Compendium of deliverables of the conservation agriculture course 2010

Bram Govaerts and Francesca Vaghi
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CIMMYT
International Maize and Wheat Improvement Center
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Foreword

This book is the result of the hard work of nine CIMMYT trainees from India, Pakistan, Iran, Ethiopia and Bangladesh, who participated in the 2010 visiting scientist program “Conservation agriculture: Laying the groundwork for sustainable and productive cropping systems”. Over 5 weeks the scientists received an intense training program that combined mentoring and problem solving approaches. They actively participated in the ongoing cropping systems management activities of the CIMMYT Mexico based Conservation Agriculture Program, at the experimental stations located near Mexico City at El Batán and Toluca, and in nearby farmers’ fields. Emphasis was given to conservation agriculture and resource conserving technologies, including conventional and reduced till permanent bed planting for both irrigated and rainfed conditions, and using alternative crop residue management strategies. Crops studied included wheat, maize, barley and dry beans.

Strong focus was given to the importance of interdisciplinary approaches. Breeders provided a better understanding of the nature of crop management by genotype interactions. Similarly, plant pathologists were involved in order to better understand disease interactions with the new tillage and crop residue management practices and an economist shed light on the complex system interactions and market chain development related to conservation agriculture. These are just some of the numerous contributions we received from several CIMMYT scientists. Upon completion of the program, the participants presented their plans to initiate activities in their home countries. This included carrying out further research including what was learnt and the extension of the new technologies to farmers. They developed the necessary skills for trial management and plant and soil monitoring as influenced by management practices.

The main objectives of the program were:
- To enhance understanding of the use and application of the conservation agriculture planting technologies and relevant agriculture implements (with emphasis on planters/planter modifications) for irrigated and rainfed wheat and maize production systems.
- To encourage and develop participants’ ability to synthesize and use the information and knowledge related to conservation agriculture technologies (e.g., seeding methodologies in the different planting systems, irrigation water management, crop nutrient management, weed control strategies, and the importance of crop residue management).
- To increase participants’ knowledge of (long-term) trial planning and management.
- To develop skills for monitoring soil and plant parameters as they relate to cropping management systems, as well as their influence on physical, chemical and biological soil quality, their effect on climate change adaptation and mitigation, and their impact on water and nutrient use efficiency.
- To foster positive attitudinal changes, such as improved confidence, increased motivation, and heightened appreciation of the benefits of team work and interdisciplinary research.
- To create a minimum level of proficiency in order to generate scientifically-sound hypotheses, determine data collection strategies, interpret data and summarize them into scientifically-sound conclusions and recommendations.

This book is the result of a training course and has to be considered as a product of the course rather than a reference book. The views expressed in the chapters are those of the corresponding author and do not necessarily reflect the views of CIMMYT.
To achieve the last objective, each participant chose a defined deliverable to work on during the 5 week course. Some scientists analyzed and summarized data they brought from their home country, others reviewed a specific theme of interest related to conservation agriculture, and others developed training material to be used in their home country activities. In this book, we present the deliverables of each participant.

We want to thank the participants of the course for the excellent work they delivered. Each of you really did an excellent job. Thanks for sharing your valuable knowledge with the group!

