 50 percent of the average size of operational holdings. Contrary to state agriculture scenario, the adopter of technology had larger holding especially by way of leasing-in of land.

Type of soil and source of irrigation

Type of soil and source of irrigation indicates that majority of the sample respondents i.e. 86.67 percent had medium textured soil while 40.00 percent had heavy type of soils. Main source of irrigation of all the farmers was tubewell and 46.67 percent of the farmers also used canal in addition to tubewell water for irrigation purpose.

Changes in input use, yield, costs and returns under new technology

Input change

Some of the inputs were used in less quantity under the new technology and some inputs were used in more quantity in relation to conventional planting system. The detail of various inputs used under both the technologies (bed planting and traditional system) is given in Table 2.

Table 2. Indicators for impact assessment of the technology by sample respondents

Particulars	Input use/output with bed planting technology		Input use/output with traditional technology		Change with new tech over trad. tech.(*%)	
	Physical term	Value (Rs)	Physical term	Value (Rs)	Physical term	Value (Rs)
Seed (kg)	76.21	668	95.80	825	-20.45	-19.05*
Irrigation (No.)	3.80	-	3.67	-	3.54	-
Hours per irrigation	9.01	-	13.39	-	-32.71	-
Total irrigation hours	34.24	653	49.14	788	-30.33*	-17.15*
Zinc/FYM	1.66	52	1.66	52	-	0.00
Fertilizers (kg)	414.90	2628	439.70	2767	-5.64	-5.04*
Insecticides	-	59	-	133	-	-55.56
Herbicides	-	1088	-	1613	-	-32.53
Chemicals (Rs)	-	1148	-	1747	-	-34.30*
Human labour (hr)	225.93	2781	201.35	2419	12.21	14.96
Machine labour (hr)	21.99	3692	22.79	3619	-3.51	2.02
Total cost of cultivation (Rs)	-	12773	-	13968	-	-8.56*
Grain yield (q)	46.79	28956	45.08	27898	3.79	3.79*
Price (Rs)	-	618	-	618	-	0.00
Yield of by-product	48.5	4607	48.35	4593	0.31	0.31
Gross return (Rs)	-	33564	-	32491	-	3.30
Net returns		20790	-	18523	-	12.24*

*: Shows that the change in the particular use of a variable 'with' and 'without' technology is significant at 5 percent probability level.

Reduction in input use

The use of most of the inputs was less under bed planting system. The various inputs reduced under new technology as compared to the traditional technology were seed rate, irrigation, fertilizers (nitrogen and phosphorus), chemicals (insecticides and herbicides) etc. In physical terms the seed rate reduction was about 20.45 percent, irrigation by 32.71 percent and fertilizers by 5.64 percent. The change in the use of seed rate, irrigation, fertilizers and plant protection chemicals under new technology is significant at 5% probability level. In value terms the use of plant protection chemicals was reduced by 34.30 percent under new technology as compared to traditional planting. The use of machine labour was found to be reduced by 3.51 percent under the new technology, though this change was not found statistically significant.

Increase in input use

The use of human labour was found to be more (not statistically significant) under new technology that was about 12.21 percent more in physical terms and 14.96 percent in value terms over the traditional planting system. The difference in physical and value terms may be due to the type of work done by human labour and their wage rate accordingly. In the context of surplus labour available in the area, higher labour use may be even a blessing in disguise.

Saving of inputs

On the whole, it has been observed that under the new technology, saving of seed is 20.45 kg per hectare. Water is a precious resource, the saving of which has been viewed from various angles of environment, cost and sustainability of crop system. Almost 32 percent saving in water requirements of wheat crop has enormous impact in reducing sustainability problem apart from reduction in cost @ Rs. 135/ha due to less intensity of irrigation. Fall in water table in the state has been viewed as a very serious problem. The present technology would help in mitigating it to some extent. The cost of plant protection chemicals used (herbicides and weedicides) is reduced by Rs.600/ha. This would be helpful not only in lowering the cost but also would improve the quality of produce and may reduce human and animal health hazards.

Yield improvement

The grain yield under bed planting system was 46.79 q/ha, which was 45.08 q/ha in conventional planting system. Thus, the grain yield under new technology was increased by 3.79 percent, which is significant at 5% probability level. The yield of by-product is more or less the same under these two systems of planting. The yield of straw under new technology is 48.50 q/ha and 48.35 q/ha in the traditional system.

Changes in Cost

Due to decline in the input use under new technology, overall cost of production also got reduced. Cost of production per hectare under bed planting system was Rs 12,734 per hectare against Rs13,969 per ha under traditional system of planting. Thus, cost of production got reduced by 8.56 percent in bed planting system over the traditional planting system and the reduction in cost of cultivation/hectare has been found statistically significant at 5 percent probability level.

Net economic gain

The yield of bed planted wheat averaged to 46.79 q/ha as compared to 45.08 q/ha in case of flat system and the yield of by-product is almost equal under the two systems as indicated in the above text. The gross returns in bed planting system were Rs. 33, 564/ha against Rs. 32,492/ha under flat system. Not only yield is more in bed planting system, the cost of production per ha is also less. So, the net returns are more under bed planting system. Net returns under bed planting system were Rs.20, 791/ha as compared to Rs. 18,523/ha. Thus, per ha gains in net return are Rs. 2268 (12.24 percent) under bed planting system over the traditional planting system and this increase in net gains has been found statistically significant. If the diffusion of technology takes place and it covers 10 percent area under wheat the net economic gain would amount to Rs. 75 crores per annum in Punjab state alone.

Sustainability, environmental and other impacts of technology

Besides the gain in net returns to the farmers there are also some sustainability and other impacts of new technology which are given as under.

The farmer's perception about the new technology in terms of selected indicators related to sustainability and other impacts (positive and negative) were studied using five-point scale i.e. very low, low, medium, high and very high. The respondents have not expressed any negative sustainability impact of the technology. The positive sustainability as well as other impacts of the technology as perceived by the farmers with varying intensity has been depicted in Table 3

Table 3 shows that more than 85 percent farmers admitted that the bed planting technology will have positive and medium to very high impact on the sustainability of crop growth. About the positive impact on soil texture/quality about 60 percent farmers admitted that it would improve the soil texture/quality medium to very high. Medium to very high positive impact of technology on soil organic matter was admitted by more than 50 percent farmers.

Table 3. Frequency distribution of the farmers' perceptions regarding the sustainability impact of technology

Parameter	Number of farmers					Total
	Very low	Low	Medium	High	Very high	
Sustainability of crop growth	-	2 (13.33)	5 (33.33)	3 (20.00)	5 (33.33)	15 (100.00)
Soil texture/quality	3 (20.00)	3 (20.00)	6 (40.00)	2 (13.33)	1 (6.67)	15 (100.00)
Soil organic matter	4 (26.67)	3 (20.00)	3 (20.00)	3 (20.00)	2 (13.33)	15 (100.00)

Figures in the parenthesis indicate the percentage of the total number of farmers.

Farmers' perception about the new technology and constraints thereof

Farmers perception about the technology, various constraints as pointed out by these farmers to adopt the new planting system on larger scale and feedback to researchers, extension and development departments has been explained as below:

- Yield enhancement.
- Saving of water.
- Saving of fertilizers, insecticides/pesticides.
- Less seed rate and less use of weedicides.
- Good quality of grains.
- Increase in gross returns.

Constraints/problems in technology adoption

Various constraints pointed out by farmers, which hinder the adoption of new technology with the level of constraints (very low, low, medium, high, very high) against the percentage of farmers facing that constraints are given in Table 4. Table 4 indicates that based on the experience of the technology adopters, it has been brought out that constraint viz. cash problems, costly machinery, time consuming technology, non-availability of labour, difficulty in straw making, more weeds in furrows and lack of extension services has not posed serious problem for the farmers. The farmers facing these constraints varied from 6-13 percent. The other constraints like non-availability/repair of bed planter and difficulty in harvesting the crop are the constraints that are faced by the sizeable number of the farmers i.e. 40-43.33 percent of the total farmers.

Table 4. Constraints/problems in technology adoption based on the experience of respondents

Constraint	Non-existent	Existent					
		Very low	Low	Medium	High	Very high	Total
Cash problems	13 (86.67)	-	-	1 (6.67)	1 (6.67)	-	2 (13.33)
Costly machinery	14 (93.33)	-	-	-	1 (6.67)	-	1 (6.67)
Non-availability/repair of bed planter	10 (66.67)	-	1 (6.67)	1 (6.67)	1 (6.67)	2 (13.33)	5 (43.33)
Time consuming technology	13 (86.67)	-	1	1 (6.67)	-	-	2 (13.33)
Non-availability of labour	14 (93.33)	-	-	-	-	1 (6.67)	1 (6.67)
Difficulty in harvesting the crop	9 (60.00)	-	2 (13.33)	2 (13.33)	1 (6.67)	1 (6.67)	6 (40.00)
Difficulty in straw making	13 (86.67)	-	-	1 (6.67)	1 (6.67)	-	2 (13.33)
More weeds in furrows	14 (93.33)	-	-	1 (6.67)	-	-	1 (6.67)
Lack of extension services	13 (86.67)	1 (6.67)	-	1 (6.67)	-	-	2 (13.33)

Figures in the parentheses indicate the percentage of the total number of farmers.

Other impacts

In addition to the sustainability the other impacts of the technology include:

- The use of chemical weedicides gets avoided which is highly desirable in the context of WTO requirements.
- It protects our natural resources like water and fuel etc.
- It increases the employment opportunities due to more human labour involvement in the manufacture of bed planting machinery under new technology.
- Bed planting system would help in achieving better yield by using lesser and efficient use of various resources i.e. water, fertilizer, seed and weedicide, etc.

- Mechanical interculture/integrated control of weeds in both beds and furrows in this system of planting would greatly help to reduce the dependence on herbicide use. Also the hand picking, if some left over *phalaris minor* plants are there, is easier in bed planted wheat. Continuous use of mechanical interculture for 4-5 years and hand picking of some left over weeds may ultimately remove the *phalaris minor* menace from the wheat fields.
- Success in developing appropriate bed forming equipment is expected to greatly improve the agro-industrial base and employment scope of agricultural workforce.
- Diversification through intercropping of sugarcane/mentha in wheat on beds would be added advantage.
- Preliminary research findings on the growing of crops (wheat, maize, cotton, soybean and even rice) on permanent (renovated) beds have shown encouraging results and the use of permanent beds would thus help reduce tillage costs and green house gas emissions from burning diesel and stubble retention system.

CONCLUSION

The results reveal that the new technology is not only helpful in the reduction of input use but also increase the yield and net returns to the farmers. The use of inputs like seed, irrigation and fertilizers was reduced by 20.45, 32.71 and 5.64 percent respectively, which is statistically significantly different from the traditional technology. Almost 32 percent saving in water requirements of wheat crop has enormous impact in reducing sustainability problem apart from reduction in cost, fall in water table in the state which has been viewed as a very serious problem. The present technology would help in mitigating it to some extent. The consumption of plant protection chemicals was reduced by 34.30 percent that is highly desirable in the context of WTO requirements. This would be helpful not only in lowering the cost but also would improve the quality of produce, and may reduce human and animal health hazard. The overall cost of cultivation was reduced by 8.56 percent. The use of human labour was increased by 12.21 percent creating more employment opportunities under new technology. The yield and net returns increased under new technology were 3.79 and 12.24 percent respectively. The other impacts of the new technology are conservation of natural resources, improved agro-industrial base, diversification opportunities through intercropping sugarcane/mentha in wheat on beds etc. Preliminary research findings on the growing of crops (wheat, maize, cotton, soybean and rice) on permanent (renovated) beds have shown encouraging results and the use of permanent beds would thus help reduce tillage costs and green house gas emissions from burning diesel and stubble retention system. The major constraints/problems highlighted by the farmers in the adoption of the new technology were non-availability/repair of relevant machinery, and difficulty in mechanized harvesting of crops sown with new technology.

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Socio-economic Impact of Zero-tillage Technology in Wheat in Punjab

Harjeet Singh Dhaliwal and Joginder Singh
Department of Economics, Punjab Agricultural University, Ludhiana 141 004, Punjab, India

ABSTRACT : The emerging dominance of rice-wheat system in the northern belt of the country has recently resulted in decelerating total factor productivity and environmental degradation, which urgently demand resource conservation technology to address such issues. The acceptance of such technology is faster if it is cost effective as well. Zero-tillage technology is considered important from these angles. Based on the perceptions of 308 adopting farmers selected from different locations of the Punjab state, it was observed that a significant decline in the cost of production is in the foresight due to less use of farm machinery, labour, agro-chemicals and higher yield due to less lodging of crop. The water requirement also goes down significantly. The air pollution caused through burning of paddy straw is also a serious problem, which can also be minimized by way of ploughing it in the field. Although some problems such as weed perpetuation, aeration, removal of paddy straw with appropriate attachments, higher seed rate requirement were also observed but the cost reduction and yield improvement and addressing of environmental concerns seem to overweigh the problems due to this technology.

INTRODUCTION

In the northern belt of the country particularly Punjab, Haryana and Western part of U.P. having higher potential of underground water resource, rice-wheat turned out to be the most profitable crop rotation in this region. Therefore, there was almost a revolutionary increase in production due to generation of farm technology, particularly HYVs, expansion of irrigation, use of agro-chemicals and farm mechanization followed by market infrastructure along with effective procurement at minimum support prices (MSP) of these crops. Now the Punjab agriculture has reached a stage where problems like deceleration of total factor productivity, freezing of MSP's, depletion of soil and water resources, environmental pollution apart from various marketing and storage problems are getting acute shape.

Reduction in cost of production is highly relevant in the context of making the farm products more competitive in the global market. Adoption of zero tillage technique is one such step in this direction. Sowing of wheat after rice in the Indo-Gangetic plains under conventional tillage involves pre-sowing irrigation, intensive land preparation and finally seeding on fine tilth soil. These operations consume time, labour, irrigation water and energy, which delay sowing of wheat and result in poor plant growth and crop yield (Fujisaka *et al.*, 1994; Harrington *et al.*, 1993; Hobbs *et al.*, 1991). As an alternative to the conventional tillage, zero-tillage technology uses direct seeding of wheat crop just after harvest of rice with the help of zero-till seed drill without preparatory tillage. Thus, zero-tillage ensures early sowing of wheat, conserves irrigation water and reduces cost of cultivation (Hobbs *et al.*, 1997; Hobbs, 2001). In case of zero-tillage, some of the farmers used reaper for the removal of paddy straw and incurred additional cost of Rs 150/acre. Some farmers also burnt the paddy straw in the field and even some farmers directly used strip tillage drill in the standing stubbles of rice. They had to use reaper, as paddy stubbles were becoming an obstacle in the smooth functioning of zero-till drill. This technology holds promise of managing rice residues more effectively than any other presently available options. The present study was undertaken with the objective to examine socio-economic impact of zero tillage technology in terms of changes in cost structure, returns, resource conservation, labour employment etc. in Punjab.

Methodology

The study was undertaken in nine erstwhile districts of Punjab State. A sample of 308 wheat growers, out of the possible list, who were practicing zero tillage technology for sowing of wheat, was purposively selected. Detailed information pertaining operational area, area sown with new technique, whether the new seed drill was owned/hired/experimental, price and hiring charges of new drill, effect on germination, yellowing of wheat crop, time taken for irrigations, use of weedicides, labour requirement, employment generation, input/cost saving, increase in productivity and suggestions to make this technology successful, was collected from the sample farmers through personal interview method using a structured questionnaire. The relevant data collected for the two technologies viz. conventional tillage and zero-tillage were analyzed and compared for assessing the impact of adoption of zero-tillage technology.

RESULTS AND DISCUSSION

Coverage

This innovative technology was found to offer great promise for economical and efficient production of wheat after rice. In Punjab, the area under zero-tillage was targeted at about 5.5 lakh hectares in 2004-05 as compared to 2.1 lakh hectares estimated during 2003-04 (Hindustan Times, Jan 21,2004). Table 1 shows the proportion of zero-till wheat area sown with new technique to the total wheat area of the randomly selected sample of wheat growers who had adopted the zero-till technique for wheat sowing. Results revealed that overall zero-till wheat area to the total wheat area was 45.37 percent.

Table 1. Proportion of zero-till wheat area sown with new technique to the total wheat area

District	No. of respondents	Area sown with new technique (acres)	Total area under wheat (acres)	Percentage of zero till wheat area to total wheat area
Kapurthala	36	102.7	132.5	77.51
Patiala	50	302.8	392.2	77.20
Sangrur	50	189.6	357.2	53.08
Ferozepur	22	80.3	344.8	23.29
Hoshiarpur	16	18.0	48.4	37.19
Gurdaspur	33	51.9	123.3	42.09
Amritsar	40	39.0	290.6	13.42
Jalandhar	41	167.8	338.2	49.61
Bathinda	20	31.0	139.8	22.17
Overall	308	983.1	2167.0	45.37

The status of zero-till drill used in different districts varied widely from one area to the other as may be viewed from Table 2. The technology is passing through different stages of adoption. Still 56.5 percent of the sample farmers used machinery available for experimental purposes. Only 13.96 percent had couraged to purchase the ZT drill while the remaining

29.54 percent adopted it through custom hiring. In Kapurthala district only 2.78 percent of the farmers owned the new zero till drill whereas maximum of the farmers (69.44 percent) used the drill on hired basis. In the district of Amritsar and Bathinda invariably all the respondents used the experimental drill. In Jalandhar district, most of farmers (43.9 percent) owned new drill whereas 17.07 percent of the farmers hired the drill for wheat sowing

Table 2. Status of zero-till drill with the farmers in different districts

District	Owned		Hired		Experimental		Total
	No.	%	No.	%	No.	%	
Kapurthala	1	2.78	25	69.44	10	27.78	36
Patiala	18	36.00	21	42.00	11	22.00	50
Sangrur	3	6.00	31	62.00	16	32.00	50
Ferozepur	0	0.00	2	9.09	20	90.91	22
Hoshiarpur	2	12.50	1	6.25	13	81.25	16
Gurdaspur	1	3.03	4	12.12	28	84.85	33
Amritsar	0	0.00	0	0.00	40	100.00	40
Jalandhar	18	43.90	7	17.07	16	39.03	41
Bathinda	0	0.00	0	0.00	20	100.00	20
Total	43	13.96	91	29.54	174	56.50	308

The average purchase price of different type of zero-till drills was Rs14293 and average hiring charges along with tractor as Rs. 762 per hectare. Wheat growers used the zero-till seed-cum-fertilizer drills manufactured by different manufacturing units. Subsidy has also been provided to the farmers for purchasing zero-till drills ranging from Rs 3000 to 3300 per drill.

Cost effectiveness

The comparative effect of both the techniques (conventional and zero-tillage) on different operations in terms of cost is presented in Table 3. Conventional method of wheat sowing requires preparatory tillage but zero-till system allows direct sowing without preparatory

Table 3. Comparative cost of land preparation and sowing operations (Rs/ha)

Particulars	Old method			New method		
	Qty/No.	Rate	Value (Rs)	Qty/No.	Rate	Value
Preparatory tillage						
a. Discs	2	450.0	900.0	-	-	-
b. Cultivators	2	330.0	660.0	-	-	-
c. Planker	3	190.0	570.0	-	-	-
Sowing						
Traditional drill	1	367.5	367.5	-	-	-
New drill	-	-	-	1.0	762.5	762.5
Total -	-	2497.5	-	762.5	762.5	

Cost saving of new technique over conventional technique= Rs1735.

tillage. In old method, the cost of different operations was recorded to the tune of Rs 2497 per hectare, whereas, in zero-tillage method, it was only of Rs 762 per hectare. So it indicates that zero-tillage planting of wheat saved Rs 1735 per hectare by eliminating the need for a number of tillage operations. Besides this, new technique reduces planting time and saves fuel and labour costs as compared to conventional method of planting and helps in timely sowing.

Farmers' perceptions about plant growth

Germination of seed is one of the most important factors affecting crop yield. It was observed that germination of wheat seed remained the same under both the methods of sowing as per opinion of 75 percent of the farmers whereas, only 25 percent of the farmers reported that seed germination was affected and recorded less germination of wheat sown with new technique (Table 4). As per the farmers' opinion, less germination can be compensated by increasing seed rate by 10 percent (10 kg/ha). Regarding aeration problem, more than 50 percent of the farmers reported that yellowing of wheat after first irrigation was the same under both the methods of sowing of wheat and only 9.42 percent reported that problem of aeration after first irrigation was more with new technique whereas more than 33 percent of the farmers observed that yellowing of wheat after first irrigation is more acute in case of conventional method. They reported that yellowing of wheat in early stages is common due to oxygen starvation as a result of first heavy irrigation under tilled conditions but this problem is nearly overcome in zero-till sown wheat. Infestation of weeds also did not increase with new technique. In Punjab, *phalaris minor* is the dominant weed. New technique helps to control this weed through suppression due to early sowing of wheat. There is need to examine the weed problem on the fields on which continuous use of zero-tillage is carried out.

Table 4. Impact of new technique in comparison to conventional technique in respect of different aspects

Aspect	Response of farmers (No.)		
	More	Same	Less
Germination	0	233 (75.65)	75 (24.35)
Aeration problem (yellowing)	29 (9.42)	172 (55.84)	107 (34.74)
Weed infestation (specially *phalaris minor*)	34 (11.04)	138 (44.80)	136 (44.16)
Insect infestation	27 (8.77)	281 (91.23)	-
Time required per irrigation	-	-	308 (100.00)

Only 8 percent of the farmers noticed the pink borer attack on wheat in zero-tillage. Some of the farmers recorded higher attack of rats in case of zero-till wheat which might be due to the residue of previous crop of rice in the field. All the respondents shared that irrigation to zero- till wheat required less time as compared to traditionally sown wheat.

Almost all the farmers gave same number of irrigations to conventionally and zero-till sown wheat but less time taken for irrigation to zero-till wheat due to hard surface of soil and low infiltration rate of water. It indicates that zero-till wheat requires less irrigation water in whole season. Thus, the irrigation cost per hectare reported by these farmers was less than that of the traditionally sown wheat. Reduction in quantum of irrigation water is one of the most important factors to make a strong case for the adoption of zero-till technique under the Punjab conditions. Some farmers also reported less lodging in zero-till wheat as compared to traditionally sown wheat because of greater grip of untilled soil with roots.