Congratulations,

**Bram Govaerts**
Head, Mexico based Conservation Agriculture Program

**Francesca Vaghi**
Language Editor
Chapter 1. Conservation agriculture and sustainable cropping systems in Bangladesh

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Abstract
Conservation agriculture is defined by its three basic principles of minimal soil disturbance, permanent soil cover and crop rotations, and is considered a more sustainable cultivation system for the future. Conservation agriculture practices are essential in Bangladesh to reduce tillage costs, soil erosion, and environmental pollution, and to increase the crop productivity and organic matter content of soil. Paddy, wheat, maize, and mungbean have been grown on permanent beds and initial results were encouraging. This paper first introduces the resources present in the country and the constraints of using conservation agriculture, and discusses how age-old conventional agricultural practices are responsible for natural resource and soil degradation. It also explains how conservation agriculture will help conserve natural resources, improve water infiltration, reduce erosion, improve soil surface aggregation, reduce compaction through promotion of biological tillage, increase surface soil organic matter and carbon content, moderate soil temperatures, and suppress weeds. Furthermore, conservation agriculture helps to reduce costs of production, saves time, increases yields through timely planting, reduces diseases and pests through stimulation of biological diversity, and reduces greenhouse gas emissions. The scarce availability of suitable equipment is a major constraint to the successful implementation of conservation agriculture, but advances in design and manufacture of seed drills by local manufacturers are enabling the country’s farmers to experiment with and accept this technology. This paper concludes by stating that, in the next decade, agriculture will have to sustainably produce more food using less land and through the more efficient use of natural resources, causing minimal impact on the environment, in order to meet demands of growing population. This will be a challenge for agricultural scientists, extension personnel, and farmers.

Key words: conventional tillage, residue management, agricultural machinery, zero tillage, conservation agriculture.

1. Introduction
Bangladesh is predominantly an agricultural country but feeding its 150 million people using 8.2 million hectares of cultivable land is a tough task (Hossain, 2009). Every year, the population increases by almost 0.20 million, whereas the estimated annual loss of agricultural land is about 0.08 million hectares which is due to various non-agricultural activities, like the construction of houses, offices, roads, mills, factories, etc. (BRRI, 2009). The country’s food production has increased from 11.0 million tons in 1971 to about 40 million tons in 2009. The country is at present about to achieve self sufficiency in cereal production. This is due to the development of high-yielding varieties, irrigation development, fertilizers, and partial mechanization. Yet, to meet the food requirements of the expected Bangladeshi population in 2015, an additional 5 million tons of food grain need to be produced from the continuously decreasing agricultural lands with intensive cropping.

Persistent use of conventional farming practices based on extensive tillage, especially when combined with removal or in situ burning of crop residues, have magnified soil erosion losses, and the soil resource base has been steadily degraded (Montgomery, 2007). Land degradation is a growing problem in Bangladesh because of increased human activity and demand as a result of the growing population. Deforestation, over-grazing, and inappropriate tillage practices are contributing heavily to land degradation. Conventional tillage, which is commonly practiced in the country, involves the use of hand hoes, ox drawn mould board plows, tractor drawn disc plows and harrows, combined with straw collection and burning during land preparation. During tillage operations, the soils are inverted and pulverized, burying most of the residues underneath. The practice frequently causes soil compaction, which affects soil physical properties, provokes biological degradation, and results in declining crop yields. Conservation agriculture (CA) promotes zero or minimum tillage and has been proven to combat soil degradation efficiently. The emergence of CA stems from the need to put a stop to the declining productivity of land and increasing cost of inputs that are inflicting tremendous pressure on the farming community. This
is an important concept in today’s agriculture, since the human race will not want to compromise its future by producing their food supplies at the cost of natural resources. This paper will introduce and promote CA as a modern agricultural practice that can enable farmers to achieve the goal of sustainable cropping systems.

1.1. Bangladesh: An overview

1.1.1. Geography
Bangladesh lies in the northeastern part of South Asia between 20°34’ and 26°38’ North latitude and 88°01’ and 92°41’ East longitude. The country is bounded by India on the West, North, and northeast with Myanmar on the southeast and the Bay of Bengal on the South. The area of the country is 56,977 sq. miles or 1,47,570 km². The limits of the territorial waters of Bangladesh are 12 nautical miles and the area of the high seas extends to 200 nautical miles measured from the base lines, which constitutes the economic zone of the country.

1.1.2. Physiography
Except for the hilly regions in the northeast and southeast and some areas of highlands in the northern part, the country consists of plain and fertile land. A network of rivers exists in the country of which the Padma, the Jamuna, the Teesta, the Brahmaputra, the Surma, the Meghna and the Karnaphuli are important. All these rivers have 230 tributaries with a total length of about 24,140 km. The alluvial soil is thus continuously being enriched by heavy silts deposited by rivers during the rainy season.