Labour displacement

Table 5 indicates labour displacement with new crop establishment method. The consensus of respondents was that sowing of wheat with zero-till technique helps in displacement mainly of unskilled and skilled, both family and casual labour. There is need to examine the opportunities available with the surplus labour and ways to make proper use of this resource.

Table 5. Labour displacement with new crop establishment method

Type of labour displaced	No. of farmers reporting	Percent of farmers
Family labour	192	62.34
Permanent labour	2	0.65
Casual labour	87	28.25
Family labour and casual labour	32	10.39
Family labour and permanent labour	7	2.27
Casual labour and permanent labour and family labour	10	3.25
Skilled labour	34	11.04
Unskilled labour	233	75.65

Implications of new technique for displacement of migrant labour were also analyzed. Obviously, there was decrease in the requirement of migratory labour for sowing wheat with zero-till technique which could in turn be visualized as positive impact on social set-up of the state. There is possibility of decrease in health hazards through contagious diseases, crime rate and traffic jams with the decrease in the requirement of migratory labour and number of slums will also decrease. Therefore, with the decrease in the requirement of migratory labour, the consumption pattern will also change to the extent of decrease in migration.

Table 6. Impact of new technique on employment in manufacturing and custom hiring service sector

Increase in employment	No. of farmers reporting	Percent of farmers
Manufacturing of new drills or modifying old drills	123	39.93
Providing custom hiring services of new drills	141	45.78
No response	44	14.29
Total	308	100

The impact of new technique on employment in manufacturing and custom-hiring service sector was also viewed. Results revealed that 45.78 percent of the farmers reported that the adoption of zero-till system would be helpful in the generation of employment in the form of providing custom hiring services and in the manufacturing industry of zero-till seed-cum-fertilizer drills or modifying old drills as reported by 39.93 percent of the farmers. Table 7 shows the impact of new technique on time saving. It can safely be estimated that on an average, 25-40 man hours per hectare are saved with the use of new technique for sowing wheat. It was also revealed that two-thirds of the total farmers reported saving in time, labour and money under the new technique, which would be helpful in expanding/ maintaining their subsidiary occupations. Therefore, by sowing of wheat with the zero-till technique, they can devote more time in their subsidiary occupation like dairy, fishery, bee-keeping, poultry farming, etc.

Table 7. Impact of new techniques on time saving for raising next crop

No. of man-hours saved (per ha)	No. of farmers reporting	Percent of farmers
0-10	-	-
10-25	50	16.23
25-40	91	29.55
40-50	16	5.19
No response	151	49.03
Total	308	100

Wheat yield

The reported impact of new technique on the wheat yield is shown in Table 8. The percentage increase in the yield of wheat per hectare was maximum in Kapurthala (20%) followed by Ferozepur (12.5%), Gurdaspur (6.67%), Hoshiarpur (6.25%) and Bathinda district (5.26%). The Patiala, Amritsar, Jalandhar districts did not show any increase in the yield of wheat with the change in the method of wheat sowing. On the whole, the increase in the yield of wheat was recorded as 5.88 percent with the adoption of zero-till system.

Table 8. Impact of new technique on yield of wheat

District	Yield			Percent-age change
	Conventional	New method	Increase yield	
	<——	q/ha	——>	
Kapurthala	37.5	45.0	7.5	20.00
Patiala	45.0	45.0	-	-
Sangrur	45.0	47.5	2.5	5.55
Ferozepur	40.0	45.0	5.0	12.50
Hoshiarpur	40.0	42.5	2.5	6.25
Gurdaspur	37.5	40.0	2.5	6.67
Amritsar	-	-	-	-
Jalandhar	42.5	42.5	-	
Bathinda	47.5	50.0	2.5	5.26
Overall	42.5	45.0	2.5	5.88

Table 9 shows the farmers' perceptions about social and economic implications of new method. Results indicated that 11.69 percent of the farmers perceived that there will be decrease in the air pollution when wheat is sown in the field without burning paddy straw. However, 8.44 and 3.25 percent of the total farmers reported that the economic condition and savings of wheat growers would be improved with the adoption of zero-till technique. Only 0.97 percent of the farmers shared the view that life of tractor and other implements will also be enhanced.

Table 9. Socio-economic impact of zero-till technique

Social and economic implications	No. of farmers	Percentage
More savings	10	3.25
Air pollution would be decreased	36	11.69
Economic conditions will improve	26	8.44
Life of tractor and other implements will be increased	3	0.97
No response	233	75.65
Total	308	100.00

PROBLEMS

The problems faced by the wheat growers with the adoption of zero-tillage technique for wheat sowing were also listed as under:

- The stubbles of paddy cause problem in the planting of wheat with zero-tillage technique.
- More moisture is required for sowing of wheat with new technique
- The zero-till drill machine is costly and it is not easily available to them.
- The straw gets attached to the tines of wheat drill. Thus the loose paddy straw and standing stubbles should be finished with burning as these cause problems.
- The zero-till drill needs more careful handling than traditional drill.
- The bunds making are also difficult in the field sown with zero-till drill method of wheat sowing.

SUGGESTIONS

The suggestions made by zero-tillage wheat growers included:

- A chain is required behind each tine of the machine to cover wheat seed properly with the soil.
- The new machine needs further improvement and farmers shared the ideas that still there is a need to improve the management of paddy straw and old drill should be modified instead of purchasing the new zero-till drill.
- More area should be sown with this method to take the benefits of new method.
- All types of zero-till drills should be supplied on subsidized rates.
- More effective technology for paddy management needs to be evolved to check burning of paddy straw. Generally the farmers are sowing wheat with the zero-till drill after burning or partial burning of rice straw. There is also a need to test other drills like Happy seed drill for proper management of paddy straw.

- Fertilizer distribution system with existing drills needs to be refined as fertilizer distribution is not uniform.

CONCLUSION

The zero-till technology is beneficial as it has been examined in this study. Though yield gains are not much but there are impressive cost reductions. The zero-till technology also has positive impact on environment and sustainability of rice-wheat cropping with the efficient use of resources. This technology also helps in consolidating gains from savings in tillage cost, fuel and increase in the productivity of wheat. The gains from zero tillage could be further improved by enhanced efficiency of resource use and a wider adoption with appropriate extension programmes.

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Studies on Extent of Adoption of Zero Till Seed-cum-Fertilizer Drill for Wheat Sowing in District Kurukshetra (Haryana)

O.P. Lathwal and K.L. Banga
Krishi Vigyan Kendra, Kurukshetra 136 119, Haryana, India

ABSTRACT : Among various resource conservation technologies zero-till seed-cum fertilizer-drill is becoming popular in rice-wheat cropping system of northern plains of India particularly in Punjab and Haryana. The use of zero-till seed-cum-fertilizer drill (ZTSFD) for sowing of wheat crop was demonstrated at farmer's fields in district Kurukshetra of Haryana state in 1997. The overwhelming response of farmers in its adoption was encouraging for two reasons- firstly it reduced the plant population of major weed (*phalaris minor*) of wheat and secondly reduction in cost of wheat production. As a result in district Kurukshetra the number of ZTSFD increased from 5(1997) to 1425 (2003) due to subsidy on this drill provided by state government, and the wheat area sown under ZTSFD increased from 50 (1997) to 40,000 hectares (2003). Keeping in view the fast spread of such viable resource conservation technology (RCT) studies were undertaken to assess the adoption of ZTSFD by different categories of farmers and data was collected from 56 farmers in 2003-04 in the district. The results indicated that the farmers having the land holdings of 2-5, 6-10, 11-15 and 16-above hectares (ha) have sown the wheat crop with ZTSFD to the tune of 1.28 (36.6%), 4.47 (30.8%), 8.55(65.7%) and 7.66 ha (42.5%) of total wheat area sown, respectively. As the land holding size increased the farmers purchased their own ZTSFD and small farmers got the sowing done on hire basis @ Rs.875 per ha. There was increase in grain yield under ZTSFD compared to conventional method (well pulverized soil) of sowing ranging from 4.65 to 6.81 percent irrespective of the land holding of the farmers. The farmers realized double benefit by adopting this RCT in the form of reduction in cost of sowing operations @ Rs. 1844 per ha and income from enhanced grain yield amounting Rs. 1260, 1738, 1675 and 1575 under four categories of farmers in ascending order of their holdings. The total benefit summed to be Rs. 3104, 3582, 3519 and 3419 under the different categories of farmers depending upon their size of holdings.

INTRODUCTION

Rice-wheat cropping system is most popular among the farmers particularly in Punjab and Haryana. The productivity of this system either has decreased or stabilized alongwith the associated damage to agro-ecosystem in the form of increasing problems of pests particularly development of resistance in the *phalaris minor* against the most commonly used herbicide isoproturon. This situation of resistance had threatened the cultivation of wheat crop and many farmers harvested their unmatured crop for fodder purpose due to high density of *phalaris minor*. Under such circumstances, the new herbicides were introduced but due to the fear of cross-resistance an alternate method of wheat sowing with zero-till seed-cum-fertilizer-drill was also demonstrated at farmer's fields. This alternate method of sowing not only reduced the weed density, it proved as cost effective resource conservation technology (Banga and Lathwal, 2000). This technology enhanced the productivity of wheat and simultaneously decreased the cost of cultivation (Lathwal *et al.*, 2002).

The demonstrations on use of zero-till-seed-cum-fertilizer-drill for sowing of wheat were conducted at farmer's fields from 1997 to 2000. The overwhelming response of farmers, its adoption was very encouraging for the obvious reasons of cost effective resource conservation technology (RCT). Realizing the fast spread of such viable RCT, studies were undertaken to assess the adoption of zero-till-seed-cum-fertilizer-drill by different categories of farmers in district Kurukshetra.

METHODOLOGY

Primary data was collected randomly from the farmers who adopted the technology for sowing of wheat crop during 2003-04. In order to collect the data, a questionnaire was developed on relevant aspects like size of holding, total wheat area sown wheat area covered under zero-till-seed-cum-fertilizer drill (ZTSFD), ownership of drill, hiring rate of drill, grain yield under RCT and conventional method of sowing. The data on various tillage operations done in conventional method of sowing was also collected for comparison purposes and for estimating the expenditure incurred in different tillage operations. Thus the data was purposely collected from 56 farmers of district Kurukshetra (Haryana) which were divided into four categories based on their land holdings at 2-5, 6-10, 11-15 and 16-above hectares (ha), respectively and the corresponding number of farmers were 21, 17, 9 and 9 under the four sizes of land holdings, respectively.

The data was analysed using simple analytical tools such as total, averages, and percentages. The returns in rupees per hectare were calculated considering the minimum support price of wheat grains as Rs.630 per quintal during 2004.

RESULTS AND DISCUSSION

Growth of ZTSFD

The demonstrations on ZTSFD for sowing of wheat were started in 1997-98 with only 5 drills which covered 20 ha area. The number of ZTSFD increased tremendously every year due to subsidy provided by state government and the number of ZTSFD increased to 1425 during 2003-04 with corresponding increase in area to 40,000 ha under RCT during 2003-04.

Table 1. Growth of ZTSFD and wheat area sown under RCT in Distt. Kurukshetra

Year	No.of ZTSFD	Wheat area covered(ha)
1997-98	5	20
1998-99	20	400
1999-2k	100	3600
2000-01	300	14000
2001-02	500	20000
2002-03	850	30000
2003-04	1425	40000

Source: Department of Agriculture, Kurukshetra.

Area sown with ZTSFD

It is obvious from Table 2 that the farmers having the land holding of 11-15 ha had sown maximum area (65.76%) with ZTSFD followed by the farmers of land holding of 16 ha and above. The farmers having land holding of 2-5 and 6-10 ha covered the wheat area with ZTSFD to the tune of 36.57 and 30.87 percent, respectively of the total area sown. The less area covered under RCT by small farmers was due to getting the sowing done on hire basis.

Table 2. Wheat area covered under ZTSFD by different categories of farmers

Category of farmers (land holding, ha)	No.of farmers	Average area under ZTSFD(ha)	%area covered under ZTSFD
2-5	21	1.28	36.57
6-10	17	2.47	30.87
11-15	9	8.55	65.76
16-above	9	7.66	42.58

Ownership of ZTSFD

The data revealed that with the increase in land holding size, the farmers purchased their own ZTSFD and the farmers of small land holdings got the sowing done on hire basis @Rs.875 per ha(Table 3). About 77 percent farmers having land holding of 16 ha and above had their own ZTSFD due to their higher purchasing powers compared to other categories of farmers.

Table 3. Ownership of ZTSFD by different categories of farmers and hiring rates of ZTSFD

Category of farmers (land holding, ha)	No.of farmers	Own ZTSFD (%farmers)	Hiring (%farmers)	Rate of hiring (Rs./ha)
2-5	21	14.28	85.72	875
6-10	17	41.17	58.83	875
11-15	9	66.66	33.34	875
16-above	9	77.77	22.23	875

Grain yield

Farmers irrespective of various categories recorded higher grain yields ranging from 4.65 to 6.81 percent under ZTSFD than conventional method of sowing (Table 4). Increase in grain yield under ZTSFD could be attributed to decrease in weeds density and improved yield contributing characters. These results corroborate with the findings of Malik (2000).

Table 4. Effect of ZTSFD on grain yield of wheat

Category of farmers (land holding, ha)	No.of farmers	Grain yield (q/ha)		%increase in ZTSFD
		ZTSFD	Conven-tional	
2-5	21	45.00	43.00	4.65
6-10	17	43.26	40.5	6.81
11-15	9	43.66	41.5	6.48
16-above	9	45.00	42.5	5.88

Expenditure on tillage operations

The expenditure involved in field preparation and sowing operations (Tables 5, 6) showed that Rs.2719 per ha were required in conventional method of wheat sowing whereas only Rs.875 per ha were required for sowing of wheat with ZTSFD. Therefore, irrespective of the category of farmers there was net saving of Rs.1844 per ha in the fields sown with ZTSFD compared to conventional method of sowing in well-tilled fields.

Table 5. Expenditure involved in field preparation for sowing of wheat under conventional method in district Kurukshetra

Tillage operations	No.of tillage operations
Harrow	4.8
Cultivator	2.1
Suhaga	2.9
Total operations	7.8
Total expenditure (Rs./ha)	2719

Source: Dhiman *et al.*, 2001.

Table 6. Expenditure involved in sowing operations under different methods of wheat sowing in district Kurukshetra

Particulars	Expenditure (Rs./ha)	
	Under ZTSFD	Conventional
Total expenditure	875	2719
Net saving	1844	-
Percent saving	67.82	-

Returns

It is evident from Table 7 that the farmers got more returns per ha to the tune of Rs.1260, 1738, 1675 and 1575 under four categories of farmers having land holdings of 2-5, 6-10, 11-15 and 16-above ha, respectively. The higher returns under ZTSFD were due to higher grain yields obtained under the method involving RCT compared to conventional method of sowing by different categories of farmers.

Table 7. Returns (Rs./ha) obtained under ZTSFD in comparison to conventional method

Category of farmers (land holding, ha)	No.of farmers	Returns(Rs/ha)		Increase in return	Percent increase
		ZTSFD	Conventional		
2-5	21	28350	27090	1260	4.65
6-10	17	27253	25515	1738	6.81
11-15	9	27505	25830	1675	6.48
16-above	9	28350	26775	1575	5.88

Total returns

The farmers got double benefit by adopting the new method of wheat sowing with ZTSFD in terms of enhanced grain yield with less investment. Thus the farmers of four categories received the total benefits per ha to the tune of Rs.3104, 3582, 3519 and 3419 in accordance with the land holdings of 2-5, 6-10,11-15 and 16-above, respectively. The small farmers had less benefit than the farmers of large land holdings because the small farmers of first category harvested lower grain yields compared to other categories of farmers.

Table 8. Total returns (Rs./ha) under ZTSFD for wheat sowing

Category of farmers (land holding ha)	No.of farmers	Increase in returns	Saving in tillage	Total benefit
2-5	21	1260	1844	3104
6-10	17	1738	1844	3582
11-15	9	1675	1844	3519
16-above	9	1575	1844	3419

CONCLUSION

From the above study it may be concluded that the four categories of farmers having the land holdings of 2-5, 5-10, 11-15 and 16-above hectares have adopted the resource conservation technology in the form of sowing the wheat crop with zero-till-seed-cum-fertilizer drill (ZTSFD) to the tune of 1.28 (36.6%), 4.47 (30.8%), 8.55 (65.7%) and 7.66 ha (42.5%) of their total area wheat sown, respectively. As the land holding size increased the farmers purchased their own ZTSFD and small farmers of small land holdings got the sowing done on hire basis @ Rs. 875 per ha. There was increase in grain yield under ZTSFD compared to conventional method (well tilled fields) of sowing ranging from 4.65 to 6.81 percent for small holding and big holding farmers, respectively. The farmers got double benefit by adopting ZTSFD in the form of reduction in cost of sowing operations @ Rs. 1844 per ha and additional income from enhanced grain yield amounting to Rs. 1260, 1738, 1675 and 1575 under four categories of farmers having the land holding of 2-5, 5-10, 11-15 and 16-above ha. respectively. Further, with the increasing trend in area sown under ZTSFD in district Kurukshetra, the adoption rate of such RCT will increase.

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Conservation Tillage for Enhancing Productivity and Protecting Environment: ICRISAT Experience

S.P. Wani, P. Pathak and R.C. Sachan and Suresh Pande
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT),
Patancheru 502 324, Andhra Pradesh, India

ABSTRACT : Indian semi-arid tropics are characterized by variable and unpredictable rainfall, structurally unstable and poor productivity. The traditional tillage and soil management systems lead to low infiltration, high soil erosion, low cropping intensity and crop production. Tillage studies on Alfisols and Vertisols at ICRISAT have shown that no-till or reduced tillage without crop residues on soil surface have no advantage since they loose water through run-off. Conventional tillage systems on Alfisols appear to be advantageous, though ephemerally, because it results into increased infiltration and reduced soil erosion, though on a long term it may be exacerbating the soil structure instability problem and its harmful effect on crop productivity. Conservation tillage have shown positive benefits in enhancing productivity and decreasing soil erosion but has limitation of availability of crop residues due to their use as animal feed. Conservation tillage should be re-examined and alternative practices should be evaluated to evolve tillage systems that ensure increased and stable crop production without effects on environment.

INTRODUCTION

The semi-arid tropics (SAT) are characterized by variable and low rainfall and the soils have low productivity. Also, the SAT regions have poor development infrastructure. The fragile ecosystems in the dry areas are prone to degradation. Widespread poverty, hunger and malnutrition with complex and diverse socio-economic characteristics make these areas challenging for both researchers and development professionals alike. The poverty in rainfed areas is primarily due to low productivity of resource base, water storage and poor institutional infrastructure.

Tillage is one of the important components to improve soil conditions and conserve soil and water. Sub-optimal soil conditions have significant impact on soil-water and nutrient regime, gaseous exchange between soil and atmosphere and crop growth. Adverse effects on crop growth have agronomic and economic implications while those on soil-water and aeration regime lead to ecological and environmental problems. Principle among these are related to water quality influenced by components of water balance, e.g. increase in surface run-off, accelerated erosion, transport of sediments and sediment borne contaminants and dissolved chemicals in surface run-off. Resource conservation leads to increased productivity and soil conservation. Minimum tillage is an ecological and science-based approach to resource conservation and sustainable production.

The magnitude of soil disturbance and its susceptibility of soil degradation processes depends on several factors including frequency and intensity of tillage, type of implements, source of power and antecedent soil moisture. Minimum tillage, an ecological approach and science based strategy, attributes includes reduced frequency and intensity of tillage operation, use of those implements that loosen the soil without turning over and do not excessively pulverize it and perform the needed tillage operations when soil conditions are within the optimum soil condition range to produce the desired tilth. It facilitates intensive cultivation with minimum risk of degradation. The term minimum tillage is often used synonymously with conservation tillage which retains productive amount of mulch on the surface.

Plow based mechanical soil disturbance although necessary for some soils for optimum seedbed preparation and for weed control has many ecological and agronomic limitations including high susceptibility of soil to erosion, rapid mineralization of soil organic matter, subsoil compaction and high-energy cost. Conventional tillage based on soil turnover and pulverization offers transient effect but increase soil and environmental degradation. Sustainable use of soil and water resources implies profitable farming on a continuous basis while enhancing productive capacity of soil and water resources.

SOILS

Alfisols and Vertisols, 2 of 8 soil orders of SAT are represented within the experimental farm of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Vertisols are heavy soils, high in clay. Because of high clay content and related physical properties, these soils have high moisture storage capacity. The typical Vertisol profile of 185 cm depth is able to hold 220 mm of available water content. Vertisols are very hard when dry and very plastic and sticky and un-trafficable when wet. The optimum moisture range for tillage is very narrow. Vertisols have low terminal infiltration rate. During the rainy season, water may pond if drainage is inadequate and the crops suffer from waterlogging. Alfisols possess an argillic horizon within the profile, clay content of these soils increases with depth and they lack structural development. These soils display rapid surface sealing following rainfall and crusting with subsequent drying cycles which can adversely affect plant establishment. Alfisols permit easy tillage when wet, they become hard and difficult to till when dry. Tillage when the soil is too wet may result in excessive compaction. Hence only limited soil moisture range is available for producing optimum tilth. Alfisols generally possess inherently low water retention characteristics because of their particle size make up and mineralogical composition which is compounded by shallow soil depth of the soil zone available for water storage (El-Swaify *et al.,* 1985).

Tillage systems in the Indian SAT

In semi-arid India, animal-drawn wooden or iron plow consisting of iron crow bar with hardened point (e.g. non inverting 'desi' plow) is traditionally used for tillage. Other special tillage tools are the 'bakhar' which is a blade harrow used for smoothening soil surface and also for weed control and a cultivator with tube attached for sowing. In most parts, sorghum, pearl millet and finger millet are the major cereals grown on Alfisols. Pigeonpea, cowpea and mung bean and black gram are the major pulses, while the major cash crops are castor, cotton, sunflower and groundnut. Intercropping of cereals with pulses or oilseeds is common. In areas where water is available from dug wells or tanks, rice is grown on the poorly drained soils while cash crops like groundnut are cultivated on well drained soils.

Since dry Alfisols are quite difficult to handle before monsoon, all agricultural operations are conducted following the onset of rainy season. Often, therefore, fields are relatively bare when monsoon begins. These soils harden into crust during intermittent dry periods, which deter the establishment of protective crop cover early during the season, leading to excessive run-off and soil loss under traditional farming practised by Indian SAT farmers using bullock drawn traditional tillage implements.