1.1.3. Land types
Land types are usually classified into five categories, and a detailed description of land types with their area coverage is given in Table 1. From the land types found in Bangladesh it is evident that, except for the highlands, all other land types are subjected to flood inundations. Normally, 20-25% of the country is inundated during every monsoon, from June to September. In the case of extreme flood events, up to 40-70% of the areas can be inundated, which was most certainly the case during the extreme flood events of 1954-55, 1974, 1987-88, and 1998. Many kinds of land types are distributed all over the country. Highlands are situated in some parts of the western, South central, northeastern and southeastern regions of the country. Except for the very lowlands, human settlements can be found in all other land categories. Population density is high in the medium high and medium lowlands. People live in the lowlands by building earthen mounds. However, the irrigated land area increases day by day (Fig. 1). The irrigated and rainfed areas are also shown in Table 2.

1.1.4. Soils
The soils of Bangladesh were developed mainly through the silt deposition from the major rivers. Major soils vary both in structure and their potential for agriculture. They are classified into the following three broad categories: floodplain soils, hill soils,
and terrace soils. The flood plain soils comprising 14 different soil types include 80% of the total land area (BBS, 2009). The Ganges and Brahmaputra River Floodplains and smaller rivers occupy an area of smooth, very gently undulating reliefs, comprising broad and narrow ridges and depressions. Differences in elevation between adjacent ridges and depressions range from about 1 m on tidal plains (near the coast), 2 to 4 meters (on the Ganges and Brahmaputra river floodplains) and 5 to 6 meters in the northeast. In the extreme northwest, elevation exceeds 20 meters above mean sea level. Except for the depression sites and highly permeable soils, the floodplain soils are suitable for cultivating most of the crops. The hill soils comprise 12% of the total land area and 3% include a wide range of soils developed over consolidated and unconsolidated sandstones, siltstones and shale, which underline the northern and eastern hills. Most of the hill soils are not suitable for agricultural production due to the steep slopes and soil erosion during the monsoon. The main use of this soil is for fruit and timber production. Terrace soils have an area of 8% and the agricultural potential of these soils is moderate to low.

### 1.1.5. Climate
Bangladesh generally enjoys a sub-tropical monsoon climate. While there are six seasons in a year, winter, summer and monsoon are namely prominent. Winter begins in November and ends in February. In winter there is not usually much fluctuation in temperature, which ranges from a minimum of 7°C-13°C to a maximum of 24°C-31°C. The maximum temperature recorded in the summer months is 37°C, although in some places this occasionally rises up to 41°C or more. The distribution of rainfall during each month is given in Figure 2. The monsoon period starts in May and lasts up to October. This period accounts for 80% of the total rainfall; the average annual rainfall is 2,030 mm. The maximum rainfall is recorded in the coastal areas of Chittagong and northern part of the Sylhet district, while the minimum is observed in the western and northern parts of the country.

### 1.1.6. Soil fertility
Increased population pressure forcing intensive cropping led to shorter fallow periods for soils to recover resulting in soil mining. The replenishment of nutrients is low because of inadequate application of manure and inorganic fertilizers. This leads to a further decline in soil fertility, which is manifested in declining crop yields. The soil of Bangladesh is deficient in organic matter (OM) content. A good soil needs to have 5% OM content, whereas most soils have less than 1.5%; some soils have even less than 1%. Soil OM improves soil physical, chemical, and biological properties and is the storehouse of almost all the plant nutrients. Fertilizer use efficiency increases if the soil contains sufficient amounts of OM. The cropping intensity of Bangladesh is more than 190%. In many areas, two to three rice crops are produced per year from the same land; wheat or maize after rice is also a predominant cropping