Tillage is normally done with animal drawn implements on flat or gently rolling land and mainly involves plowing, harrowing and intercultivation operations to remove weeds, break soil crust especially at early stage of plant growth in order to improve infiltrability of the soil.

Hydrologic studies conducted on Alfisols at ICRISAT on the traditional farming system have shown that of the total rainfall potentially available, an average of about 26 percent is lost through run-off, 33 percent through deep percolation, and balance 41 percent is utilized for evapotranspiration by crops (Laryea *et al.,* 1991).

Table 1. Estimated water balance components and soil loss observed for traditional cultivation system[1] on Alfisols at ICRISAT Centre

Year	Rainfall (mm)	Run-off (mm)	Evapotranspiration (mm)	Deep percolation (mm)	Soil loss (t ha^{-1})
1978	106	391	395	274	5.19
1979	671	113	335	223	1.83
1980	765	149	345	271	1.62
1981	1130	292	415	423	5.61
1978-81[2]	100	26	41	33	3.71[3]

[1] Traditional varieties of sorghum and sorghum/pigeon pea intercrop were grown.
[2] In percentage of rainfall; [3] Average annual soil loss.

The traditional system of tillage on Vertisols in most parts of India involves fallowing the land in rainy season and growing a post-rainy season crop on stored moisture in the profile. In this system, the land is harrowed occasionally using animal traction during rainy season to control weeds. Undependability of rainfall and risk aversion are important reasons for rainy season fallow in low rainfall areas of India (Binswanger *et al.,* 1980). In high rainfall zones rainy season fallowing is practised because of risky cropping due to flooding and waterlogging. Furthermore, difficulty encountered in tilling the hard clay soils prior to commencement of rains or sticky wet soil after onset of rains are some other reasons for rainy season fallow in high rainfall areas (Michaels, 1982).

Hydrologic studies of this traditional system of tillage (Table 2) on Vertisols indicate that of total rainfall received during the period under study; about 28 percent was lost as run-off. Evaporation losses from bare fallow soil constitute 24 percent, while 9 percent was lost as percolation. Only 39 percent was utilized as evapotrasipartion by post-rainy season sorghum (Laryea *et al.,* 1991).

Table 2. Water balance components and soil loss for traditional rainy season fallow systems[1] on Vetisols at ICRISAT Centre

Year	Rainfall (mm)	Run-off (mm)	Evaporation (fallow rainy season) (mm)	Evapo-transpiration (mm)	Deep percolation (mm)	Soil loss (t ha^{-1})
1976	710	238	169	272	31	9.20
1977	586	53	201	317	15	1.68
1978	1117	410	185	301	22	9.69
1979	682	202	166	272	42	9.47
1980	688	166	175	300	47	4.58
1976-80[2]	100	28.2	23.7	38.5	9.46	6.93[3]

[1] Traditional varieties of sorghum was grown as post-rainy season crop, land was harrowed occasionally during the rainy season.
[2] Percentage of rainfall; [3] Average annual soil loss.

Resource conservation and conventional tillage

Soil tillage has a distinct but short-term effect on the physical conditions of Alfisols and Vertisols. Indian SAT is dominated by low mechanization level. Primary tillage operations include plowing, chiseling using animal traction and secondary tillage operations such as harrowing carried out for seed bed preparation at the beginning of growing season and for weed control during the crop season.

The tillage and soil management systems employed should ensure a sustainable crop production without deterioration of the resource base. Soil management include among other things, water entrapment system that enhance *in-situ* water conservation and conservation tillage practices such as contour cultivation ridging, surface and vertical mulch on gently sloping areas, mechanical and vegetation barriers, e.g. contour and graded bunding, conservation ditching on moderate sloping areas and bench terracing on steep slopes.

Graded land configurations on Alfisols which have less than 1.5 percent slope, cultivation on flat seed bed is effective in reducing run-off and soil loss as well as in increasing crop yields (Table 3). Graded raised land configuration (e.g., broadbed and furrow, ridge and furrow system) does not offer any particular advantage for cereal production on Alfisols occurring on these gentle slopes (Pathak *et al.,* 1987). These results were attributed to the tendency of BBF-shaped fields to undergo surface smoothening along the slope resulting into low surface depressions and exposure of soil layers with low infiltration rates (e.g. argillic horizon while constructing furrows). Where supplemental irrigation is part of rainfed crop production, ridge and furrow system is appropriate. On slopes greater than 1.5 percent, a gated-outlet-contour bund system has shown a good potential to increase and stabilize crop yield (Table 3). The performance of these practices have been discussed in detail by Pathak *et al.* (1985), Pathak *et al.,* (1987) and El-Swaify *et al.,* (1985).

Table 3. Effect of alternative land surface configurations on crop yield, run-off, and soil loss on Alfisols at ICRISAT, 1981-84

Land treatments	Crop yield (t ha^{-1})			
	Intercrop system		Run-off	Soil loss
	Sorghum	Pigeonpea	(mm)	(t ha^{-1})
(A) Land slope < 1.5%				
Broadbed and furrow at 0.4% slope[1]	2.74	0.83	315	3.79
Ridge and furrow at 0.4% slope [1]	2.9	0.87	282	3.02
Flat contour cultivation [1]	2.96	0.86	172	2.05
Flat-o-grade at 0.4% plus ridging up later	2.88	0.84	180	2.78
SE	± 0.15	± 0.07	± 16	± 0.24
(B) Land slope > 1.5%				
Contour bund[1]	2.52	0.71	75	0.97
Modified contour bund with gated outlet[1]	3.02	0.97	160	0.92
Flat-on-grade with field bunds[1]	2.81	0.9	215	3.35
Traditional flat with field bunds[2]	0.38	0.22	256	4.79
SE	± 0.18	± 0.06	± 23	± 0.19

[1] Treatment with recommended crop management practices, implying the use of acceptable or recommended variety, cropping system, chemical fertilizer, and other practices for weed, pest, and insect control.

[2] Treatment with traditional management practices, implying the use of variety, cropping system, farmyard manure, implements and other practices.

However, for groundnut, raised land surface configurations such as broadbed and furrow (BBF) has been found to be beneficial in increasing pod yield (Sujatha, 1992). In an experiment at ICRISAT, using two groundnut genotypes ICGS-11 and ICG (FDRS) 10, grown on three land surface configurations-broadbed and furrow, 30-cm narrow ridge and furrow, and flat seedbed cultivation, Sujatha (1992) observed throughout the growing season, that the bulk density of 0-15 cm soil layer was significantly lower in BBF than in the narrow ridges and the flat seedbed treatments in that order. Differences in bulk density between treatments persisted at 30, 60, 90, and 145 days after sowing. During the growing season, the total porosity of the 0-15 cm soil layer was significantly greater in the BBF system than in the ridge and flat seedbed systems. Similar differences in penetration resistance were observed between the different systems. Lowest penetration resistance was recorded in the BBF system. Significantly higher pod yields were obtained in BBF followed by ridge and flat (Table 4). This trend was observed for both varieties.

On Alfisols, crusting and sealing problems are encountered frequently during the early part of the growing season, when the crop canopy is not yet fully developed. During this period, considerable run-off has been observed even when the soils were dry. An experiment was conducted at ICRISAT Centre, from June 1981 to March 1983 to determine whether the excess run-off which occurs during the early part of the rainy season can be reduced by breaking the crust or the compacted top layer using various inter-row tillage practices in addition to normal inter-row cultivation. In all three years, the inter-row tillage, in addition to normal inter-row cultivation, was effective in reducing run-off and soil loss. Except in a very high-rainfall year, crop yields were also significantly increased by additional inter-row tillage during the other two years.

Table 4. Groundnut pod yield, as influenced by different land surface configuration on an Alfisol at ICRISAT Centre, 1991-92

Treatment	Pod yield (t ha^{-1})	
	ICG (FDRS)10	ICGS 11
Flat	3.45	2.86
Ridges	3.71	3.09
BBF	4.22	3.39
SE	± 0.09	± 0.09
CD	0.20	0.20

Source: Sujatha (1992).

Conventional tillage, in most of the SAT, is a high energy demanding cultural operation. It is a bottleneck to the areal expansion of cultivated land by farmers either because of labour shortage in the case of hand hoeing or inadequate financial resources in the case of draft animals and tractor plowing. Also by removal of vegetation from soil during the initial land clearing operation, conventional tillage exposes the soil to the rains of the SAT, resulting in most cases in high run-off and erosion. However, if done properly and at the appropriate time, tillage operations serve the purpose for which they are intended. For example intensive primary tillage has been found to be generally necessary to create a favorable root proliferation zone and to increase rainwater infiltration in Alfisols. In a normal rainfall year (about 800 mm), Klaij (1983) reported that "split strip plowing" increased the pearl millet yield from 1500 to 1840 kg ha^{-1} (SE ±79) (in this system a ridger is used to split the old bed followed twice by tillage in which the bed is rebuilt using plows set successively more widely apart.

The mean bulk density of the upper soil layer in this tillage system was reduced from 1.44 to 1.11 Mg m^{-3}. Clear benefits from deep tillage (25 cm deep) have also been recorded from a tillage experiment conducted at ICRISAT Centre where, in addition to high crop yields, deep tillage was effective in reducing run-off and soil loss (Table 5). Deep tillage is strongly recommended by Charreau (1974) for the Cambic Arenosols and the Alfisols of the Sahelian region. It helps to overcome low porosity and hardening of soil after rains and permits root proliferation and exploitation of soil water and nutrients at deep horizons of the soil profile, thereby producing higher yields. Charreau (1978) suggests that the benefits of deep tillage are gained only with soils with a poor structure, having a sandy texture and less than 20 percent low activity clays. Thus, meaningful and consistent results are obtained with deep tillage only if proper characterization of the soil is first undertaken. Tillage studies on Alfisols at ICRISAT (Laryea *et al.*, 1991) where normal tillage was compared in which normal tillage with sub-soiling every year, and normal tillage with sub-soiling every third year. Sub soiling increased the sorghum grain yield from 3.09 t ha^{-1} for normal tillage alone to 3.97 t ha^{-1} for the mean of normal tillage with sub-soiling either every year or every third year (SE ± 0.33), and total dry matter from 6.16 to 7.78 t ha^{-1} (SE ±0.68) (ICRISAT, 1987). Sub-soiling also resulted in better root proliferation, especially at greater depth (Table 6). Steady state infiltration rates at 2.5 h after the commencement of infiltration were 0.3±0.0 cm h^{-1} for the conventionally tilled soil and 1.4±0.55 cm h^{-1} for the sub-soiled treatments. The accumulated amounts of water infiltrated at this time were 4.1±0.97 cm for the normal tillage and 8.6±2.37 cm for the sub-soiled treatments (ICRISAT, 1985).

Table 5. Effect of different tillage treatments on sorghum grain yield, run-off and soil loss, Alfisols, ICRISAT Centre, 1983-87[1]

Treatment	Sorghum grain yield[2] (t ha^{-1})	Run-off[3] (mm)	Soil loss[3] (t ha^{-1})
10 cm deep traditional plowing	2.52	128	1.66
15 cm non inverting primary tillage	2.83	102	1.62
15 cm deep moldboard plowing	2.76	106	1.70
25 cm deep moldboard plowing	3.22	85	1.41
SE	± 0.07	± 4.9	± 0.28

[1] *Source:* ICRISAT (1988); [2] Average values of four years (1983, 1984, 1986 and 1987).
[3] Average values of 1986 and 1987.

Table 6. Effect of sub-soiling on root density (cm cc^{-1}) 89 days after emergence of maize (Deccan Hybrid 103) on a Alfisols, ICRISAT Centre, rainy season 1984[1]

Soil depth	Root density (cm cc^{-1})		
(cm)	Sub-soiling	Normal tillage	SE
0–10	0.55	0.42	± 0.072
10–20	0.29	0.21	± 0.022
20–30	0.20	0.09	± 0.034
30–40	0.15	0.10	± 0.028
40–50	0.12	0.06	± 0.016
50–60	0.14	0.05	± 0.039

[1] *Source:* ICRISAT (1985).

In contrast to primary tillage, secondary tillage (cultivation practice executed after seeding a crop) may be repeated several times usually up to the time crop canopy prohibits further entry into the field. Shallow cultivations (inter-row cultivation), used as a secondary tillage practice control weeds, enable incorporation of fertilizer, break surface crust and may create a "dust mulch" to reduce soil evaporation. In years when early rains are poor, additional shallow tillage can be effective in reducing seasonal run-off and increasing yield (Table 7).

Table 7. Effect of inter-row cultivation (shallow tillage) in addition to normal tillage on run-off, soil loss and grain yield from a Alfisols ICRISAT Centre, 1981–83[1]

Year	Rainfall (mm)	Tillage treatment	Run-off (mm)	Soil loss (t ha^{-1})	Grain yield (kg ha^{-1}) Sole sorghum	Intercrop Sorghum	Intercrop Pigeon pea	Sole pearl millet
1981	1072	Normal[2]	246	5.0	2350			
		Additional[3]	223	4.9	2360			
		SE	±10.6	±0.34	±50			
1982	780	Normal[2]	159	3.1		2260	925	
		Additional[3]	120	2.6		2620	920	
		SE	±8.0	±0.33		±25	±41	
1983	990	Normal[2]	231	4.2				2620
		Additional[3]	196	4.0				2970
		SE	±12.3	±0.24				±32

[1] *Source:* ICRISAT (1985); [2] Two inter-row cultivations; [3] Two additional shallow inter-row cultivations.

Conservation Tillage Systems

Characteristic rainfall of SAT and limited water holding capacity of the soils make them either too wet or too dry to cultivate them. This makes timely tillage operations difficult due to limited draft power. "Conservation tillage" techniques that lower energy inputs and prevent the structural breakdown of soil aggregates have been used particularly in the U.S.A., Australia and in experimental station trials of developing countries of the SAT. Conservation tillage as defined by the Conservation Tillage Information Center (CTIC) and cited by Mannering *et al.* (1987) is any tillage or cultivation system that maintains at least 450 kg ha^{-1} of flattened small grain residue equivalent on the surface during critical erosion periods.

The success of mechanized conservation tillage depends largely on herbicides (which may be expensive and hazardous to the resource-poor farmers of the SAT), crop residues being left on the soil surface to protect it against the impact of torrential rains, and no-till planting equipment to allow precision sowing through trash. Unfortunately, most of the farmers in the SAT use crop residues to feed their animals and to construct fences and buildings. Animals are allowed to roam freely after the crops have been harvested and these animals consume residues left over.

Surface roughness is one of means to provide more time for water to infiltrate and it has attracted attention to improve *in-situ* water conservation in SAT. Pathak and Laryea (1992) studied effect of scoops (or pitting) with or without mulch under simulated rains. Run-off from scoops was significantly lower that from flat land and they were more effective under low intensity and mulch conditions. The mulching reduced run-off by 62.5 percent under pitting at rainfall intensity of 28 mm h^{-1} compared with 42.3 percent under intensity of 65 mm h^{-1}. Flat land mulching reduced run-off by 48.2 and 24.9 percent for intensities of 28 and 65 mm h^{-1} (Table 8). Similar results were obtained for soil loss. Soil loss differences were much less between for two intensities in case of scoops alone. However, mulching and pitting reduced soil loss by 60 percent at 28 mm h^{-1} rainfall intensity compared to 26.7 percent reduction in soil loss for rain intensity of 65 mm h^{-1}.

Table 8. Run-off and soil loss from pits and flat treatments from an application of 46 mm rainfall on an Alfisol at ICRISAT Centre, 1991

Treatment	Run-off			Soil loss (t ha^{-1})		
	Pits	Flat	SE	Pits	Flat	SE
Bare surface						
Rainfall intensity 28 mm h^{-1}	16	27	±3.1	1.8	2.9	±0.21
Rainfall intensity 65 mm h^{-1}	26	34	±4.2	5.0	8.3	±0.48
Surface with mulch (60% cover)						
Rainfall intensity 28 mm h^{-1}	6	14	±2.1	0.8	1.9	±0.14
Rainfall intensity 65 mm h^{-1}	15	24	±1.9	2.1	2.8	±0.29

In another experiment Pathak and Laryea (1992) compared pitting, tied ridging and flat seedbed for their effectiveness in controlling run-off and soil loss and in increasing crop production. They reported that: (i) pitting and tied ridges significantly reduced run-off and soil loss compared to flat seed bed; (ii) pitting were more effective than tied ridges for reducing run-off and soil loss and more stable; (iii) largest advantage of pitting over flat cultivation was observed during early part of growing season; (iv) there was significant increase in pearl millet grain yield in 20 mm storage capacity pittings (2.42 t ha^{-1}) over the flat seed bed (1.79 t ha^{-1}); and (v) there was no significant difference in grain yields between 10 mm storage pittings and flat treatments.

Yule *et al.* (1990) and Rao *et al.* (1998a,b) evaluated rainfall infiltration and run-off from Alfisols in no-till and tilled systems at ICRISAT centre. They compared effects of tillage (i.e. no-till, 10 cm deep and 20 cm deep) organic amendments (i.e. bare soil, rice straw mulch applied at 5 t ha^{-1} and farm yard manure applied at 15 t ha^{-1}) and biological amendments (e.g. perennial pigeonpea, *Centurus ciliaris* and *Stylosanthes hamata* alone or in combination) on run-off and infiltration.

For run-off from no-till system without any plant or straw cover the infiltration rate was controlled by surface crust. Infiltration rate through a surface crust was 9.6 mm h^{-1} and showed little change over time. Straw mulch consistently reduced run-off compared with bare plots. Their results showed that adding organic residues to no-till system could significantly lower the run-off and increase the amount of water available for the crop. Run-off from tilled plots declined sharply after tillage operation and reverted back to that from an untilled plot after a few storms totaling about 150 mm of rainfall suggesting breakdown of soil aggregates in tilled plots. Run-off of tilled system may be reduced from 35 to 10 percent of rainfall by straw. On average, straw mulch and tillage increased infiltration by 127 and 26 mm respectively. No-till mulched plots had 101 mm more water infiltrated during the year than 20 cm deep tilled bare plots, while annual infiltration in *Stylosanthes hamata* plots was only 13 mm more than no-till with straw mulch plots.

Tillage, mulch and perennial and annual rotational crop-based systems were compared for five years. Results indicate significant benefits to annual crop yield (maize, sorghum) from improved water supply due to mulching with farmyard manure or rice straw and rotation with perennial crops. Grain yields were 16 to 59 percent higher in mulched treatments compared to un-mulched treatments, with similar increases in fodder yields. Annual crop yields after four years of perennials were 14 to 81 percent higher than unmulched treatments, except for low fertility maize with *Centurus ciliaris* (Cogle *et al.*, 1997).

Lee *et al.* (1996) reported that number of vesicular-urbuscular mycorrhiza spores and propagules in the earthworm casts from the 20 cm tillage treatment was significantly higher than in the earthworm casts from other two treatments. Reddy *at al.* (1995) examined earthworm across all 15 treatments. Earthworms biomass was higher during post-monsoon period than in the early rainy season. No earthworm biomass was recorded during dry season and the worm biomass was significantly higher in perennial grasses treatment compared to annual cropping treatments with organic amendments.

Their data clearly suggest that: (i) surface crust is major factor that limit infiltration; (ii) conventional practice of mechanical tillage to break crust has little long term impact in increasing infiltration; (iii) amendments offer a sustainable way to improve infiltration rates and productivity but is constrained by the availability of the material; and (iv) there is need to develop alternative methods to improve the organic matter content and structural stability of the soil to maintain high infiltration rates.

Comparison between different tillage practices on a Vertisol at ICRISAT Centre showed run-off to be highest from zero-tilled plots and it was higher from soil tilled to a normal depth (15 cm) than from deep-tilled (30 cm) soil. Phosphogypsum treatment gave the least with losses being similar in the other three treatments in Table 9.

Table 9. Effect of different tillage practices and amendments on run-off and soil loss from maize plots, Vertisol, ICRISAT Centre, rainy season 1984[1]

Treatment	17 July rainfall 39 mm		1 August rainfall 91 mm	
	Run-off (mm)	Soil loss (kg ha^{-1})	Run-off (mm)	Soil loss (kg ha^{-1})
Zero tillage	6.8	60	14.8	103
15 cm deep tillage (normal tillage)	4.4	110	12.9	205
30 cm deep tillage	2.1	65	7.5	93
30 cm deep tillage + phosphogypsum	1.3	25	1.8	35
Crop residue + 30 cm deep tillage	2.0	70	7.4	98
SE ±0.20	± 5.9		± 0.5	± 4.9

[1] *Source:* ICRISAT (1986).

On flat land, the highest yield of maize–chickpea relay cropping on the Vertisol in the two seasons was obtained from the 30 cm deep primary tillage treatment while zero-tilled plots gave the lowest yield. On broad bed and furrow (BBF) configuration, incorporation of 5 t ha^{-1} crop residue with deep primary tillage (30 cm) gave on average the highest yield of maize and chickpea. There were no significant differences between the other treatments for both maize and chickpea (Table 10).

Table 10. Effect of different tillage practices and amendments on grain yields (kg ha^{-1}) of maize and chickpea, Vertisol, ICRISAT Centre, 1983-84 and 1984-85[1]

Treatment	Yield (kg ha^{-1})			
	1983-84		1984-85	
	Maize RS[2]	Chickpea PRS[2]	Maize RS	Chickpea PRS
Flat configuration				
Zero tillage (including chemical weed control)	3500	330	2320	340
15 cm deep primary tillage (normal tillage)	4030	990	2970	970
30 cm deep primary tillage	4390	1160	3140	1060
BBF configuration				
15 cm deep primary tillage (normal tillage)	4380	1150	3320	1090
15 cm deep primary tillage, cross plowing and reformation of beds every year	4290	1160	3110	1030
30 cm deep primary tillage	4240	1050	3300	1170
30 cm deep primary tillage (without blade hoeing before sowing second crop)	4210	830	3280	1060
30 cm deep primary tillage + application of phosphogypsum at 10 t ha^{-1}	4710	1280	3270	1060
Crop residue[3] incorporation at 5 t ha^{-1} with 30 cm deep primary tillage	5010	1240	3240	1250
SE ±133	±49	±105	±56	

[1] *Source:* ICRISAT (1986); [2] RS is rainy season; PRS is post-rainy season; [3] Chopped dry rice straw incorporated in 1983-84, chopped dry maize stalks incorporated in 1984-85.

A system of improved management for Vertisols has been developed at ICRISAT. The essential components of this management strategy (Kanwar, 1981; Kampen, 1982) include:

- A system of resource conservation, management, and use based on small watersheds;
- A well-designed, semi-permanent or permanent broad bed and furrow system or well-graded flat system;
- Land smoothing and installation of drains to ensure effective surface drainage and run-off disposal from the field;
- Performing primary tillage operations for both post-rainy as well as rainy season crops immediately after harvesting the previous season's crop, when the soil has adequate moisture and is friable;
- Shallow cultivation of the land (only the beds) whenever an effective rainfall (>20 mm) is received;
- Application of moderate amounts of N and P fertilizers, followed by dry sowing about 1 week before the expected date of onset of the rainy season;
- Use of high-yielding varieties and other recommended agronomic practices.

Using the above techniques, Vertisols have been managed successfully at ICRISAT to produce high and stable yields even under very fluctuating rainfall conditions (Table 11). El-Swaify *et al.* (1985), Kanwar (1981), and Kampen (1982) have discussed various aspects of this approach for the management of Vertisols. In addition to direct benefit to crop yield, improved soil and crop management has been more effective in reducing resource losses in terms of run-off and soil erosion than the traditional rainy season fallow system (Pathak *et al.*, 1985). On an average, the improved system reduced annual run-off to one-third, soil loss to one-eleventh and peak run-off rate to one-half when compared with traditional rainy-season fallow system (Table 11).

As shown in Table 11, the performance of the broad bed and furrow system was consistently superior to the traditional system in reducing annual run-off, soil loss, and peak run-off rate. In 1977, when rainfall was very low and moisture conservation was crucial, the broad bed and furrow system conserved most of the annual rainfall, producing an annual run-off of only 1 mm. In contrast, when removal of excess water by drainage was crucial, during the high rainfall years of 1975 and 1978, this system produced substantial run-off of 162 mm in 1975 and 273 mm in 1978. The good control of run-off in the improved system was due to good crop cover during the rainy season, land smoothing, slope adjustment, and controlled run-off velocity as it flows through many furrows and disposed through grassed waterway.

Table 11. Annual rainfall, run-off, soil loss, and peak run-off rate for a cropped Vertisol with broad bed and furrow system and a traditional rainy season fallow system (1975–1980)

Year	Rainfall (mm)	Broad bed and furrow at 0.6% slope, cropped			Traditional flat, rainy season fallow		
		Run-off (mm)	Peak run-off rate (m^3 s^{-1} ha^{-1})	Soil loss (t ha^{-1})	Run-off (mm)	Peak run-off rate (m^3 s^{-1} ha^{-1})	Soil loss (t ha^{-1})
1975	1041	162	0.06	1.39	253	0.15	5.21
1976	687	73	0.09	0.98	238	0.16	9.20
1977	585	1	0.01	0.07	53	0.06	1.68
1978	1125	273	0.11	2.93	410	0.15	9.69
1979	690	73	0.08	0.70	202	0.15	9.47
1980	730	116	0.06	0.97	166	0.11	4.58

Results of 27 years study on two Vertisol watersheds BW1 (improved system, broad bed and furrow, cropped) and BW4 (traditional flat, rainy season fallow) show that yields were higher in the improved system than in the traditional system. Sorghum and pigeonpea together recorded an average grain yield of 4.7 t ha^{-1} yr^{-1} compared with 0.9 t ha^{-1} yr^{-1} average yield of sole sorghum in the traditional system (Fig. 1). Annual gain in the grain yield improved system was 77 kg ha^{-1} yr^{-1} compared with 26 kg ha^{-1} yr^{-1} in the traditional system (Wani *et al.*, 2003). Improved system not only increased crop productivity but also increased soil organic content, total N, and available N, and Olsen P and soil respiration (Table 12). It was estimated that an additional capacity of 7.3 t C ha^{-1} (335 kg C ha^{-1} yr^{-1}) was sequestered in soil under the improved system compared with the traditional system over 26-year period (Wani *et al.*, 2003). Pathak *et al.* (2004) evaluated biophysical indicators for impact assessment in improved and traditional systems and reported that soil properties (texture, bulk density, total and air filled porosity, penetration, sorptivity and cumulative infiltration) were better in improved system compared to traditional system (Table 12). Recent research on a watershed (500-1000 ha) scale in India has also shown that natural resource management interventions (the use of improved varieties along with soil fertility management and soil and conservation practices) reduced soil loss and increased groundwater recharge and storage in surface tanks (Wani *et al.*, 2002a).

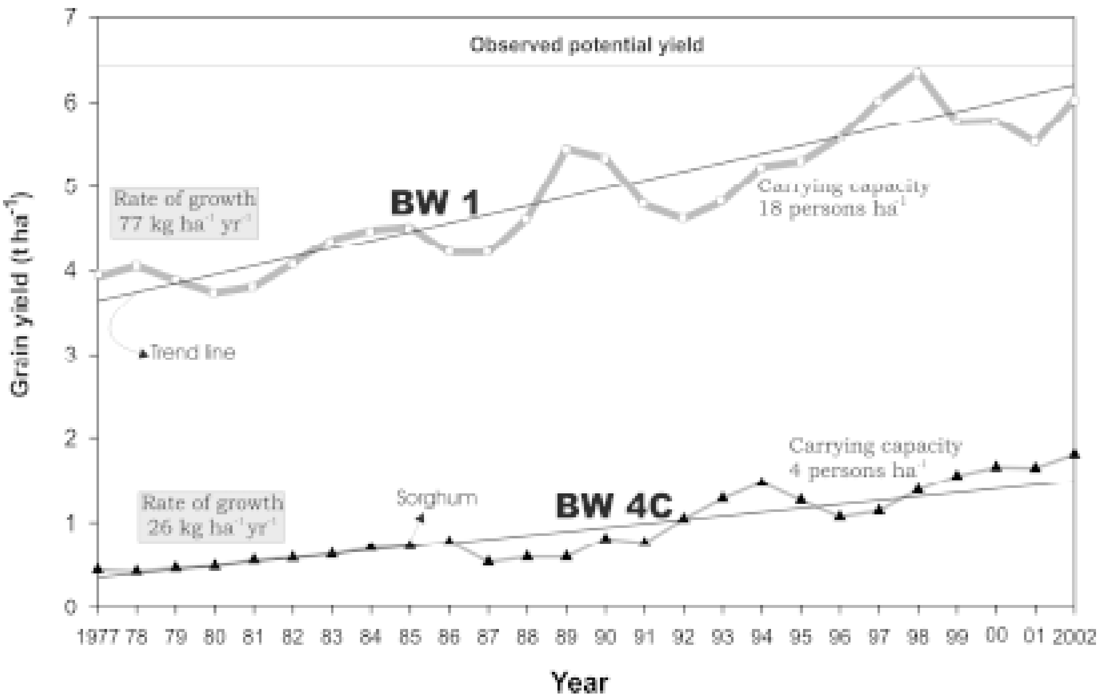

Fig. 1. The effect of management practices on physical properties of Vertisols at ICRISAT,Patancheru, India (1998–99).

Application of the improved technology has implication to grow crop during monsoon season in region such as Madhya Pradesh where approximately 2.02 million ha is under fallowing (Wani *et al.,* 2002b). It will help in increasing income to the farmers besides preventing land degradation due to run-off erosion.

Table 12. Annual rainfall, run-off, soil loss, and peak run-off rate for a cropped Vertisol with broad bed and furrow system and a traditional rainy season fallow system (1975–1980)

Soil properties	Improved land management technology		Traditional technology
	Broadbed	Furrow	Flat
1. Texture (0-10 cm soil layer)			
Clay (%)	50.8		46.3
Silt (%)	21.5		21.4
Fine sand (%)	15.5		15.4
Coarse sand (%)	12.2		16.9
Gravel (%)	4.8	1.5	14.5
2. Bulk density (g/cm^3)	1.2	39.5	1.5
3. Total porosity (%)	52.1	33.0	41.5
4. Air-filled porosity (%)	41.0	9.8	32.0
5. Penetration resistance (Mpa)	1.1	100.6	8.5
6. Sorptivity ($mm/h^{4/2}$)	121.2	205.7	88.5
7. Cumulative infiltration in 1 h (mm)	347.2		264.7

Source: Pathak *et al.,* 2004.

CONCLUSIONS

Tillage research conducted at the ICRISAT Centre on Vertisol and Alfisol show that some of the improved management practices such as minimum tillage can have immediate and positive benefits over the traditional management tillage system. Benefits are ephemeral and include increases in crop yield, marked reduction in soil erosion and run-off losses. For Alfisols several soil management practices such as deep tillage/ripping, pittings, frequent shallow tillage, flat on grade, organic and organic and biological amendments were more effective than traditional tillage systems. There is need to adopt crop production system which generate more biomass for its use as mulch on soil surface and tillage system with long testing benefits on Alfisols. A system of broad bed and furrow system has been found to be effective and sustainable for enhancing productivity and protecting environment in ensuring good surface drainage of water, control of erosion and in conserving water and improving physical, biological and chemical properties of soil profile on Vertisols.

Conservation tillage systems have proved to be effective at ICRISAT Centre both on Alfisols and Vertisols and worth extending to the farmers. The major drawback with its adoption in India is lack of crop residues availability (used to feed animals) and also unavailability of bullock drawn equipment to sow seeds precisely into residue left on the soil surface. Mass production of biomass and crop residues and its use as organic amendment should be explored and applied to increase and sustain long-term productivity and protect the environment.

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Prospects and Limitations of Reduced Tillage in Arid Zone

Pratap Narain and Praveen Kumar
Central Arid Zone Research Institute, Jodhpur 342 003, Rajasthan, India

ABSTRACT : In the last 2-3 decades considerable research has been done to evolve effective reduced tillage/no-tillage system of crop production in view of increasing costs of energy, equipment, labour and concerns about soil erosion and sustainability of production system. Conservation tillage comprises tillage in conjunction with residue management. In reduced tillage systems, tillage intensity or frequency is reduced. In some reduced tillage systems, the entire surface is tilled at least once and all residues are incorporated while in others, the entire area is tilled but most residues are retained on the surface. In no-tillage systems, the land surface is disturbed just to place seeds in the soil, retaining entire residue on the surface.

INTRODUCTION

The residue-retaining systems of reduced tillage and no-tillage are especially effective in controlling soil erosion and increasing soil water storage by reducing run-off, increasing infiltration and curtailing evaporation. As water and soil conservation are crucial for favourable and sustained crop production in arid and semi-arid regions conservation tillage is important in these regions.

Although favourable results have been obtained with reduced tillage/no-tillage systems in many cases, there are some problems associated with them. One major problem in arid and semi-arid regions is limited availability of crop residue and its utilization for feed and fuel. Reduced tillage systems of developed countries cannot be copied in toto without modification in India, albeit with caution and the prevailing soil, climatic, social, and economic conditions of the region must be considered. Some results and issues of no-tillage and reduced tillage on crop production in arid zone have been discussed.

There has been a paradigm shift in agriculture in last couple of years mainly due to international trade agreements (WTO) where direct or indirect subsidies to farmer continue to be a bone of contention between developed and underdeveloped nations and a realization that under the cover of self-sufficiency in food and overflowing granaries there is a huge population which is either underfed or suffers from malnutrition. These realizations direct us to increase the benefit: cost ratio of our agriculture. In other words we have to get best out of investment and resources need to be properly utilized which is the basic philosophy behind conservation agriculture.

Conservation tillage in agriculture

In ancient times, seeds were sown in soil with little or no soil preparation but tillage came into being to alleviate detrimental effects of weeds and poor soil conditions. The number of tillage operations used to produce a crop varies widely and depend on the crop grown, soil and climatic conditions, the economic level, degree of mechanization used, attitudes, and management capability of the producer. Still subsistence farmers in Africa undertake one pre-planting operation with hand tools and one or two post-planting operations to control weeds. In most districts of arid Rajasthan like Pali, Jodhpur and Nagaur soils are tilled with harrow after receiving the first showers and seeds are sown in crossed furrows with tractor drawn harrow fitted with a seed placing device after second rainfall. Only in duny areas seeds are sown directly with a harrow after monsoon showers without pre-sowing tillage. Planting, spraying, and harvesting are not tillage operations yet, impose traffic on the land. Commonly referred conventional tillage is observed with more than the lowest and less than the highest number of operations. A conventional tillage may actually be excessive tillage for optimum soil and water conservation and sustained crop production under the prevailing conditions and may cause decrease in soil organic matter, deterioration of soil structure, increased run-off, low water storage, increased evaporation, increased erosion, and thus poorer crop yields.

Reduced tillage forms an essential component of conservation agriculture mainly due to: (i) adverse effects of tillage on soil structure and organic matter, and (ii) tillage operations demand lot of energy which is the main ingredient in agriculture production. The relationship between crop yield and power is generally linear. Average farm power availability is 2.4 hp ha^{-1} in Japan which is highest in the world against 0.35 hp ha^{-1} in India which is among the lowest. Power availability in drylands of India is even lower (about 0.25 hp ha^{-1}). Of the various sources of power in arid and semi-arid regions in India, human labour constitute 11.6% while 50.8% is needed for drafting in various tillage operation. By adopting zero tillage we reduce the power requirement and hence reduce the cost of cultivation.

Reduced tillage systems

The emphasis on reduced tillage systems apart from its adverse effects on soil resulted from such factors as increasing energy costs, high equipment inventories and costs (e.g., tractors and related implements), high labour costs, increased concern about soil erosion, and the need for more efficient utilization of water for crop production (Unger, 1984). Effective weed control has been a major limitation in reduced tillage, but wide array of herbicides helped effective weed control in reduced tillage systems for many crops. There are two well recognized systems of reduced tillage: (i) stubble-mulch tillage, and (ii) no-tillage.

Stubble-Mulch Tillage

Stubble-mulch tillage refers to tilling a soil in such a manner that crop residues are maintained on the soil surface. It is also referred to as mulch farming, trash farming, mulch tillage, and plough-less farming. The system was developed to combat erosion by wind in the Great Plains of the United States and Canada. With stubble-mulch tillage, residues remained anchored in the surface soil and thus help control erosion by wind and water and also conserve soil moisture (Duley and Russel, 1942; McCalla and Army, 1961). Tillage implements that loosen a soil and retain most residues on the surface include V-sweeps (60 cm or wider), straight-blade machines, chisel plows, one-way disk plows (used when large amounts of residue is present), and rodweeders (Unger and McCalla, 1980).

Stubble-mulch tillage is adaptable to all soil types, but coarse-textured soils require more surface residues than fine-textured soils to control erosion by wind (Table 1) (Fenster, 1973; Hanway, 1970; McCalla and Army, 1961). Hence, erosion by wind would be more easily controlled by stubble-mulch tillage on fine-than on coarse-textured soils. In addition, where residues amounts are low, a rough, cloddy surface that aids control of erosion by wind usually can be produced by tillage. Such roughened surfaces provide additional protection against erosion by wind in emergency situations.

Table 1. Approximate amount of residues needed to maintain erosion below a tolerable level of 11 Mg ha^{-1} over various types of soil

Soil texture[a]	Water erosion flat wheat residue (Mg ha^{-1})	Wind erosion (Mg ha^{-1})					
		Wheat residue		Growing wheat		Sorghum residue	
		Standing	Flat	Standing	Flat	Standing	Flat
Silts	16	5	10	6	5	20	29
Clays and silty loams	21	9	18	11	9	37	53
Loamy fine sands	10	12	24	13	10	47	69

[a] Silts with 50%, clay and silty clay with 25%, and loamy sand with 10% non-erodible fractions (greater than 0.84 mm diameter).
Soucce: Anderson (1968) and Fenster (1973).

No-tillage systems

A major reason for performing tillage is to loosen a soil and improve its condition for crop establishment and growth and to improve water infiltration. However, except on poorly drained soils, on some sandy soils, under low-temperature conditions, or where weed control is poor, crop yields are generally favourable and water infiltration often is higher on no-tillage than on tilled area (Unger, 1984). The generally favourable results with no-tillage are attributed to the fact that soil compaction, as measured by bulk densities, is often not much higher with no-tillage than with other tillage methods after the tilled soils have become settled by rainfall, except where the surface soil has been compacted by traffic or by grazing animals. Such compaction can usually be alleviated by a sweep or chisel implement operation without destroying a significant part of the surface residues. As a result, water conservation was similar where no-tillage and limited tillage (e.g., one sweep tillage) were used (Unger, 1981; Unger *et al.,* 1971). The advantages of no-tillage systems compared to clean tillage or even other reduced tillage systems include improved erosion control, increased use of land, increased water conservation, equal or higher crop yields, reduced energy requirements, reduced equipment inventories, reduced equipment wear and tear, reduced labor requirements, and greater net returns.

Improved water conservation with no-tillage results from surface residues that retard the flow of water across the surface, thereby providing more time for water infiltration, and from the surface protection provided by residues. These residues dissipate the energy of falling raindrops, thus minimizing dispersion of soil aggregate and surface sealing and, thereby, maintaining favourable rates of water infiltration into soil. Surface residues also reduce soil water evaporation. As a result, more stored water is retained for later crop use.

Weed control in reduced tillage systems

Lack of proper weed control without tillage had been a major impediment in reduced tillage systems. Development of a wide array of herbicides contributed greatly to the development of effective reduced tillage systems for many crops. By controlling weeds with herbicides, tillage for weed control is often no longer required. Hence, reduced tillage systems have the potential for minimizing soil degradation that can result from excessive tillage. There are many tillage-herbicide combination systems. Common practices are to: (i) use tillage initially to control existing weeds, loosen the soil, or incorporate some residues, and then use herbicides for subsequent weed control; (ii) control weeds initially with herbicides so that more residues can be maintained on the surface during highly erosive periods, and then use tillage to prepare a seedbed as planting time approaches; or (iii) use tillage for one crop and herbicides for the second crop in two-crop rotations. The tillage is often performed with sweeps or blades that undercut the surface, thereby controlling weeds and retaining most crop residues on the surface.

Of late there has been excellent results of zero-tillage in rice-wheat under ridge and furrow system in Indo-Gangetic plains. This system allows advancing the date of sowing, economize water use, recycling of huge quantity of crop residues and increases crop yield. The practice was nearly non-existent couple of years ago but had spread to about 1 m ha by 2003-04. The situation in arid region is vastly different from Indo-Gangetic plains in terms of water availability and also availability of crop residues. Stewart (1992) has suggested that far greater efforts are needed to obtain sustainability in the dry and hot climate than in wet and cool climate. Against this background the results of conservation tillage at CAZRI are presented.

Conservation tillage in arid region: Experiences at CAZRI

The research on no-tillage in arid zones of India started in early eighties. In these studies effect of no-tillage was compared with 1, 2 and 3 disking for two years. Results showed that growth and yield of cowpea was better after tillage (Table 2). Addition of mulch increased crop yield in both tillage and no-tillage plots but the yields continued to be lower than in tilled plots. This may be due to higher weed growth in no-tillage plots. These results show the necessity of tillage to achieve good crop yield. The duration of the study was far too short to get a longer term perspective. From 1995 to 98 another experiment was conducted to study the effect of no-tillage on pearl millet yield. Results showed that in all the four years average yield of pearl millet was lower under no-tillage and compared to tillage but in 1998 no grain yield was recorded from no-tillage plots (Table 3). During 1998, 25 days long drought phase (from 5 days after sowing) had reduced initial plant population of 200,000 plants ha^{-1} to 89785 and 130928 in no-tillage and tillage plots respectively. Root growth was also nearly half in no-tillage plots (average volume 13.5 cc $plant^{-1}$ and weight 10.8 g $plant^{-1}$) as compared to tilled plots (average volume 30.4 cc and weight 24.6 g $plant^{-1}$). These results indicated adverse effects of no-tillage on plant growth under the conditions of early drought.

Table 2. Effect of different tillage levels on soil properties, grain yield and water use efficiency of cowpea in 1983 and 1984

Tillage	BD ($g\ cc^{-3}$)	Pre-mergence mortality in 1983 (%)	Grain ($q\ ha^{-1}$)		WUE ($kg\ ha^{-1}\ mm^{-1}$)	
			1983	1984	1983	1984
No-tillage	1.55	80	4.60	11.7	1.6	6.9
1 disking	1.38	30	10.0	14.7	4.4	7.5
3 disking	1.30	16	12.0	12.1	5.4	8.2

Source: Gupta and Gupta (1986); Gupta (1987).

Table 3. Pearl millet yield under tillage and no-tillage conditions

Year	Pearl millet yield ($q\ ha^{-1}$)	
	Tillage	No-Tillage
1995	6.48	5.84
1996	9.09	2.26
1997	7.14	2.26
1998	3.83	-

Source: Aggarwal *et al.* (1998).

Table 4. Effect of addition of clusterbean residues on pearl millet yield

Treatment	Yield (q ha^{-1})	
	Grain	Straw
No-Tillage with clusterbean residue	5.09	12.09
Tillage with clusterbean residue	5.60	16.09

Source: Aggarwal *et al.* (1998).

crop residues in arid region is very low on one hand and on the other hand the residues of the major crop i.e. pearl millet are used as animal fodder. Therefore, the scope of residue application under no-tillage is largely limited and will have very few takers. In view of this, in next experiments rotations of pearl millet with three legumes (mung bean, moth bean and clusterbean) was tried under no-tillage conditions. The hypothesis was that deep penetration of soil by taproots of legumes, consequent addition of organic matter at lower depths by roots would help in water movement. Further arid legumes shed most leaves at maturity and thus leaf fall on surface would mimic the effect of residue application thus increasing the productivity of no-tillage systems. Research work in Australia also supported this view where introduction of legumes lead to a higher increase in crop yield as compared to fertilizers. Pearl millet grown in rotation with all legumes after completion of two cycles, still yielded lower in no-tillage than in tilled plots (Table 5). Soil chemical analysis showed that microbial activity is drastically reduced due to no-tillage (Table 6). This in turn may drastically reduce nutrient transformation. Also the weed biomass in the no-tillage plots was about three times higher than in tillage plots (Fig. 1).

Table 5. Pearl millet yield due to crop rotation (after two complete rotations)

Rotation	Grain yield (q ha^{-1})		Straw yield (q ha^{-1})	
	Tillage	No-tillage	Tillage	No-tillage
Pearl millet after pearl millet N_0	6.2	5.2	22.5	20.0
Pearl millet after pearl millet N_{40}	9.4	7.8	33.8	28.5
Pearl millet after clusterbean	9.4	7.8	30.0	28.1
Pearl millet after moth bean	8.3	7.4	28.8	26.5
Pearl millet after mung bean	9.1	7.6	28.2	26.6

Source: Kathju *et al.* (2002).