#### Table 2. Irrigated and rainfed land area in Gazipur Hub areas

<table>
<thead>
<tr>
<th>District</th>
<th>Total cropped land (ha)</th>
<th>Irrigated (%)</th>
<th>Rainfed (%)</th>
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</thead>
<tbody>
<tr>
<td>Narayangonj</td>
<td>95,439</td>
<td>65.0</td>
<td>35.0</td>
</tr>
<tr>
<td>Manikgonj</td>
<td>221,373</td>
<td>57.5</td>
<td>42.5</td>
</tr>
<tr>
<td>Gazipur</td>
<td>204,051</td>
<td>55.1</td>
<td>44.9</td>
</tr>
<tr>
<td>Narshinghdi</td>
<td>173,542</td>
<td>70.1</td>
<td>29.9</td>
</tr>
<tr>
<td>Tangail</td>
<td>204,051</td>
<td>72.0</td>
<td>28.0</td>
</tr>
<tr>
<td>Mymensingh</td>
<td>473,850</td>
<td>48.0</td>
<td>52.0</td>
</tr>
<tr>
<td>Jamalpur</td>
<td>350,567</td>
<td>83.9</td>
<td>16.1</td>
</tr>
<tr>
<td>Kishoregonj</td>
<td>350,567</td>
<td>82.0</td>
<td>18.0</td>
</tr>
</tbody>
</table>

Source: DAE, 2009

#### Figure 2. Monthly temperatures in Bangladesh
Growing continuous and exhaustive crops without many soil amendment practices has led to declining soil fertility and crop productivity. The lower OM content, higher cropping intensity, improper cropping sequence, unbalanced use of fertilizer and faulty management practices, are the major causes of depletion of soil fertility. Cow dung is the main source of OM. Another source of OM is rice and paddy straw. But due to scarcity of domestic fuel, farmers depend heavily on all these. Another reason for low soil fertility is the erosion of top fertile soil by air and water. Erosion rates from conventionally tilled agricultural fields average 1-2 orders of magnitude greater than erosion under native vegetation and long-term geological erosion exceeds soil production (Montgomery, 2007). Aggregate breakdown is a good measure for soil erodibility, as breakdown to finer, more transportable particles and microaggregates increases erosion risk (Le Bissonais, 2003). For plain land soil erosion loss is much lower than hill erosion loss, but is still significant due to high rainfall incidence and windstorms.

1.1.7. Agriculture and main crops
Bangladesh is mainly an agricultural country. Agriculture is the single largest producing sector of the economy and its contribution to GDP is about 21.11%, of which crops, fisheries, livestock, and forestry account for 11.72, 4.73, 2.90 and 1.76%, respectively (BBS, 2008). This sector also accommodates around 48.1% of the labor force. The GDP growth rate of Bangladesh mainly depends on the performance of the agricultural sector. Yet, in recent years, there has been a substantial increase in food grain production. Agricultural holdings in Bangladesh are generally small but the use of modern machinery is gradually increasing. Rice, jute, sugarcane, potato, pulses, wheat, tea, and tobacco are the principal crops. The cropping pattern of the Central East (CE) Bangladesh hub is shown in Table 3. The crop diversification program, credit, extension, research, and input distribution policies pursued by the government are yielding positive results. The country is now on the threshold of attaining self-sufficiency in food grain production.

1.1.8. Land holding
Bangladesh has an area of 147,570 km², i.e., 14.76 million ha, of which 8.29 million ha is cultivable. Of the cultivable land, 7.19 million ha, i.e., 87% is cultivated (BBS, 2009). The average farm size is only 0.68 ha. Table 4 shows the farmer category and their percentage on the basis of land holding in the hub areas. From the table it is evident that most of the farms are small. Furthermore, these small farms are fragmented into many pieces, making the individual farm plots even smaller. Therefore, small-scale tillage machinery, like two-wheel hand tractors (commonly known as power tillers) are appropriate for farmers in Bangladesh.