Table 6. A comparison of soil and plant parameters of tillage and no-tillage fields after three years.

Parameter	Tillage	No tillage	% Increase or decrease
Soil compaction (kg cm^{-2})	2.15	2.58	20.0
Weed mass (g m^{-2})	10.04	36.88	267.3
Dehydorgenase activity (p kat)	4.80	4.50	7.0
Cellulase (n kat)	1.41	1.65	17.0
Acid phosphatase (p kat)	3.62	3.91	8.0
Alkaline phosphatase (p kat)	8.81	9.69	10.0
Protease (p kat)	0.14	0.16	14.0
Transaminase (p kat)	17.82	20.31	14.0
Leaf turgescence (%)	66.80	73.68	10.0
Chlorophyll content (g^{-1})	1.31	1.35	3.0

Source: Kathju *et al.* (2002).

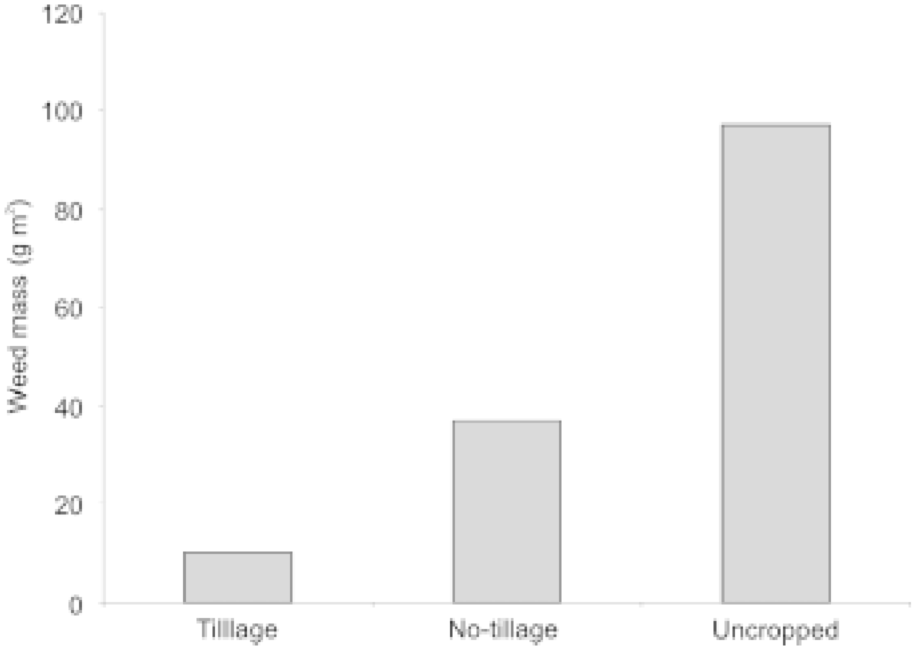

Fig. 1. Effect of tillage on weed mass.

These results clearly bring out heavy competition by weeds and low nutrient transformation due to low enzyme activity as the major reasons of low yield under no-tillage in arid zone. In the no-tillage conditions followed in developed countries, weeds are controlled by weedicides. But advocating weedicides under the monsoon dependent and uncertain yield situations of Indian arid zone is itself questionable.

Soils in arid region are generally sandy, and very poorly structured and consequently capillary spaces are fewer as compared to a fine textured soils. In the sunny days following rains, surface soil dries rapidly but movement of moisture retained in deeper layers to surface is restricted due to mulching function of sand and therefore root activity continues in deeper layers. Consequently, infiltration of water to lower depths is extremely important for plant growth in arid region. In no-tillage plots, the surface pores are clogged by silt due to beating action of raindrops. This reduces infiltration and also aeration whereas in tilled plots the clogged pores are broken due to mechanical action of tillage thus improving infiltration and aeration. Slow infiltration and low aeration may thus be others reason for low crop yield under no-tillage. To further prove this point, we estimated water content from different soil depths during growing period of pearl millet. We had expected higher depletion of moisture from upper layers in no-tillage plots due to shallower roots and from deeper layers in tillage plots due to deeper root growth. But we did not find such differences. Apparently the opposite effects of shallower water movement, poor plant growth and consequent lower use of water in no-tillage plots and deeper water movement, better growth and higher water use nullified the differences. In 2004, we measured the waterfront after first rain of 18 mm. The water moved to 17 and 22 cm depth in no-tillage and tillage plots respectively in twelve hours after rains (Fig.2) which proved our point of view.

Our results with no-tillage show a limited success with this concept in Indian arid region. One of the major reason is that the soils are tilled only once or twice every year and not excessively as in Punjab, Haryana, western UP etc and therefore problems associated with excessive tillage are also not observed. Another major factor that thwarts the success of no-tillage systems in arid and semi-arid regions is low residue production by rainfed crops. Anderson (1968) had shown that 47 Mg ha^{-1} residues are required in loamy sand soils to

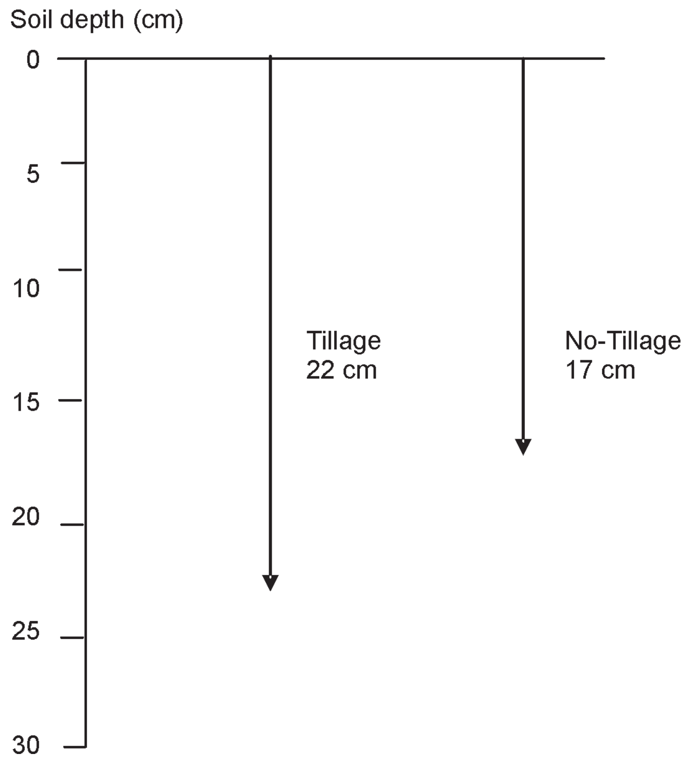

Fig. 2. Movement of water front in tilled and untilled field.

control wind erosion (Table 1). Pearl millet residues are similar to that of sorghum. The average production of pearl millet in the region is generally about a Mg ha^{-1}, therefore, required quantity of residues are just not available. Further, pearl millet residues are a major source of animal feed. This is an important factor in this region negating the use of residue for soil application as about 19% of the farmer's income is from livestock. Further even when applied in field on experimental scale residues are easily destroyed by termites. Mustard and sesame residues are not used as fodder but due to their slow decomposition are generally not used for soil application and are burnt.

CONCLUSION

Lack of residue availability, is a major deterrent to the adoption of reduced tillage systems in arid regions. High cost of tillage-herbicide combination, limited availability of some herbicides and the limited availability of suitable herbicide application equipment, is another limitation. Of increasing concern worldwide is also the effect of increased chemicals (including herbicide) usage on the environment which may offset the beneficial effects of no-tillage. As a rule, higher management levels are required for no-tillage than for conventional tillage crop production. Because no-tillage systems, in many cases, are vastly different from conventional tillage systems, farmers would require to be trained. The harsh climatic condition can also be an impediment in success of no-tillage in arid region. In arid Rajasthan where residues are limited, the soil and water conservation benefits of residues cannot be achieved, alternative practices like contouring, terracing, forming depressions for temporary water storage on the surface, and strip cropping may be helpful. Producing a cloddy surface though tillage may also help against wind erosion. Also we may concentrate on utilizing sesame and mustard residues but till that is achieved we may continue with tillage albeit carefully. There is lack of systematic long term studies proving superiority of no-tillage or otherwise in arid zone and this needs to be perused.

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Conservation Agriculture in Rainfed Semi Arid Tropics – Some Past Experiences, Lessons Learnt and Future Scopes

Y.S. Ramakrishna, K.P.R. Vittal and K.L. Sharma
Central Research Institute for Dryland Agriculture, Hyderabad 500 059, Andhra Pradesh, India

ABSTRACT : The cumulative effects of long-term cultivation had deleterious effect on the soil organic carbon status in our country. This has led to reduction in soil buffering capacity against drought. Further deterioration fortunately is hampered by low amount of draft power involved in various rainfed agricultural activities. In future drought amelioration in rainfed agriculture is entirely dependent on rejuvenating soil organic carbon status. Time has come to look into other practices other than increasing not only the rainwater use efficiency. An important concept in this direction is conservation agriculture, which can be defined as tillage, soil cover and rotation activities. The available research experience in an integrated fashion shows a possibility in practising the same. An example is that, with the low labour productivity in total factor productivity, the weedicides are attracting the attention of farmers at present to control the weeds. The past experiences of conservation tillage reveal that the major toll of yield is taken by poor germination and poor crop stand because of poor microclimatic environment and hard setting tendencies of soil, excessive weed growth and less infiltration of water to the crop root zone. Therefore, the important aspects which need concentrated research focus include appropriate time of sowing, suitable seed rate, depth of seed placement and soil contact, row orientation, etc. Suitable cultivars having responsiveness to inputs also become important component of conservation farming.

INTRODUCTION

Agricultural use of land is causing serious soil losses in many places across the world including Indian subcontinent. It is probable that human race will not be able to feed the growing population, if this loss of fertile soils continues at the existing rate. There are several causes of inadequate land use. In many developing countries, hunger is compelling the community to cultivate land that is unsuitable for agriculture and which can only be converted to agricultural use through enormous efforts and costs, such as those involved in the construction of terraces and other surface treatments. Indian sub-continent predominantly represents wide spectrum of climate ranging from arid, to semi-arid, sub-humid and humid with wider variation in rainfall amount and pattern. Seasonal temperature fluctuations are also vast. Soils representing rainfed regions are marginally low in organic matter status. The first predominant cause of soil degradation in rainfed regions undoubtedly is water erosion. The process of erosion sweeps away the topsoil along with organic matter and exposes the subsurface horizons. The second major indirect cause of degradation is loss of organic matter by virtue of temperature mediated fast decomposition of organic matter and robbing away of its fertility. Above all, the several other farming practices such as reckless tillage methods, harvest of every small component of biological produce and virtually no return of any plant residue back to the soil, burning of the existing residue in the field itself for preparation of clean seed bed, open grazing etc aggravate the process of soil degradation. If it is recalled back, several of these causes made even the highly developed country like United States of America to reorient their agriculture towards conservation agriculture many decades back. To combat the problem of wind erosion, stubble mulching was developed in Great Plains of United States and Canada. It was understood that the falling raindrops is the main detaching agent in sheet erosion by water. Pioneering work of mulching in cropping systems was started in Nebraska by Duley and Russel (1939). Development of non-selective contact weed control methods that became commercially available in the mid 1960 was a major breakthrough in making conservation tillage work in some of the countries. Nevertheless, advertently and inadvertently, crop rotations, inclusion of legumes in cropping systems, addition of animal based manures, adoption of soil water conservation practices, various permutations and combinations of deep and shallow tillage, mulching of soils with *in situ* grown and externally brought plant and leafy materials always remained part and parcel of Indian agriculture time to time during the past.

Despite all these efforts, the concept of conservation farming could not be followed in an integrated manner to expect greater impact in terms of protecting the soil resource from degradative processes.

CONSERVATION AGRICULTURE – BROADER CONCEPTS AND DEFINITION

Conservation agriculture, in broader sense includes all those practices of agriculture, which help in conserving the land and environment while achieving desirably sustainable yield levels. Tillage is one of the important pillars of conservation agriculture which disrupts inter-dependent natural cycles of water, carbon and nitrogen. Conservation tillage is a generic term encompassing many different soil management practices. It is generally defined as 'any tillage system that reduces loss of soil or water relative to conventional tillage; mostly a form of non-inversion tillage allows protective amount of residue mulch on the surface (Mannering and Fenster, 1983). As elaborated by Lal (1989), the tillage system can be labeled as conservation tillage if it has the following features:

i) allows crop residues as surface mulch,

ii) effective in conserving soil and water,

iii) maintain good soil structure and organic matter contents,

iv) maintains desirably high and economic level of productivity,

v) cut short the need for chemical amendments and pesticides,

vi) preserves ecological stability, and

vii) minimizes the pollution of natural waters and environments.

In order to ensure the above criteria in agriculture, there is a need to follow a range of cultural practices such as;

i) using crop residue as mulch;

ii) adoption of non-inversions or no-tillage systems;

iii) promotion of crop rotations by including cover crops, buffer strips, agroforestry, etc.;

iv) enhancement of infiltration capacity of soil through rotation with deep rooted perennials and modification of the root zone;

v) enhancement in surface roughness of soil without jumping into fine tilth;

vi) improvement in biological activity of soil fauna through soil surface management; and

vii) reducing cropping intensity to conserve soil and water resources and building up of soil fertility

Conservation tillage approach, in its spirit is based on three cardinal components employed in soil and crop management. These are tillage, mulch and rotations.

The effects of conservation tillage on various soil properties, organic matter status, soil nutrient status and environmental quality have comprehensively reviewed by Blevins and Frye (1993), Lal (1989), Unger and McCalla (1980) and Unger (1990). From the various reviews, it is understood that no single tillage system is suitable for all soils and climatic conditions. The predominant advantages of the conservation tillage have been found in terms of soil erosion, to control water conservation, less use of fossil fuels specifically for preparation of seed bed, reduced labour requirements, more timeliness of operations or greater flexibility in planting and harvesting operations that may facilitate double cropping, more intensive use of slopping lands and minimized risk of environmental pollution. Some of the discouraging and undesirable effects of conservation tillage has been reported as: (1) increase in use of herbicides and consequently increased cost, (2) problems and difficulties in controlling some of the infested weeds, (3) difficulty in managing poorly drained soils, (3) slower warming of temperate soils due to surface residue layer during winter and springs which delays germination and early growth. However, in tropics this negative aspect can become an asset in helping in maintaining relatively lower temperature and thereby enhancing germination. It also helps in preserving soil and water resources.

Scope of conservation farming in rainfed agriculture

As stated above, broadly, the conservation agriculture has the main aim of protecting the soil from erosion and maintaining, restoring and improving soil organic carbon status in the various production systems, hence more suited and required in rainfed agriculture. Predominantly, this goal can be achieved through minimizing the soil tillage, inclusion of crop rotation or cover crops (mostly legumes) and maintaining continuous residue cover on soil surface. The former is governed by the amount of draft, a farmer is using and the latter by produce amount, harvesting index and fodder requirements including open grazing. The crop rotations are induced by crop diversification, which has wider scopes in the rainfed agriculture than in irrigated agriculture. Diversification will help not only in minimizing the risk occurred due to failure of crops, improving total farm income but also in carbon sequestration.

Tillage, which is one of the predominant pillars of conservation agriculture, disrupts the inter-dependent natural cycles of water, carbon and nitrogen. Tillage unlocks the potential microbial activity by creating reactive surface area for gas exchange on soil aggregates exposed to higher ambient oxygen concentration (21%). Tillage also breaks the aggregate to expose fresh surfaces for enhanced gas exchange and perhaps, may lead to more carbon loss from the interior that may have higher carbondioxide concentration. Thus, an intensive tillage creates negative conditions for carbon sequestration and microbial activity. However, the main question is whether the intensity of tillage or length of cultivation of land which is an environment enemy in production agriculture in terms of loss of carbondioxide, soil moisture through evaporation and biota dwindling is a major production constraint to agriculture or not. The developed countries suffer from heavy-duty mechanization, while India is suffering from long use of plough without caring much about the maintenance of land cover. The major toll of organic C in slopping lands has been taken by water erosion due to faulty methods of up and down cultivation.

Work done in dryland centers – Research experiences

The salient features of the studies conducted on some of the aspects of conservation farming comprising soil water conservation aspects, tillage, residue application, mulching, INM and other related aspects representing rain fed areas is presented in the following section (AICRPDA, 1999-2003)

The total energy input in Indian agriculture has increased 5.4 times during past 60 years, while the production increased 3.6 times. The total power availability for Indian Agriculture has increased from 0.25 kW/ha in 1951 to 1.13 kW/ha in 2002. However, the average power availability for dryland agriculture is only 0.45 kW/ha. From the viewpoint of production, in short run, among the various implements used, mold bold plough was found to be beneficial in Red Alfisols having hard murrum layer at subsurface depth. This was beneficial in the inversion of clay argillic horizons to the top and its mixing,. Apart from bringing the fertile layer at the top, this also temporarily alters the relative proportion of textural constituents in the surface layer. Contrary to this, mold bold plough and disc plough have been ranked as major enemies of soil from the viewpoint of inversion of surface residues and their fast decomposition resulting in more CO_2 emissions to the atmosphere from the agricultural lands (Anderson, 1968; Jones *et al.,* 1990).

Table 1. Energy use for seed bed preparation in rainfed crops

Rainfed crop	State	Energy (MJ/ha)
Rice	West Bengal, Orissa, Madhya Pradesh	1460
Wheat	Madhya Pradesh	940
Soybean	Madhya Pradesh	790
Chickpea	Madhya Pradesh	765
Sorghum	Madhya Pradesh	840
Sorghum + Pigeonpea	Andhra Pradesh	480
Castor	Andhra Pradesh	450
Groundnut	Andhra Pradesh	420

In general, the rainfed soils suffer due to low soil organic matter and surface crusting with high run-off but low soil loss. The tillage in rainfed lands, mostly done for seedbed preparation and as inter-culture operations to avoid weed competition, does not use any heavy equipment. Apart from this, the summer tillage with the blade harrow is mostly practised as weed control measure and for enabling the capture of early season rainfall for soil moisture builds. This helps in better establishment of seedlings. Mostly, the amount of tillage in dryland regions depends on cropping intensity, soil type and rainfall patterns. At Hyderabad, the off-season tillage helped in weed control and better *in situ* conservation of rainwater during early showers, which paid dividends.

Table 2. Effect of off-season tillage in Alfisols at Hyderabad

Practice	Sorghum grain yield (3) (Mg/ha)	Castorbean (2) (Mg/ha)
Without off-season tillage	1.87	0.32
With off-season tillage	2.60	0.31

In general, the summer tillage helped in higher moisture retention by 20% and reduced weed infestation by 40%.

Among the users of intensive mechanization, land shaping was found very important. In sub-montane region of Hoshiarpur and in the Inceptisols, However, the benefits were seen mostly in low rainfall seasons due to even moisture distribution (Table 3)

Table 3. Effect of land shaping on the yields of wheat and chickpea in Sub-montane soils at Ballowal-Saunkhri and pearlmillet in alluvial soils of agra

Land Shaping	Wheat and Chickpea mixture, 3 seasons (Mg/ha)	Pearlmillet (Mg/ha)	
		Rainfall 320 mm	Rainfall 660 mm
Natural	1.05	1.34	2.22
With land leveling	1.65	1.63	2.31

The primary tillage is mostly carried out for seedbed preparations. Depending upon the distribution of rainfall, the tillage before seeding is carried out one to three times. The deep tillage was especially helpful more in drought prone regions as it helps in establishing good crop stand and deep rooting. In the moderate less drought prone region, its relative advantage was less (about 10%) (Table 4).

Table 4. Crop response to primary deep tillage

Crops (seasons)	Grain (mg/ha)		Response (%)
	Shallow tillage (10-15 cm)	Deep tillage (20-30 cm)	
	Severe drought		
Coarse cereals (5)	0.92	1.30	41
Legumes (6)	0.61	0.76	25
	Moderate drought		
Coarse cereals (16)	0.61	0.76	25
Legumes (2)	1.21	1.38	14
	Less Prone to drought		
Coarse cereals (4)	2.14	2.37	11
Legumes (1)	0.25	0.29	16

Another important aspect of the related studies on land treatments was that the most proven practice in rainfed agriculture was found to be ridges and furrows. The ridges and furrows were mostly helpful in reducing the run-off and enhanced *in situ* moisture conservation. Thus, the response to land treatment like ridges and furrows was seen in moderate to less drought prone regions (Table 5).

Table 5. Response to land treatments

Crops (seasons)	Grain (mg/ha)		Response (%)
	Flat	Ridges-Furrows	
	Severe drought		
Coarse cereals (19)	1.73	2.02	17
Legumes (24)	0.71	0.78	10
	Moderate drought		
Coarse cereals (12)	1.51	1.92	28
Legumes (1)	0.30	0.42	40
	Less prone to drought		
Coarse cereals (1)	0.79	0.91	15

Various practices like tillage, ridges, mulching, contour cultivation and cultivation on graded bunds or other practices have been found effective and are recommended in conservation of moisture in soil. Some of the related data have been presented in Table 6.

Table 6. Effect of land management on runoff and crop yields in Alfisols

Land management	Runoff reduction (%)	Crop	Yield increase (%)
Deep tillage	34 – 46	Sorghum	28 – 31
Tied ridges	39	Sorghum	NS
Straw mulch, 5 tha^{-1}	76	Maize	53
Prior perennial	79	Maize	36
Contour bunds	37	Maize	NA
Graded bunds	31	Maize	NA

The deep tillage was always helpful with respect to important soil moisture profile by reducing run-off, soil loss and peak flow significantly (Table 7).

Table 7. Effect of tillage on yield, runoff, soil loss and peak flow

Tillage treatment	Sorghum ($mg\ ha^{-1}$)	Run-off (mm)	Run-off (%)	Soil loss ($t\ ha^{-1}$)	Peak flow ($l\ sec^{-1}$)
Farmer's method	2.74	173	27	4.7	53
Minimum tractor tillage	3.11	135	21	3.1	24
Deep tillage	3.38	45	7	1.2	9.4

Apart from cover crops, the soil mulch has also been found quite effective. The effect of mulching is seen more in *rabi* crops than in *kharif* crops. The advantage of mulching is also seen where there was enough moisture in soil. Thus, its usefulness was found limiting from moderate drought prone regions to less drought prone regions. This benefit was mostly seen in shallow and fibrous rooted crops (Table 8).

Table 8. Effect of mulching for ameliorating mid season drought

Crops	No mulch (mg/ha)	Mulch (mg/ha)	Response (%)
Severe drought			
Coarse cereals (5)	1.44	1.39	-4
Legumes (6)	0.55	0.70	27
Moderate drought			
Coarse cereals (19)	1.40	1.81	29
Legumes (3)	0.29	0.33	13
Less prone to drought			
Coarse cereals (1)	1.04	1.44	38

In the deep Vertisols, cracks are more common. These cracks are sealed on expansion with rainfall. The soil is sealed for infiltration permanently thereafter. To reduce the development of cracks, the vertical mulching is proposed. This helps in maintaining the gaps between cracked surfaces and consequently, protects the soil from sealing. There is a benefit pursued in yields of *rabi* sorghum from such practices (Table 9).

Table 9. Vertical mulch on post-rainy season sorghum on deep Vertisols

Practice (seasons)	Grain (mg/ha)
Control (4)	1.31
5 m interval (4)	1.65
10 m interval (4)	1.24

The crop residues of unused legumes are beneficially utilized for reducing fertilizer nitrogen dose by 50%. Long duration study showed that conjunctive use of 50% of recommended N through fertilizer + 50% recommended N through organics was quite effective in reducing the dependence on inorganic fertilizers (Table 10).

Table 10. Reduction in requirement of inorganic fertilizer N by half with substitution of N through organic residues without yield reduction

Crop (seasons)	Grain yield (mg/ha)	
	Recommended dose of fertilizer	50% N + 50% N through organics
Post-rainy season sorghum (16)	1.19	1.16
Pearlmillet (17)	2.03	2.08
Fingermillet (22)	2.21	2.92
Groundnut (16)	1.06	1.05
Cotton (14)	0.76	0.82
Greengram (14)	0.52	0.56

To reduce on conventional tillage, plough planting can be practised which was once upon a time a traditional practice. The plough planting was inferior to conventional tillage due to heavy weed infestation and reduction in infiltration of water due to compactness of the surface in Alfisols of Hyderabad.

Table 11. Long-term effects of land management on crop yields and sustainable yield index (8 years)

Residues	Sorghum (kg ha^{-1})		Castor (kg ha^{-1})		SYI	
	Conventional tillage	Plow planting	Conventional tillage	Plow planting	Conventional tillage	Plow planting
Sorghum	1127	810	820	477	0.49	0.35
Gliricidia loppings	1201	895	925	507	0.50	0.37
No residue	1103	840	840	448	0.48	0.31
	1144	848	862	477	0.49	0.34
Tillage	**	**	*			
Residue	**	**	*			
T x R	NS	NS	NS			

NS — non-significant at P > 0.05.
* Significant difference at P = 0.05.
** Significant difference at P = 0.01 (Sharma *et al.,* Soil Tillage Res. 2004).

However, the soil quality was not different between conventional or plough planting methods. The addition of fertilizers or organics improved the soil quality index (Fig.2).

MBC: Micro Biomass C; HC: Saturated Hydraulic Conductivity; CT: conventional tillage; MT: plough-planting; SS:sorghum stover; GL: glyricidia loppings; NR: no residue; N0, N30, N60 and N90 nitrogen levels (kg ha^{-1}). (Sharma *et al.*, Soil Tillage Res. 2004)

The weed problem can be reduced by use of herbicides. Once upon a time, the herbicides were not attractive to the farmers due to being high cost input. However, with the low labour productivity in total factor productivity, the weedicides are attracting the attention of farmers at present to control the weeds. However, there is a benefit by yield increase with herbicide application (Table 12).

Table 12. Performance of weedicides on farmers' fields

System	Maize (11 seasons) (kg/ha)	Soybean (3 seasons) (kg/ha)	Maize (7 seasons) (kg/ha)	Groundnut + sesame (7 seasons) (kg/ha)	Upland rice (4 seasons) (kg/ha)
Control	1.75	0.86	1.54	0.90	0.45
Weedicide	2.76 (Alachlor)	1.83 (Basalin)	2.41 (Atrazine)	1.49 (Pendimethalin)	1.66 (Butachlor)
Savings in cost of production (Rs. Per ha)	125	250	125	400	120

The network tillage experiment is being carried out since 1999 at various centers of All India Coordinated Research Project on Dryland Agriculture. A summary of results is presented in Fig. 3.

The sustainability yield index and rainfall relationship show that in arid (< 500 mm rainfall) region, low tillage is equivalent to conventional tillage and weed problem is controllable. Infiltration of rainfall depends on soil opening and its receptiveness and thus requires more surface disturbance. In the semi-arid (500 – 1000 mm) region, conventional tillage was superior. Success of crops depends on rainfall infiltration and soil moisture holding in the profile. Weed problem is ephemeral depending upon the seasonal rainfall distribution in sub-humid (< 1000 mm), there is a possibility of reducing the intensity of conventional tillage by using herbicide. Weed control is a large problem due to incessant rains. Soil moisture will not be a problem for rainfed crops due to high rainfall. Thus, there is a possibility of reducing tillage further in rainfed lands in low or high lands in low or high rainfed regions.

It is important to note that the term conventional tillage is common between North American continent, Europe and Indian sub-continent. In Europe, the zero tillage or minimum tillage was found quite helpful due to the reason that in that region, agriculture being in vogue for last 40-200 years and the organic carbon status is higher compared to the Indian soil which are being cultivated anywhere between 1500-10000 years. This long-term cultivation has degraded the soils to the bottom most point in the degradation level. Therefore, Indian agriculture can accrue more benefits of conservation farming especially low tillage, if followed appropriately depending upon the type of soils. In general, in rainfed agriculture, there is likely reduction in yield due to minimum tillage or low or zero tillage (plough planting) in soils with hard setting tendencies which happens due to poor infiltration of rain water leading to low and patchy germination, uncontrollable weed population, high-bulk density root zone and several other reasons. However, ill effects such as hard setting tendencies of soil and poor infiltration can be mitigated by building up more and more employing various

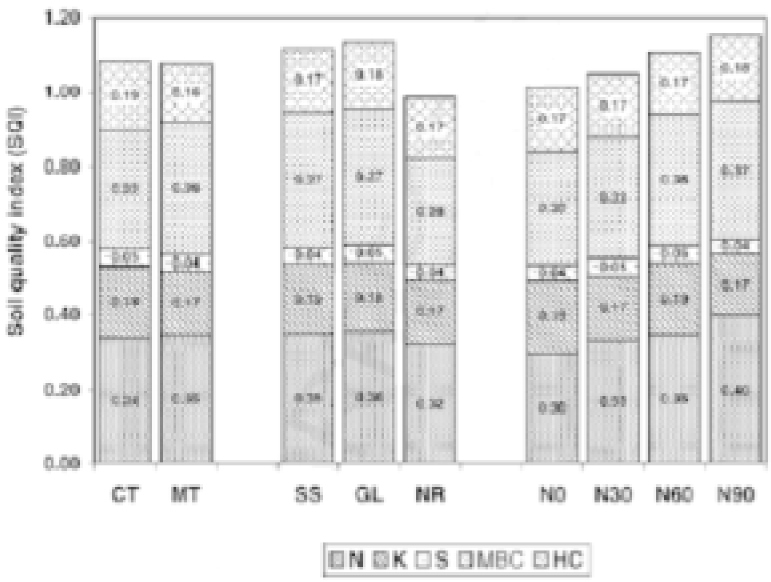

Fig. 2. Soil quality, residues and tillage.

approaches of C sequestration. Researchers across the world have very well established that the low tillage or zero tillage approach can make the desirable difference over a period of time if the crop residue is allowed to remain on the Surface. It should be protected from burning, grazing, displacement from the field due to wind or run-off water and undesirable decomposition by termites, etc. In the present scenario, the goal of Indian conventional tillage should be somehow to achieve organically rich surface cover. This in turn will need to recycle crop residues and use of animal based manures in the agricultural fields. This can be achieved by adopting farming systems mode embedding livestock therein. Alternative fodder production mechanism needs to be strengthened. Unproductive livestock needs to be culled out. It is very true that the general principle of improving “grain is to man and residue is to land” cannot be immediately applicable under Indian conditions; nevertheless, the concept can be promoted in phases. The plant carbon input and tillage carbon output needs to be balanced. The conventional agriculture should not ignore the farming system mode that provides food, fibre, fodder, fish, fuel, etc. This will lead to the economic prosperity, environment protection, conservation of energy, apart from the successful completion of

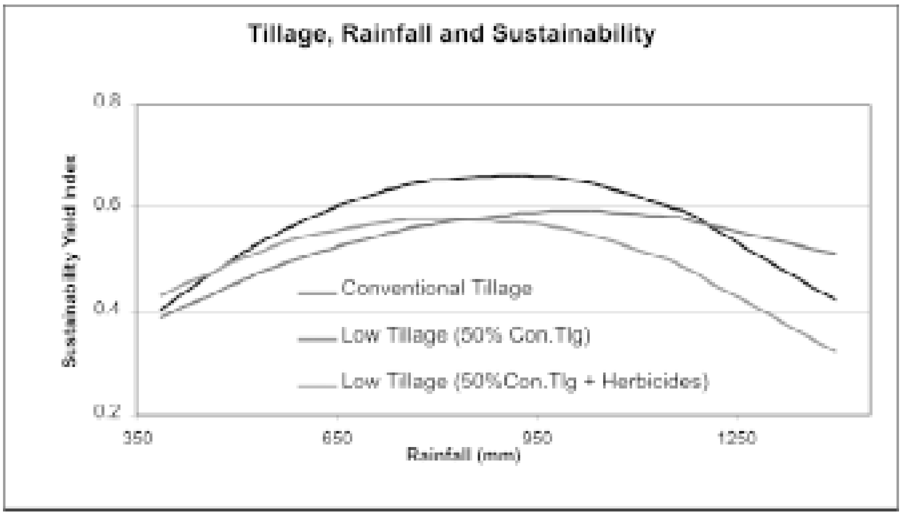

Fig. 3. Effect of rainfall on the sustainability of conventional and low tillage practices.

social responsibility of handing over the healthy soil to next generation.

At present, for improving the carbon content in soil, apart from crop residues, the agro-forestry also becomes important. However, nothing comes free. The agro-forestry system comprising perennial components depends on the sub-soil components. It has been observed that grasslands and tree system play an important role in improving soil properties, such as bulk density, mean weight diameter, water stable aggregates and organic carbon. Apart from the above, other soil properties such as infiltration rate and hydraulic conductivity also got influenced due to agro-forestry systems compared to agricultural systems. An industry and agro-forestry linkage focusing on export-oriented products may help in reviving the tree systems.

The micro catchments development, supplemental irrigation and indigenously developed technical knowledge and logically developed cropping systems including inter-relay systems are some of the examples leading towards conservation agriculture. There is a lot of responsibility on the shoulder of farmers and the researchers to hold the battle in this race of rejuvenating the soil to their original stand.

Steps for thrust in conservation farming

1. There is a need to create awareness among the communities about the importance of soil resources, organic matter buildup in soil. Traditional practices such as burning of residues, clean cultivation, intensive tillage and pulverization of soil upto finest tilth need to be discouraged.
2. Systems approach is essential for fitting conservation tillage in modern agriculture. In order to follow the principle of "grain is to man and residues is to soil", farming systems approach introducing alternative fodder crops is essential. Agroforestry systems with special emphasis on silvipastures systems need to be introduced. Unproductive livestock herds needs to be discouraged
3. For the adoption of conservation tillage, it is essential that complete package of practices may be identified based on intensive research for each agro ecological region.
4. The increased use of herbicides has become inevitable for adopting conservation tillage/ conservation farming practices. The countries that use relatively higher amount of herbicides are already facing problem of non-point source pollution and environmental hazard. In order to reduce the herbicidal demand, there are scopes to study the allelopathic effects of cover crops and intercultural and biological method of weed control. In other words, due concentration is needed to do research on regenerative cropping systems to reduce dependence on inorganic chemicals.
5. Low tillage, crop rotation, cover crops, maintenance of residues on the surface, control of weeds through herbicides, are the key components of conservation farming. Therefore, it is essential that these themes must be studied in depth under diverse soil and climatic conditions across the country on long-term basis.
6. The other objective of conservation farming is to minimize the inputs originating from non-renewable energy sources, e.g., fertilizers and pesticides. Hence, research focus is required on enhancing fertilizer use efficiency and reduction in use of pesticides. This aspect can be strengthened by following integrated nutrient management and integrated pest management approach.
7. The past research experiences of conservation tillage reveal that the major toll of yield is taken by poor germination and poor crop stand because of poor microclimatic

environment and hard setting tendencies of soil, excessive weed growth and less infiltration of water to the crop root zone. Therefore, the important aspects which need concentrated research focus include appropriate time of sowing, suitable seed rate, depth of seed placement and soil contact, row orientation, etc. Suitable cultivars having responsiveness to inputs also become important component of conservation farming.

8. The issues related to development of eco-friendly practices for tillage and residue recycling – appropriately for specific combination of soil-agro climatic cropping system – to alleviate physical constraints with higher water and nutrient use efficiency need to be addressed.
9. Inter-disciplinary research efforts are required to develop appropriate implements for seeding in zero tillage, residue incorporation and inter-cultural operations.
10. Research focus is needed on modelling of tillage dynamics and root growth, incorporation of soil-physical properties in crop-growth simulation models and relating it to crop yields under major cropping sequences.

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An Appraisal of Soil Quality Assessment Indicators

D.L.N. Rao and M.C. Manna
Indian Institute of Soil Science, Nabibagh, Bhopal 462 038, Madhya Pradesh, India

ABSTRACT : There is a surge of interest in soil quality assessments through measurement of various physical, chemical and biological parameters that are sensitive to soil management. Minimum data sets have been developed alongwith their integration into a soil quality index so as to assess the influence of various soil management practices. A worldwide review indicates that practices like minimum tillage with residue retention, crop residue incorporation, balanced fertilization, application of manures, legume cropping have all been found to improve important soil quality indicators like hydraulic conductivity, soil aggregation, organic matter content, available nutrients, particulate organic matter (POM) and microbial biomass. Organic matter content is the mainstay of soil quality as it interacts and affects almost all the important physical, chemical and biological attributes of soils. But improvements in soil quality ratings have not always resulted in increased yields of crops. Yield declines have been reported even when SOC was building up and vice versa. POM and microbial biomass are sensitive indicators of soil quality and predict the direction and rate of change due to soil management practices, earlier and better than other indicators. Despite a lot of work, some reservations remain about interpretation of soil quality data, soil quality indexing etc. and several issues need to be addressed in the future before soil quality assessment data can be used with confidence for farmer advisory purpose akin to soil testing for soil fertility.

INTRODUCTION

Sustaining and improving soil quality over the long term are frequently identified by farmers as their primary management goals. Together with alarming rates of soil degradation, it has resulted in a worldwide interest in ecological farming. The terms *soil quality* or *soil health* describe the soil's capacity to sustain crop productivity, maintain environmental quality and provide for plant, animal, and human health (Karlen *et al.,* 1997). There are many soil attributes encompassing a broad range of soil physical, chemical and biological properties that can be used to assess the quality of soils. It is important to recognize that soil quality indicators are limited to properties impacted by soil management only and do not include inherent soil characteristics. Although it is useful to examine these properties individually, soil should be viewed as an integrated system rather than as a collection of separate parts or processes. For example, physical and chemical properties are shaped by biological activity, and biological activity is enhanced or limited by chemical and physical condition. Because soils perform many simultaneous functions, the goal of relating indicator properties to specific functions or processes is very difficult, if not impossible. Indicator properties that are frequently identified as important are listed in Table 1.

Doran and Parkin (1994) proposed an index of soil quality as a function of six specific soil quality elements such as food, fibre production, erosivity, ground water quality, surface water quality, air and food quality. Over the last several years, researchers and farmers alike have tried to establish *minimum data* sets of physical, chemical, and biological properties that can be used as quantitative indicators in soil health assessments. Fairly definitive standards have been set for air and water quality, but not only the definition and assessment of soil quality is more problematic but it is also virtually impossible to set the lower or upper limits for the various attributes of soil quality. In this paper, we have reviewed the soil quality

Table 1. Soil properties frequently recognized as indicators of quality

Physical	Chemical	Biological
Texture	pH	Biologically active organic matter
Bulk density	Electrical conductivity	Microbial biomass
Penetration resistance	Organic matter	Respiration rate
Aggregate stability	CEC	Nitrogen mineralisation
Water-holding capacity	Extractable N, P and K	Earthworms
Water-infiltration rate	Contaminants (metals, toxins)	Soil microbiota
		Enzymes
		Pathogens (plant and human) and disease suppressiveness

attributes that contribute to a healthy soil and present examples from literature to illustrate the effect of various interventions in improving soil quality and examine the soil quality-productivity linkages.

SOIL QUALITY INDICATORS

Physical indicators

Important physical indicators of soil quality include those related to water storage and movement, e.g., soil infiltration rate, bulk density, water holding capacity, depth of soil and rooting, and texture. Extensive tillage operations under different landuse management systems disrupt the soil structure, and increases the rate of biomass decomposition and mineralization, and expose soil organic carbon in the soil surface to the climatic elements, and thereby cause reduction of the retention and transportation of water and chemicals, productivity potential and erosivity. Various kinds of conservation tillage practices have been widely adopted worldwide and also in India. The results of many studies in USA showed that no-till management improves soil physical quality ratings over plowing. In a study in India, five years of maize-wheat growth on a sandy loam soil with minimum tillage and surface residue retention significantly decreased the bulk density, increased the mean weight diameter of aggregates and water retention at 5 and 10 kPa in surface layer of soil (Ghuman and Sur 2001, Table 2).

Table 2. Tillage effect on soil aggregation and water retention in 0-5 cm soil layer in a sandy loam after 5 cropping cycles of maize-wheat

Tillage treatment	Mean weight diameter of aggregates (mm)	Soil water retention (g kg^{-1})	
		5 kPa	10 kPa
Minimum tillage with residue	0.22	207	157
Minimum tillage	0.18	160	127
Conventional tillage	0.19	180	133
LSD (p=0.05)	0.03	20	13

Source: Ghuman and Sur (2001).

Residue (*Lantana* biomass) incorporation for twelve years to a typic hapludalf @ 20 and 30 t/ha resulted in a significant improvement in physical properties alongwith reduced percolation and seepage, improved water use efficiency and increase in rice yields (Bhagat *et al*., 2003; Table 3). Yields over 12 years in puddled rice, showed a decline in unmanured control (although yield trend analysis indicated it to be non-significant) but were maintained in manured treatments. But the significant point to note is that the improved physical properties with increasing rates of green manure addition did not translate into increased yields.

Table 3. Mean values of water stable aggregates (WSA) > 0.25 mm, mean weight diameter (MWD), bulk density and total porosity for 0-0.15 m depth under different treatments

Structural indices	Treatments				L.S.D
	M0	M1	M2	M3	(p <0.05)
WSA>0.25 mm (g $(100g)^{-1}$)	27.0±6.2	35.0±7.1	45.0±7.9	59.0±8.6	8.4
MWD (mm)	2.01±0.39	2.78±0.46	3.42±0.52	3.96±0.61	0.79
Bulk density (mg m^{-3})	1.52±0.09	1.40±0.07	1.38±0.08	1.35±0.08	0.11
Total porosity (%)	41.5±2.4	46.1±2.6	46.9±2.5	48.1±2.6	3.1

M0=No *Lantana* incorporation; M1, M2 and M3 = *Lantana* incorporation @ 10, 20 and 30 Mg ha^{-1}. *Source:* Bhagat *et al.* (2003).

Chemical indicators

Soil fertility, nutrient restoring and recycling, and environmental quality issues are directly related with chemical indicators. These include soil organic matter, pH, electrical conductivity, and extractable N, P and K. Soil organic matter (SOM) includes a number of fractions such as light fraction, microbial biomass, water soluble organics and humus. SOM is a very useful indicator because it interacts with numerous other soil components which affect many soil properties like water retention, aggregate formation, bulk density, infiltration and aeration, pH, buffering capacity, cation exchange properties, mineralization, sorption of pesticides and other agrochemicals and activity of soil organisms. Soil pH also indicates the solubility of most chemical elements in soils and their associated availability, deficiency, or toxicity to plant growth. At low pH, Al and Mn become more toxic to plants. Solubility of most micronutrients except for Mo decreases as pH increases, and deficiency symptoms are often seen when pH is greater than 7. The adverse impact of high pH and sodicity on physical properties and nutrient availability is well known. Soil pH has also significant impact on soil microbial and mineralization processes. CEC is highly related to clay content and the amount of organic matter content in soil. The pH dependent CEC of acid soils increases slowly with pH from 3 to 5 and rather rapidly afterwards, and soil organic matter is the major contributor to pH–dependent CEC.

Soil organic matter (SOM) is the mainstay of soil quality. As a general rule, declining yield trends have been ascribed to reduction in SOC levels by many researchers. In long-term fertilizer experiments in India, Manna *et al.* (2004) reported that SOC decline is the general cause of reducing yield trends in the initial years. However, as a result of continuous cropping with fertilizers or fertilizers + FYM there was a subsequent build up of soil carbon which reduced the extent of negative yield trends but which did not result in restoration of the original yields. As a result of imbalanced fertilization (applying only N) there was reduction in yield, and in SOC levels as well as a remarkable reduction in active fractions of organic matter like particulate organic matter and microbial biomass. This can be remedied only by balanced fertilization (NPK and micronutrients) and application of organics. However, the specific causes of yield declines even though SOC was building up may be due to other factors like vagaries of climate, pests and diseases or other variables, not considered in the study. Thus, it may not be possible to easily establish straightforward relationships between SOC levels and productivity or define the threshold levels of SOM. Soil extractable N, P and

K were significantly improved by surface fertilizer application under continuous cropping system. Lesser P concentration in soil could be attributed to P fixation by colloids and exchangeable Ca. Soil with a coarse texture and less colloids, would have reduced ability to fix P, as a result, P availability increased.