1.1.9. Agricultural labor
Most of the young workers are occupied in textile and garments industries, as well as other industries. New industries are being established, thus most of the young workers prefer employment in modern industry, since payment is higher and it is mostly cosmopolitan. On the other hand, the labor crisis is severe in agricultural sectors, particularly in the peak Boro rice transplanting (January-February) and harvesting time (April-May). The peak transplanting time for T. Aman rice is July-August and harvesting is November-December. Moreover, the cost of a unit of labor is rising with the increase of living costs. Thus, profit in rice farming has become marginalized through hired labor. This situation could worsen in the future, due to higher demand for labor in the growing industry and service sectors.

<table>
<thead>
<tr>
<th>Districts</th>
<th>Primary</th>
<th>Secondary</th>
<th>Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manikgonj</td>
<td>Mustard-Boro-T. Aman</td>
<td>Mustard-Boro-Fallow</td>
<td>Potato+Maize-T. Aman</td>
</tr>
</tbody>
</table>

Source: DAE, 2009
1.2. Crop production constraints

The rice-wheat cropping system, which is one of the major cropping systems in Bangladesh and parts of South Asia, is confronted with many management problems. Rice requires puddled compacted soils to hold standing water during the growing season, while wheat grows best in well-drained soils to allow deep penetration of the root system. The puddling operation to form hardpan is important for water retention for rice cultivation, but unless this hardpan is broken, wheat may suffer problems related to water logging. However, some of the major production constraints of the rice-wheat cropping systems in Bangladesh are discussed in the following section.

1.2.1. Late sowing of wheat crops

One obvious cause of delayed planting of wheat is the late harvest of the preceding rice crop, which is a preferred crop, regardless of its lower yields, as it represents a staple food for farmers. Farmers grow a long duration, photosensitive rice that matures later. Therefore, the rice harvest is inevitably delayed leading to late sowing of wheat. Accordingly, there is a short window of time available for land preparation for the wheat. Moreover, reduced day length and sunshine decreases soil and air temperatures. Wheat is planted late on 40% of the area in Bangladesh. It has also been established that delay in wheat planting after optimal sowing time (i.e., 20th November) results in the reduction of potential yield by about 1-1.5% each day. Moreover, farmers often cultivate land without achieving suitable seedbed conditions for planting wheat, which results in poor crop yields.

1.2.2. Conventional planting techniques

Another factor that hinders the potential optimum wheat yield in paddy areas is that wheat seeds are generally broadcasted leading to much reduced plant emergence. It is not surprising that wheat yields in rice-wheat areas are significantly lower as compared to other irrigated areas of the country.

1.2.3. Drought, excessive rainfall, and flash floods

Drought causes severe damage during the Rabi and Kharif-I seasons, particularly for rice and vegetable production. Excessive rainfall in the winter often damages mustard and Boro rice. Sometimes, flash floods occur, causing crop loss in Kharif-II crops, particularly T. Aman rice and also early flash floods in Boro rice.

1.2.4. Use of low quality seeds

Supply of quality seeds to the grassroots farmers could increase the production of cereals, pulse, edible oilseed, and onion, and reduce the country’s dependence on importing these essential items. If a sufficient supply of high-quality seeds were ensured to the farmers, the production of these vital crops would increase. It has been proven that by using high quality seeds, production could be increased by 15-18% cultivating the same amount of land and under the same management.

1.2.5. Application of unbalanced fertilizers

The use of chemical fertilizers mainly of N, P, K, and S has been increasing steadily, but they are not applied in balanced proportions. Continuously cropped areas were observed to have problems related to the decline in OM and the unbalanced use of fertilizers was found, aside from its
impacts on P and K fertilization, to cause emerging deficiencies of micronutrients like Zn, B, Mn, and Mo. Disproportionate use of urea and non-urea chemical fertilizers has become a major factor in reducing land fertility hampering crop production while increasing pest attacks.

1.2.6. Labor crisis for rice cultivation
Like other South Asian countries, the rice crop in Bangladesh is established by hand transplanting young rice seedlings. The nature of the job is cumbersome, as it involves enormous drudgery and human stress in sweltering weather. The operation is also very laborious as it takes 110-125 man-hours per acre, or 40% of total labor requirement of the crop. In the recent past, with the onset of industrialization in urban areas, employment opportunities increased and an acute shortage of agricultural labor is experienced during transplantation. The low availability of labor has further aggravated the situation and paddy transplanting has emerged as the stark problem in all rice-growing areas. Optimum plant density and timeliness of transplanting operations in paddy areas are considered essential for optimizing paddy yields, and this can be achieved if dependence on hired labor is minimized.

1.2.7. Undulated topography
A considerable amount of water is wasted during irrigation of un-leveled fields. Studies have indicated that a significant amount of irrigation water is lost during its application in the farms due to poor farm design and uneven fields. The problem is more pronounced in the case of paddy fields. It has been noted that most of the farmers apply irrigation water until the highest point in a field is covered. This leads to over-irrigation of low-lying areas and under-irrigation of higher spots. Over irrigation leaches soluble nutrients from the crop root zone, makes the soil less productive, and degrades groundwater quality. Moreover, layouts of most of the farms are based on traditional flood basins comprising a number of unwanted dikes and ditches covering a length of over 2 km in each square (25 acres). The fields being not properly leveled cause wastage of land, low irrigation efficiencies, and ultimately results in substantially lesser yield than the potential.

1.3. Problems with machinery use
Machinery in the country is always associated with some inherent drawbacks, like fragmented lands, poor buying capacity of farmers, lack of quality machines for farm operation, inadequate knowledge about machines, and insufficient awareness of building activities.

1.3.1. Fragmented lands
In 1980, the average farm holding was 0.91 ha, which decreased in 2000 to 0.68 ha (Roy, 2008). It has been found that many farmers cultivate only about 1.0 decimal of land using traditional methods. Furthermore, the total holding of land is not located in one place, rather, it is found in split plots in several places. This restricts power-operated tilling, seeding, and harvesting machines from performing at optimal efficiency. Even two-wheel tractors, reapers, and combines face tremendous problems from frequent turnings in such fragmented lands.

1.3.2. Poor buying capacity of farmers
The rural people are mostly poor and can hardly afford to buy a costly machine individually. Some richer farmers that have a larger quantity of agricultural land, possess some costly machines like tractors, power tillers, power tiller operated seeders, combines, etc. They use these machines on their own land and also rent them out to other farmers and earn a substantial return. Yet, the number of such farmers is very limited.

1.3.4. Lack of quality machines
Due importance was not given to farm mechanization until the beginning of this century. Earlier, only a few manufacturers started fabricating simple, manually operated machinery like weeder, threshers, winnowers etc. With the growing need for food, policy makers realized that Bangladesh had no other alternative than to adopt mechanized cultivation to feed its ever growing population. This helped some agricultural manufacturing workshops in the country to expand. Yet, many small workshops are manufacturing sub-standard machinery, which adversely impacts farmers.

1.3.5. Lack of knowledge and skill of users, artisans, and traders
The machine users, artisans, and traders are mostly illiterate and don’t have substantial knowledge and skill about machine operation, repair, and maintenance. The manufacturers do not provide ‘after sale service’ to the users. From field experience, it has been found that machines are left idle for minor and easily repairable faults. On availability of an artisan or a mechanic, the farmers get them repaired at high expense. But in other cases, where mechanics are not readily available, they leave the machines and stop using them.
1.3.6. Current farming practices in Bangladesh

The population of Bangladesh was only 70 million in 1971 and that has increased to over 150 million during the last four decades. As a result, per capita land availability has declined. Similarly, per capita agricultural land availability has reduced from 0.44 to 0.17 hectares during the last 40 years. Likewise, per capita water availability has also reduced. The above facts reveal that an abrupt change in crop production systems, which can be achieved through the adoption of new technologies for making efficient use of available natural resources, is essential. It will otherwise become extremely difficult to fulfill the food demand of the population. The best option is to adopt the principals of conservation agriculture. The major cropping system in Bangladesh is alternating rice and wheat, with rice grown in the wet, humid monsoon season, and wheat in the dry, cool winter.