Biological Indicators

Soil organisms contribute to the maintenance of soil quality in that they control the decomposition of plant and animal materials, biogeochemical cycling including nitrogen fixation, the formation of soil structure and the fate of organics applied to soils. A large, diverse, and active population of soil organisms may be the most important indicator of a healthy, high-quality soil. Yet, soil biological activity may be the most difficult indicator to satisfactorily measure and interpret. A high quality soil is 'biologically active' containing a wide diversity of microorganisms. However, diversity is so little understood, less than 1 percent of the microorganisms have been actually been isolated and identified. A good ecological indicator should also show prompt and accurate response to an external perturbation, reflect some aspect of the functioning of the ecosystem, be readily and economically accessible and be universal in distribution yet show individual specificity to temporal or spatial variations in the environment. Such a stringent requirement coupled with a poor understanding of diversity-function relationships has meant that we have made very little progress in identifying such indicators. This situation is unlikely to change in the near future. Therefore, for a working definition of soil biological quality and ease of analysis, biologically active fractions of SOM and biochemical attributes of soil have proven more useful.

Particulate organic matter (POM, >53mm) represents a significant proportion of the slow pool of SOM and is important in maintaining the stability of macroaggregates (>250mm). POM and microbial biomass are considered as biologically active fractions of SOM and are sensitive indicators of management-induced changes in the fate of crop residues and the turnover of SOM constituents. They have been found to predict the direction and rate of change of soil quality earlier and better than other indicators. Soil respiration and nitrogen mineralisation are widely used as indices of biological activity. Decrease of microbial biomass carbon as a fraction of total organic carbon implies a reduction in microbial transformation and intensity. The metabolic quotient or qCO_2 is a more sensitive indicator of soil microbial reaction to cropping systems, lower values implying more stable and mature systems where carbon utilization efficiency of the microbial population is higher due to shift from zymogenous to autochthonous microflora. Dehydrogenase activity has been widely used as a generalized comparative index of microbial activity but it has not always been consistently correlated with microbial activity. There have been numerous attempts to correlate soil biology/ fertility with the activity of extracellular soil enzymes but strong correlations can be expected only in unmanaged ecosystems or low input agricultural systems. Increased activity of several enzymes have been shown with addition of organic amendments, and green manure/crop residues. Soil fauna communite and redistribute organic residues in soil, increase the substrate surface and speed the turnover of microbial biomass. Enumeration and identification of at least the burrowing soil fauna, and measurements of faecal deposits has been recommended to be a part of minimum data for assessing soil quality. The influence of some management interventions on biological attributes of soil quality attributes is discussed below.

Continuous cropping without application of adequate quantity of nutrients in balanced doses or without addition of organics leads to loss of soil quality and unsustainability of crop production systems. In the study of Manna *et al.* (2004) applying only nitrogen or nitrogen + phosphorous led to a decline in particulate organic matter (Table 4) and soil

Table 4. Long-term effect of fertilizer and manure on soil biological quality in (0-15 cm soil) in different cropping systems

Locations	Treatments	pH	SR[1]	SMBC (mg/kg)	qCO_2	SMBN (mg/kg)	POM-C (g/kg)	TOC (g/kg)	TN (mg/kg)	SMBC/ TOC (%)	SMBN/ TN (%)
Barrackpore	Control	7.0	22.3	190	1.20	7.5	0.54	5.4	422	3.31	2.70
(Typic Eutrochrept)	N	7.0	22.8	189	1.20	8.9	0.94	5.7	660	2.84	1.62
Rice-wheat-jute	NP	7.0	23.1	245	0.94	9.1	1.14	6.3	748	3.31	1.46
(1971-2001)	NPK	6.9	37.0	398	0.92	14.0	1.48	7.4	867	4.41	1.75
	NPK+FYM	7.3	49.7	576	0.86	18.7	2.19	7.9	927	6.15	2.17
Ranchi	Control	5.0	18.3	154	1.18	7.8	0.48	3.5	445	4.40	1.75
(Typic Haplustalf)	N	4.2	19.8	185	1.07	7.1	0.69	3.4	460	5.44	1.54
Soybean-wheat	NP	5.0	21.8	204	1.06	12.6	0.75	3.9	475	4.85	2.02
(1972-2001)	NPK	4.9	22.7	210	1.08	13.6	1.43	4.2	505	4.66	2.70
	NPK+FYM	5.3	24.0	231	1.01	14.5	1.82	4.5	570	5.63	2.54
Akola	Control	8.0	18.3	201	0.91	8.1	0.04	3.6	360	5.58	2.38
(Typic Haplustert)	N	8.0	22.3	220	1.01	11.0	1.22	5.2	456	4.23	2.34
Sorghum-wheat	NP	8.1	24.6	244	1.01	12.3	1.50	5.6	460	4.35	2.67
(1989-2001)	NPK	8.1	25.9	382	0.67	13.3	1.84	6.1	486	6.26	2.73
	NPK+FYM	8.0	33.3	465	0.72	16.4	2.82	7.0	590	6.64	2.77

Source: Adapted from Manna *et al.* (2004); [1] SR =Soil Respiration; mg CO_{2}-C evolved /100g/10d.

biological activity (soil respiration, microbial biomass C and N), which were however improved significantly on addition of NPK or NPK+ organics. They further observed that SMBC and SMBN comprised 2.8-6.2 percent of TOC and SMBN comprised 1.5 to 2.7 percent of TOC. Biomass C and N, POM and respiration were lower in Alfisol as compared to Vertisol and Inceptisol. Continuous cultivation with removal of residues or without addition of any organics year after year disrupted the aggregate stability, resulting in loss of physically protected organic matter such as POM thus resulting in loss of readily respirable substrates for microorganisms in the long run.

Inclusion of legumes in crop rotations is known to improve sustainability. In an alkali soil in Haryana cultivated with different crop rotations and irrigated with good quality or sodic water [EC 1.75 dS m^{-1}, RSC 8.25 meq L^{-1} and SAR (10.5 mmol L^{-1}) $^{1/2}$], soil respiration (CO_2 evolution), organic C and N were significantly greater under rice-clover at 2 and 5 years than under other cropping sequences (rice-mustard, rice-wheat and sorghum-wheat) (Table 5, L. Batra and D.L.N. Rao, 2005-under publication). The mean soil respiration in the surface layer (0-15 cm) for both the years was 118, 33, and 24 percent greater for rice- clover, rice-mustard and rice-wheat, respectively, compared to sorghum-wheat which was the lowest. Microbial biomass carbon was lower when mustard was grown. Higher soil respiration, metabolic quotient and microbial biomass nitrogen under rice-clover treatment may be because of higher buildup of organic carbon and nitrogen in this treatment. Soil respiration and metabolic quotient were more useful as parameters for determining the effect of crop rotation and other management practices than dehydrogenase activity (data not shown).

Table 5. Effect of different cropping sequences on microbiological properties of an alkaline soil (0-15 cm) after 5 years of cropping

Crop sequence	pH	Soil respiration CO_2 evolved (mg/100 g soil)	Dehydro-genase activity (µg TPF/g soil)	Organic C (%)	Microbial biomass C (mg / kg)	Total N (%)	Microbial biomass N (mg / kg)	q CO_2
Rice-mustard	8.9	56.5	98.0	0.52	201.7	0.064	26.4	2.80
Rice-wheat	8.7	42.3	83.0	0.60	270.0	0.055	32.6	1.57
Rice-clover	8.8	69.3	155.6	0.72	241.8	0.083	56.5	2.87
Sorghum-wheat	9.0	40.0	96.6	0.55	231.2	0.061	36.3	1.73
LSD (p = 0. 05)	0.14	11.8	21. 1	0.14	NS	0.001	14.3	0.56

Source: Batra and Rao (2005) (under publication).

In a study by Biederbeck *et al.* 1998, the sensitivity of the soil quality attributes decreased in the sequence: Initial potential rate of N mineralization > C mineralization > wet aggregate stability > light fraction of SOM > total organic C or N and highlights that monitoring only a few sensitive parameters would suffice.

SOIL QUALITY INDEX

To evaluate soil quality, various properties are assigned index values which are then averaged into a single index to represent the quality of the soil. But the index is a relative measure of soil quality that can be used to compare different soils and management systems and to evaluate the same soil over time but is not an absolute index. Larson and Pierce (1991) expressed soil quality Q as a function of measurable soil attributes referred to as soil qualities (q_i): Q =f (q_i….n), with the magnitude of Q being a function of the collective contribution of all q_i values. They also measured soil quality over time (dQ/dt) and proposed the use of a minimum data set of the measured soil properties and use of pedotransfer functions for others so as to assess soil quality. A soil tilth index has also been developed and it is based on using five physical soil properties such as bulk density, cone penetration index, aggregate size uniformity coefficient, organic matter and plastic index (Singh *et al.*, 1992). This index is a multiplicative combination of the tilth coefficients and it could be expanded to include other soil attributes such as soil chemical and biological properties. These indices could be used to monitor and predict the effect of farming systems and management practices on soil quality or could provide early warning of soil degradation/aggravation/sustainability.

Based on farmers perception of soil quality, a score card was developed for assessing soil quality on a rating scale of healthy, impaired and unhealthy based on sensory observations such as look, feel and smell (Romig *et al.*, 1997). Karlen and Stott (1994) developed a framework for quantifying soil quality using multi-objective analysis principles. They defined critical soil functions and potential chemical and physical indicators of those functions. For each indicator, a scoring function, and a realistic baseline and threshold values were established. This systems approach was tested in two long-term studies to show the effects of tillage and crop residues on soil quality ratings.

CONCLUSIONS

During the past decade, concerns about soil quality have increased significantly throughout the world. Approaches ranging from simple scorecard and test-kit monitoring to comprehensive quantitative assessment and indexing using soil database, have been pursued. It is argued that the soil quality concept will not replace soil survey programs or soil management strategies but will be useful for guiding and developing improved soil management practices. However, the definition of the standards and interpretation of the data generated remain issues associated with the use of all indicators. We also need to ask- Are all soil quality parameters reflected on yield trends ? Do all the parameters in the minimum data sets need to be measured ? Are the parameters to be included or their relative weightages to be assigned the same for different land uses?. All the proposed minimum data sets of soil quality indicators include a measure of soil organic matter, which is the mainstay of soil quality. However, it is very difficult to state: (a) what is a 'normal' SOC level, (b) what is the critical 'threshold'? and (c) what level of SOC constitutes good or bad soil quality? The greatly increased crop yields during last 40 years in India have often been obtained despite decrease in SOC, to levels below those posed as critical. Similarly, generalized evidence for a threshold of SOC in relation to soil physical properties below which catastrophic failure of, for example, soil aggregation will occur, is lacking. Such issues need to be addressed not only for organic carbon but for all physical, chemical or biological parameters before any kind of soil quality indicator can be used in a practical way by farmers advisory purpose akin to soil testing for soil fertility.

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Remote Sensing/GIS/GPS for Diagnosis, Prognosis and Management of Soil Water Domains

Madhurama Sethi
Central Soil Salinity Research Institute, Karnal 132 001, Haryana, India

INTRODUCTION

The challenge of sustainable food production is heightened by the expected population expansion. To meet the demands for food, crop yields will need to increase consistently by over 2% every year. Notwithstanding advances in technology, increasing food production would certainly lead to intensification of agriculture in areas that are already cropped, and necessitate conversion of other lands such as forests and grasslands into cropping systems. Much of the changes will happen in semi-arid regions and on lands that are marginally suitable for cultivation, increasing the risk of soil erosion, accelerated water use, salinity/alkalinity and further land degradation. The resulting land-use changes will be the single cause for global change over the next century.

Therefore our agricultural production systems must be enhanced, well maintained, and reliable if we are to consistently meet the food requirements of the country's projected billions of inhabitants beyond 2050. Sustainable development practices, consistent with protection of bio-diversity and ecosystems, are seen as the key. Such practices require a broad range of information on all scales for efficient management. Parameters of importance include:

- Land-cover, land-use, crop yield and vegetation status;
- Land degradation and desertification;
- Soil characteristics including fertility and moisture levels;
- Water availability and groundwater resources;
- Total irrigated area; and
- Population distribution, production intensity, and food provision.

Consequently managing soil and water resources and conserving them require intense futuristic research to enhance the ability to predict the future. So far the prognosis for all resources is bleak for human activities. These will further result in extreme stress conditions by enhancing already existing environmental problems such as depletion and contamination of land and water resources. Using remote sensing, GIS and GPS technologies enhance abilities to diagnose faults and provide prognosis for management.

DIAGNOSIS AND PROGNOSIS

Prognosing and foreseeing problems and recognizing faults and anomalies in order to predict time to failure would essentially provide an opportunity to bring to a standstill the debilating effects that might bring on failure under different agro-eco soil water systems. New applications for providing prognosis for management have to go beyond simple crop identification and land use classification to address topics of interest on a regional and global scale. Remote sensing, field work and indepth analysis of other chemical and physical conditions of soils, water and crops would be necessary to provide new methodologies for remediation and could be termed "Optimized remediation prognosis" for investigations and risk analysis for degrading soil and water.

Management must consider the inter-relationships between prognosis, diagnosis and the need to find solutions. To understand the technical and scientific inputs that would be required to improve the management of the natural resources and provide for conservation agriculture we must have an evolved and feasible methodology that is both practical and applicable.

Theoretical knowledge and practical skills are needed for collecting, interpreting and managing geographical information to support the planning and decision-making processes. If a fault can be recognized before it occurs, meaning that there is an alarming trend that has not yet become undeniably "abnormal", the process is usually termed prognosis. Diagnosis results are used for reactive decisions about corrective actions; prognosis results are used for proactive decisions about preventive and/or evasive actions with the goal of maximizing the life of any environmental system while minimizing operational risk. The philosophies and techniques are the same. However, the decision-making goals of the two are different On the other hand, in many situations diagnosis and prognosis aid each other. Diagnostic techniques can be used to study where incipient faults have occurred based on observed degradation in a system's performance; these faults can then become the focus of prognostic methods to estimate when incipient faults would progress to critical levels causing a system failure.

Answers to questions such as what constitutes failure or end-of-life may be straightforward in many applications when posed in the context of the system of interest. However, they may not be as straightforward if the observed data and features derived from them do not have a known quantifiable relationship with the failure event. For example, degradation may be observed via worsening; as groundwater rises through the soil layers, it carries stored salts. When this salt is mobilized by groundwater and reaches the surface, it evaporates and concentrates the salt it contains at the surface causing salinization. Similarly, irrigation salinity occurs where excess water from the irrigation systems cause saline groundwater to rise to the root zone or soil surface. To predict the time to failure still depends on other considerations in formulating the prognostics problem. This includes: what data is available? To what extent is remote sensing data successful in the prognostic analysis (training). Is only the current or past data available? What is the intensity of ground observations required? If available how successful will the training sets prove accurate in providing information on the area under stress and predicted failure?

The first requirement is to identify domains that require management in order to provide an efficient prognosis. Essentially, the focus must be on what major problem or issue is to be resolved and the way to resolve it. To provide a prognosis, a methodology must be in place for each problem area. Farmers are striving to increase their productivity per unit of land, water and fertilizer, and seeking new ways to customize their growing practices to accommodate within-field variability in potential productivity (i.e. site specific, or precision crop management). Farming itself has become more complex with environmental guidelines mandating safer and more efficient use of agricultural chemicals. Agriculture must be resilient to possible changes in global climate (e.g. rising levels of CO_2, increasing temperatures, etc.) and the potential consequences this may have on production practices. As a result, growers are requiring an increasing amount of information on field and plant conditions to manage their farms in a sustainable and environmentally sensitive manner and still make a profit. Increasingly growers are starting to rely on RS approaches to monitor and manage their farms on a routine, cost-effective basis. For maximum benefit, the RS data provided to them requires an underpinning of sound science and needs to be accurate and consistent across locations and years. The data should also be available at temporal and spatial scales that match the grower's evolving capabilities to vary water and agrochemical inputs according to crop requirements and differences in soil characteristics. The prognostic process would have to include an examination of the problems plaguing land, water and soil. Using the successful application of RS technology to all these issues requires a basic understanding of how changes in plant growth, form, and function affect spectral reflectance and thermal emittance properties of crops and soils in the field.

Taking into account the predominance of the fragmented land holdings, heterogeneity of crops and livestock and concept of farm families in rural conditions, the model of precision agriculture representing the typical Indian Agricultural Scenario is yet to evolve. While the ecological integrity of farming systems is an imperative need it is equally important to extend the access of information and transfer all information to small and marginal farmers. The precision agriculture model for India while addressing these issues should provide an innovative route for sustainable agriculture in an effort to evolve a more globalized and liberalized economy.

Applying Remote Sensing, GIS, GPS technologies

The only known way then to start prognosing soil water management domains is to resort to quick and efficient technologies for management. Remote Sensing, GIS and GPS are the effective and accurate methodologies for identifying, diagnosing and prognosing problems of land and water and their management. An integrated approach using remote sensing offers technologically the appropriate method of analyzing land and water resources, characterizing coherent agricultural zones and identifying constraints for natural resource management. A lack of data and information prevents management indicators to be evolved both at the regional and farm level.

The existing resource constraints in rice-wheat systems include salinity, alkalinity, high water tables, on set of water logging and nutrient deficiencies. These domains require targeting for both technology and for the development of a decision support system employing remote sensing, GIS and GPS technologies. Each specific domain would require besides remotely sensed biophysical information and cropping system database, generation of socio-economic and ancillary information for assessing the status of the site-specific adoption of resource conserving technologies. Therefore the specific technology to manage it would have to be put into place taking into consideration different parameters in different agro-ecological zones but first we must understand site-specific problems.

The specific problem of increasing salinity in command areas for instance has been widely diagnosed by different organizations. IRS-1B LISS II data were used for mapping and monitoring salt-affected soils in Nagajunsagar right bank canal command areas, in Andhra Pradesh, and Periyar-Vaigai command area in Tamil Nadu (National Remote Sensing Agency, 1995, 1996 and 1997). Dubey *et al.*, (1995) mapped the salt affected soils of all of the state of Gujarat using IRS IB data on 1:1 m scale. This study was based on visual interpretation and ground truth. The salt waterlogged soils were mapped by Sethi and Gupta (1996) in the Ukai-Karapar command area using visual interpretation and ground truth. The salt affected soils of Kanpur district were mapped using IRS IB imagery on 1:50,000 scale by Sethi *et al.* (2001). A digital analysis showed the area affected to be 11.9 percent of the total district. Although the attempts at mapping have brought forth varying levels of accuracy the attempts to appraise salt affected soils more accurately are continuing. Prognosis is a much harder assignment and researchers need to build up skills to predict salinity. In a recent prognostic study, rising water tables are bringing on secondary stalinization in South-West Punjab. There is a drastic change in cropping patterns from wheat-cotton to rice-wheat-sugarcane after the cotton crop failed. Using multi-tasking and multi-temporal remotely sensed data of 1997and 2001 it was found that in an area covering 2000 sq km, almost 40 percent of the areas would degrade into salty lands if remedies were not put into place(Sethi *et al.*, 2005). Using such site-specific data and modeling would aid in understanding the problems and help in providing technologies for improvement. In fact, remote sensing and GIS will provide the essential ingredients for evolving management strategies for different soils/water/ cropping systems and aid in accurate implementation. More recently, Chandna *et al.* (2004) successfully tested a suite of resource conserving technologies and disseminated it through the Rice-Wheat Consortium and its regional partners in the five transects of the Indo-Gangetic Plains. Similar studies have been carried out where remote sensing has proved invaluable in diagnosing. Providing a prognosis requires greater understanding and use of modeling techniques in remote sensing and GIS.

Important considerations for implementation

A major fear is that the remote sensing technology might be over sold. Caution must be excercised in what expectaions we raise and the ability/constraints of the remote sensing/ GIS/GPS technologies.This happened in the 1970s when people were told that they would be able to detect diseases, nitrogen deficiencies, and many other stresses—all which proved false or inconsistent. But the conditions for applying remote sensing to natural resource management are now greatly improved. The improvements have come through advances in sensor technology as well as dramatic improvements in computer hardware and software, and the ability to rapidly transfer data between remote locations. We must realize, however, that we are dealing with complex technologies that require specialized training

It is true that voluminous data gathered with the help of remote sensing techniques are better handled and utilized with the help of geographical information systems (GIS). GIS functionality can be extensively utilized in the preparation of erosion and natural resources inventory and their analysis for assessing soil erosion and soil conservation planning. The methodology needs to be further developed to provide more precise evaluations and decision support at sub-national and local level, e.g., by identification of socio-economically defined resource management domains by characterization of zones for land development and natural conservation, land management and research planning, and by assessing land degradation. Activities should also focus on improvement of computerized geo-referenced databases combining information on terrain, soils, climate, crops/production systems, land uses and socio-economic factors such as land tenure, markets and prices; dissemination of computerized models, software packages, reports and training materials for land resources analysis, land resources optimization and decision support systems. It is important to encourage and expand applications of new geographic information technologies and newly available geographically referenced data and to introduce the next generation of scholars to this integrated approach and increase collaborative interdisciplinary networks that address core issues.

There is no better source from which to learn about the needs of technology users than the users themselves. For this reason it is important to have focus groups. Remote sensing can provide data on agricultural activities in inaccessible areas, or simply obtain more accurate information than otherwise available. This information can be obtained from radar images, and interpreted using machine vision techniques to identify different agricultural regions or crop types.

Over the last two decades, the role and impact of Geo-Information and Communication Technologies has significantly changed. It is evolving toward a 'strategic' role with the potential not only to support chosen agricultural advancement strategies, but also to shape new strategies. This addresses, emerging policy links and trends in Geo-Information

Management for Land and other domains such as topography, geology, land cover/uses and natural resources at the national and district levels. We need to confront the issues of:

- Data sources, data acquisition, data conversion and processing;
- Data models, process models and databases (central/local);
- Electronic exchange and distribution of geo-information; and
- Quality parameters and review procedures;

We must recognize that the use of geo-informatics must become an essential ingredient for data base collection and dissemination as well constitutes the basis for diagnosis and prognosis for management. It is of great import that we develop conceptual and logical models of geo-information systems using system development methodologies focusing on stakeholder's requirements, data sources, and acquisition, maintenance and data models. There is also a need to ensure that those who might benefit most from this kind of information are suitably equipped with the knowledge and equipment to effectively apply it for long-term benefit. This will require investment in capacity building for training and infrastructure projects.

FUTURE CHALLENGES

To completely exploit the capability of technology available, for diagnosis, prognosis and management of soil water domains as also to widen the usage and acceptability and accuracy future challenges need focus on:

- Increased co-ordination between national satellite programmes and their counterpart development assistance programmes including state remote sensing agencies.
- Stronger links between ground observations and related satellite observations by all organizations.
- Better understanding of user needs for earth observation data in the agricultural and rural sectors, certainly more assessments are needed.
- Improvements in product development, validation, and continuity of data sources, in particular of high (5m) and medium (30-40m) resolution satellite systems such as IRS.
- Improved data archieving and access by users. Integration of data collection, management, and assimilation is necessary and integral to any diagnostic procedure for land/water/soil studies.
- Current prices of software and output hardware are so high that often even if the data are available the digital analysis cannot be attempted. Ground truth radiometers remain elusive because of prohibitory prices affecting their use. Prices of data available are too high to practically bring in it to use for farmer's fields. Data more than a year old must be sold by the NRSA at highly discounted prices so that the NRSA and the user can both benefit.
- Strengthened links between *in-situ* data gathering networks and satellite programmes to assist product validation such as land cover, land use, crop production, and cultivated area.
- Imperative that we overcome the impediment of broad band widths to finer and more calibrated spectral ranges similar to those available in Hyperion data, the band widths are dedicated and calibrated to ground data making working simple and accurate. We need to refine and hone the information with ground instruments.
- Create inter-institutional and intra-institutional exchange of information through the internet and greater transparency.

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Policy and Institutional Requirements for Transition to Conservation Agriculture: An Innovation Systems Perspective

Rajeswari S. Raina [1], *Rasheed Sulaiman V.* [2], *Andrew J. Hall* [3], *and Sunita Sangar* [4]
[1]National Institute of Science, Technology and Development Studies, New Delhi, India
[2]National Centre for Agricultural Economics and Policy Research, New Delhi, India
[3]Institute of New Technologies of United Nations University, The Netherlands
[4]Centre for Advancement of Sustainable Agriculture, New Delhi, India

ABSTRACT : The transition from conventional agriculture to conservation agriculture demands a combination of technological innovations and institutional innovations or new/modified ways of working. This paper analyses some of these new or modified ways of working or institutional arrangements that have enabled conservation agriculture. It uses this understanding to explore broader policy contexts and institutional arrangements that can facilities the promotion of conservation agriculture more widely in varying contexts. In doing this, it has highlighted some important institutional changes that can enable these ways of working among other organizations and individuals. The innovation system approach offers analytical insights into the mechanisms/processes of conservation agriculture.

INTRODUCTION

The agricultural knowledge system now confronts rapidly evolving and complex political, social, economic, scientific and ecological contexts. Conservation agriculture is central to safe and healthy natural resources as well as a means to improved agricultural and rural livelihoods. Coalitions of practitioners, scientists and other stakeholders contend that conservation agriculture can enable improved ecological, economic and social performance. Increasing evidence of several actors/organizations playing active and varied roles in agricultural/rural innovations offers a new set of lessons that will alter conventional wisdom about knowledge/technology generation and its utilization.

Technologies to tackle/solve soil degradation problems have been with us for some time now. The current re-awakening of the Leopoldian land ethics in the form of conservation agriculture, especially among soil scientists and agronomists, stems partly from their disillusionment with the slow adoption of soil improvement technologies. Conservation agriculture, unlike the reductionist technologies generated earlier, demands a combination of conservation technologies (i) zero/reduced tillage, (ii) crop residue management, and (iii) water/nutrient conserving cropping systems (Gupta *et al.*, 2003; Ladha *et al.*, 2003). These are the three pillars of conservation agriculture. However, this is a narrow technological view. It cannot help us understand the processes or institutions – the software that makes conservation agriculture work.

The transition from conventional agriculture to conservation agriculture has been difficult (despite all the benefits of production and productivity and cost savings that have been documented and analysed) because conservation agriculture demands a combination of technological innovations and institutional innovations or new/modified ways of working. This paper analyses some of these new or modified ways of working or institutional arrangements that have enabled conservation agriculture. It uses this understanding to explore broader policy contexts and institutional arrangements that can facilitate the promotion of conservation agriculture more widely in varying contexts.

Understanding conservation agriculture in context

Four features that distinguish conservation agriculture R&D from the conventional linear R&D models are: (i) the inter-disciplinary combinations of divisible, flexible and context specific conservation technologies; (ii) acknowledgement of systems concepts and relationships in the natural resource and cropping systems, and between ecological and social systems; (iii) significant participation of farmers and other stakeholders in the R&D programmes, willing to learn from each other; and (iv) an active learning, redefinition, and redesigning of technologies and processes amongst all the participants. Conventional agricultural policy and institutional arrangements that compartmentalize generation, diffusion and adoption of technology into distinct organizations each with limited mandates, following a linear top-down flow of knowledge and technology from research down to extension and ultimately the passive adopters at the field level, have much to learn from these four features.

Conservation agriculture marks an evolution in the agricultural sciences from linear R&D models (with technology generation, diffusion and adoption located in and handled by at least three different organizations – research institutes, extension departments and farms, in a linear sequence of knowledge flow) to significantly non-linear systems with actors involved in several processes and activities of knowledge production and use. Conservation agriculture coalitions reveal examples of knowledge being accessed and employed from multiple sources. We observe knowledge from farmers about field conditions, pest incidence, soil compaction, labour costs, reliable input suppliers, etc., combining with and modifying or improving the knowledge from scientists about raised bed planting techniques, irrigation efficiency, residue incorporation, weed growth patterns, etc. These specific processes of knowledge sharing and learning from experience are highly context specific. But knowledge flows among a system of actors, the emergence of new technologies and new roles/capacities in each of the actors (organizations and individuals), and new ways of working (rules or processes) are evident in cases of conservation agriculture innovations presented from the rice-wheat cropping system in Haryana and Punjab, the maize based cropping systems in the Deccan, or the zero-tillage systems in Bhopal, Uttaranchal or Bihar (Seth, 2003; Gupta *et al.*, 2003; Gupta and Ladha, 2004; Singh *et al.*, 2004). These are among the principles of innovation systems (Hall *et al.*, 2004).

Conservation agriculture — An innovation systems perspective

The features of conservation agriculture reveal the principles and practices of an innovation system in operation. The concept of innovation encompasses activities and processes associated with the generation, production, distribution, adaptation and utilization of socially relevant knowledge. When research is conceptualised as part of a wider process of innovation, there is scope to identify the actors (including public/private research, enterprise, market, technology user sectors) involved and the wider set of relationships in which research is embedded. At its simplest, an innovation system can be described in terms of three elements:

(1) all the organizations and individuals involved in generating, diffusing, adapting and using new knowledge and new ways of working;

(2) the interactive learning processes that occur when organizations engaged in the above activities, and the ways in which these activities lead to innovation (i.e., new processes and products); and

(3) the institutions – rules, habits and conventions – that govern how these actors (organizations and individuals) work and how these interactions/processes occur.

The question at hand now is about ways and means to enable the transition from conventional agriculture to conservation agriculture. In the recent past, several academics and policy-makers have addressed the need for transformation in conventional agricultural R&D. Conservation agriculture experiments that have led to successful innovations, if explored using the innovation systems framework, can offer lessons about technologies and ways of working or institutional arrangements that can help transform conventional agriculture.

The need for transition – policy requirements

An overview of the institutions that govern natural resources research tells us that coalitions or partnerships among multiple stakeholders are crucial to the success of natural resources management innovations (Biggs and Smith, 1998; Douthwaite, 2002; Blumenthal and Jannink, 2000; AABNF, 2001). Institutions are basically rules of the game or norms that govern the way organizations (structures) like research institutes, NGOs, private sector, universities, farm households, research programmes or projects work. A policy is a framework more like a set of working guidelines that specifies a goal(s) that is to be achieved. In a conventional system, there are technologies and organizations that lead to the achievement (or otherwise) of these policy goals, drawing a clear causal and chronological sequence, from policy prescription to institutional arrangements that help implement the policy instruments and activities in existing or new organizations, and lead to achievement of policy goals. Conservation agriculture reveals a breakdown of this conventional causality and chronology. These innovations present a complex scenario where new institutions like partnerships among science, farming, agricultural markets and environmental concerns have emerged (although in the periphery) to achieve certain goals that go beyond current policy goals in the agriculture sector. There appears to be a mutual determination of institutional arrangements, technologies and policy framework. And these successful innovations and the institutional arrangements that enable them challenge current policies and demand a change.

The dominant policy goal emphasising food security has led to a model of agricultural development based exclusively on cereal production, agricultural research to test and release varieties (especially of wheat and rice), and subsidies and price supports that encourage mindless exploitation and degradation of natural resources and unsustainable rural livelihoods. It is increasingly evident that in India, and other developing countries *well articulated and dynamic policies for livelihood security, ecological and social sustainability, and development must now replace the myopic 'food security' policy*. The transition to policies and scientific research for sustainable agriculture is bound to be slow and painful. In practice, the relationship between policy and science in the agriculture sector is one that is in the order of coalition building, negotiation and persuasion in the 'competitive arena of politicking.' (Gass *et al.,* 1997) *Researchers and practitioners of conservation agriculture must engage in a pro-active policy dialogue to enable this shift from production concerns to livelihood concerns in agricultural science and policy* (Gaunt *et al.,* 2003).

The complex contexts and the institutional history of conservation agriculture also bring in new policy research questions. There is a felt need for policy analyses to understand how conservation technologies integrate with other technologies, policy instruments and institutional arrangements that promote/repress conservation agriculture. For instance, if the principles and practices of rice cultivation (in the arid/semi-arid terrains of north-western states in India) contradict the technological and institutional innovations that enable conservation agriculture and sustainable livelihoods and ecosystems, then how can the policy process be informed and policy instruments be designed to address these issues? Applying pro-poor criteria to this successful innovation system may bring out other wider policy questions, especially about the employment impacts due to widespread adoption of conservation agriculture.

Given that sustainable innovations are characterized by a good partnership among a coalition of organizations/individuals, building effective partnerships with the different constituencies is a role that research management has to learn to play. Research management must learn to systematically address these processes or ways of working with as much attention as they address the technological issues. Institutional arrangements, say developing a coalition of interest groups for delivering livelihood improving, poverty relevant and eco-friendly knowledge as well as development processes, must become part of agricultural research policy.

Institutional requirements: Innovation systems

New institutional arrangements are evident in conservation agriculture systems compared to conventional agricultural R&D. Observations on the institutions or ways of working of conservation agriculture reveal that there is a non-linear innovation system in place instead of the conventional compartmentalized and hierarchical arrangements of research that generates technologies, extension that delivers it and farmers who passively adopt it. Transition to conservation agriculture is possible only IF and WHEN the agricultural knowledge community, including all its stakeholders in agriculture and allied sectors acknowledge, adapt, enable and adopt these institutions, processes or ways of working. Some of the important institutional changes that can/must be introduced in conventional agricultural R&D to enable their transition to conservation and enhancement of natural resources and rural livelihoods are highlighted below.

Learning in coalitions

One of the key principles that make an innovation system is the focus on innovation than on research. Innovation is enabled by the continuous learning and the processes of change that result from this learning (Sulaiman and Hall, 2002; Hall *et al.*, 2004a). This learning takes place without any hierarchy, and in non-linear formats, with farmers, scientists, department officials, extensionists, rural bankers and others learning together and from each other.

Farmers who have adopted conservation agriculture vouch for the close collaboration and hands on learning in the field with their scientists and other stakeholders (input dealers, seed suppliers, implement manufacturers etc.). The research organizations involved in these coalitions have made changes in rules i.e., developed new institutional arrangements by enabling modifications in travel plans/schedules, re-designing data collection formats (to make them user friendly and reflect the flexibility of farm level operations), new learning practices and platforms (the travelling seminar, local discussion groups), and devising new ways to understand the adaptability of the (three pillars of) conservation technologies. *Mainstream agricultural research organizations must find ways of enabling such learning processes and new institutions or rules that enable learning. This is a sure way to promote such non-linear innovation systems in collaboration with other stakeholders.*

The responses from mainstream agricultural research to innovations such as the Systems of Rice Intensification (SRI) (Stayanarayana, 2004; Stoop *et al.*, 2002) have been characterised by a reluctance to engage with and learn in collaboration with these systems. This, however, should not surprise us. Conventional agricultural science has still not acknowledged the institutional arrangements that made the green revolution actually happen, instead of consigning the Norin 10 genes and high yielding dwarf varieties to the display shelves or annual reports of research institutes. A study on rhizobium inoculants in Thailand concluded that scientific research and extension components involved in the inoculant technology did not learn from or change with the diversity of biological and social contexts they encountered (Hall and Clark, 1995). That a 'learning disability' exists in conventional R&D organizations must be acknowledged before any attempt is made to enable learning and innovations.

Appropriate partnerships: respecting different interests/stakes

Given that we know that successful natural resources management takes place when there are coalitions of partners, it is imperative that we highlight what conventional agricultural R&D can do to enable the formation and evolution of partnerships. First, joint task identification and definition of purpose is crucial to build a good partnership. While the overall purpose of a partnership is to accomplish a complex task that cuts across disciplinary, organizational and sectoral mandates, it is important to recognize that all the partners may not have the same stakes or interests in the partnership outcomes. It is clear from the history of several resource conserving technologies that soil fertility improvement is not enough to drive the system (Hall and Clark, 1995; AABNF, 2001). Conservation agriculture is being adopted for multiple benefits that cut across bio-physical and socio-economic systems and varying scales (micro–household level, meso-farming systems/village levels, and macro-regional level). Now *soil scientists and agronomists should work with other social scientists to identify what these benefits are and on fine-tuning the system to maximize the range of benefits including benefits to the soil. For this it is important to identify and build relationships with appropriate stakeholders keeping in view the interests and agenda that each stakeholder brings to the conservation agriculture innovations*. It is often seen that innovations are best triggered by one partner — a catalyst organization. Identifying this catalyst to facilitate broad based partnerships is a crucial part of capacity building for conservation agriculture.

Evolution is another principle of partnerships; genuine partnerships evolve over time. Partnerships last only as long as there is a task to be accomplished – they are not permanent relationships. While a clear definition of tasks and roles of partners is important, the roles of partners will change during the innovation process, with partners acquiring new skills or capabilities, assuming greater or different responsibilities in the task, or branching off on tangents/complementary roads. Good partnerships are not fettered by the hierarchy of expert opinion or professional blinkers; and they allow more effective linkages among the organizations and individuals involved. *Conventional agricultural R&D has to recognize the inherent flexibility in these partnerships, and find new ways or norms to enable such flexible ways of accomplishing tasks*.

Non-conventional /"out of the box" partners

Examples from successful resource conserving technologies reveal that partnerships with private and voluntary sector organizations led to the uptake, increased adaptation, and adoption of technologies (Biggs and Matsaert, 2004; Raina *et al.*, 2004). Like a partnership among organizations, the collaborative effort of diverse disciplines leads to resource management innovations. The *mucuna* fallow system teaches us that animal sciences, food sciences, toxicology and analytical chemistry contributed significantly to the uptake of the technology and delivering benefits of *mucuna* to poor farmers (Carsky *et al.*, 2004). In Nigeria and Brazil the success of BNF technology and soybean was due to the contributions from food scientists who helped to create a market for soybean and Striga biologists who helped to identify additional benefits of grain legumes to the cereal systems. In order to deliver the resource improvement benefits to farmers and ecosystems, *conservation agriculture now needs to decide how it will encourage other useful disciplines/actors to contribute.* It is the responsibility of conservation agriculture coalitions to explain to conventional agricultural research organizations how different skills, perceptions, social capital, and sources of funding were brought together, and how these conventional organizations can scout for these out of the box partners.

Capacity development

Partnership skills and learning processes/practices are not available with all organizations and individuals. It takes special effort to develop the capacities for these institutions or ways of working to exist and evolve in different partner organizations. The institutional changes detailed above may come incrementally or with some radical changes in the policy framework or context. One of the lessons from analyses of rural innovation systems is that institutional changes can be achieved by encouraging a spirit of experimentation and learning in the agricultural development establishment. *Conservation agriculture demands initiation of several new (especially small experimental) projects aimed at multiple benefits (instead of an exclusive focus on soil fertility/resource management/crop productivity) in various locations. This will force organizations in research and policy-making, farmers, resource conservation, rural inputs or finance, agricultural markets and post-harvest sectors to form need based partnerships to address the key rural livelihoods issues through conservation agriculture.* Given that there is no single given set of technologies or one prescribed way of making conservation agriculture work, these partners can then identify the ideal entry point and set of tasks to be taken up in each context. It is important that linear 'training' programmes for conservation agriculture are not the only source or main tool for building capacities. We need small projects which will facilitate hands on learning within organizations and different coalitions of partners in each context. These will then enable all the partners to reflect on the processes, results and outcomes of conservation agriculture projects, identify the institutions/rules that have changed during the course of the project, address the institutions/rules that have to change, and help learning and evaluation within project coalitions. Capacity development in this manner, through small locally relevant projects, will ensure that the technological and institutional changes are acknowledged and the new rules/norms/ways of working are not lost.

An evaluation culture

Viewing learning and critical internal assessment of learning processes and learning capacities are important within dynamic innovation systems. These internal learning and assessment processes, which are the core of an evaluation culture, are essential for the actors themselves, their sponsors (whether government, national or international institutes/donors, or private or voluntary sectors), and for future coalitions. While hands on learning is important to enable actual institutional change in organizations, documenting and analysing the research processes and products will ensure that others will have access to these lessons – the principles and practices that are helpful, and not waste precious time and material resources in learning by doing. *Conservation agriculture demands an 'evaluation culture' that evaluates the technological components and institutional processes that go into the making and conduct of a research programme and not conventional impact assessment that takes place at the end of the research process.*

When institutions are seen as rules/norms or ways of working and not as organizations, the perspective helps us analyse how existing institutions enable science to observe, interact with, analyse and recommend solutions for natural resource problems that hamper agricultural development. Institutions often impede the capacity of science to address these problems within their own research organizations, and to convince farmers, their societies, and policy makers to change agricultural research policies and agricultural policies (Bigss and Matsaert, 2004; Hall *et al.*, 2001; Raina and Sangar, 2002; Raina, 2003). It is useful, as part of this introspection to enquire about the *extent to which conservation agriculture has informed or changed the institutions/ways of working of conventional productionist agricultural R&D. An evaluation culture demands an active role of the social sciences within the innovation system* – it is doubtful if the social sciences within the agricultural R&D establishment have reached out to partner with natural sciences in order to understand decision-making and other innovation processes.

In effect, the institutional changes that have been listed here can help the transition to conservation agriculture. The processes of institutional innovations will be unique to each context, the tasks at hand and the stage of evolution of the coalition of partners. This brief paper has tried to understand and emphasize the need to understand the ways of working that conservation agriculture espouses. In doing this, it has highlighted some important institutional changes that can enable these ways of working among other organizations and individuals. The innovation systems approach offers analytical insights into the mechanisms/ processes of conservation agriculture. The way ahead for conservation agriculture is not clear yet; but it is clear that institutional changes are crucial to facilitate this way ahead.

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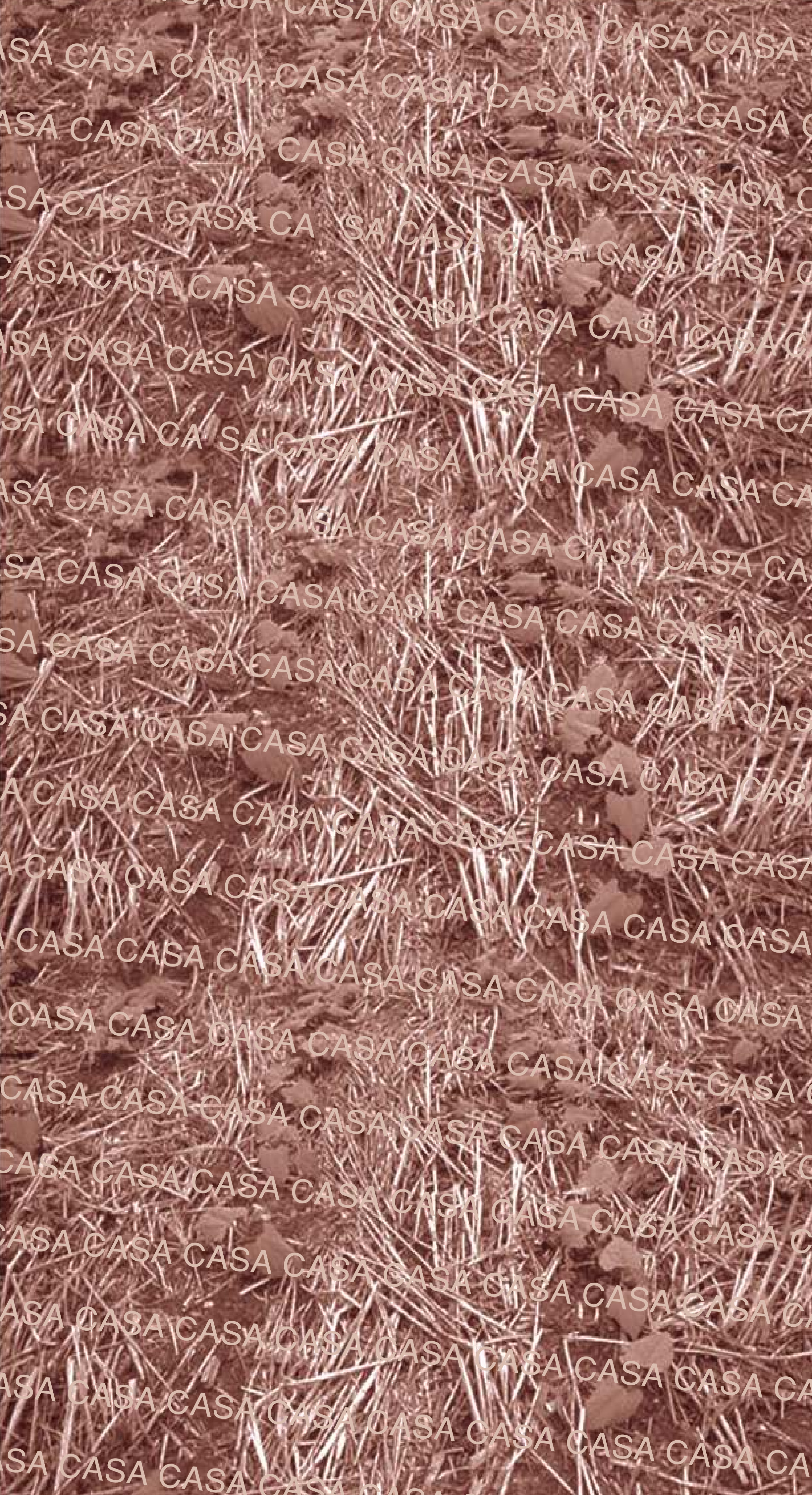

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