Tillage has been, and still is, promoted as an essential component of management of these two crops in Bangladesh. For rice, the soils are plowed, flooded, and then puddled. This is done to reduce the percolation of water and preserve standing water, which helps control weeds. Rice seedlings from separately raised seedbeds are transplanted into the softened soil in the main rice field. The puddling of rice fields degrades the soil’s physical properties and probably has significant negative impacts on the soil properties. The land requires repeated plowing (more so on heavier, finer-textured soils) after the rice is harvested, to obtain a fine seedbed suitable for planting the next crop, usually wheat. This plowing is costly, consumes large quantities of fossil fuels, emits large amounts of greenhouse gases, and delays the planting of wheat, whose yield is affected by delayed crop establishment. The poor physical condition of the soil leads to poor crop stands and to water logging after irrigation, with aeration stress and yellowing of the young wheat plants. All these factors take their toll on yield potential, natural resource use efficiency, and environmental quality. These standard practices are now being replaced by new practices focused on more ecologically sound management of plants, soil, water, and nutrients, supporting beneficial soil biological processes.

It has been observed that average wheat yield of most of the Asian countries is higher than Bangladesh. This is a clear indication that Bangladesh is not achieving the potential yields of wheat varieties in the region. Similarly, average rice yields of other countries in the region are also higher. For example, China and Korea are producing 3.7 and 4.0 t/ha of wheat, and 6.0 and 6.9 t/ha of rice, respectively. So there is great scope for achieving higher yields of wheat and rice in Bangladesh. The whole concept and practice of CA has not been adopted by all farmers, but the main principles of zero tillage and maintaining residue cover on the soil are gaining small acceptance. More comprehensive management strategies are still evolving.

2. Elements of moving towards sustainable production systems in Bangladesh

- Less labor and input requiring technology, such as direct-seeded rice (DSR) or CA based technology, to save labor and cultivation costs.
- Demonstration on balanced fertilizers, such as Site Specific Nutrient Management.
- Use of quality seeds along with production of Truthfully Labeled Seed (TLS) at farmers’ level.
- Value added agricultural products have a big market. Improve value addition and marketing of agricultural products.
- Rice cum fish cultivation in bunded medium lowland.
- More diversification of cropping systems through high value crops/fruits/other enterprise such as cattle/fish farming.

2.1. Adoption of conservation agriculture

Nowadays, people have come to understand that agriculture should not only lead to high yields, but should also be sustainable (Reynolds and Borlaug, 2006). Conservation agriculture has been proposed as a widely adapted set of management principles that can assure more sustainable agricultural production, or is an approach for the design and management of sustainable and resource-conserving agricultural systems. It seeks to conserve, improve, and make more efficient use of natural resources through the integrated management of soil, water, crops and other biological resources in combination with selected external inputs. Such a technological package represents a resource-saving and efficient agricultural method that contributes to environmental conservation and, at the same time, enhances production on a sustainable basis (Fig. 3). The name conservation agriculture has been used to distinguish this more sustainable agriculture from the narrowly defined ‘conservation tillage’ (Wall, 2007). Conservation tillage is a widely-used terminology to denote soil management systems that result in at least 30% of the soil surface being
covered with crop residues after seeding of the subsequent crop (Jarecki and Lal, 2003). Conservation agriculture, on the other hand, encompasses a set of complementary agricultural practices:

- minimal soil disturbance (through reduced or zero tillage) in order to preserve soil structure, soil fauna, and organic matter (Fig. 4);
- permanent soil cover (cover crops, residues, and mulches) to protect the soil and contribute to the suppression of weeds (Fig. 5);
- diversified crop rotations and crop combinations, which promote soil micro-organisms and disrupt plant pests, weeds, and diseases.

The CA principles are applicable to a wide range of crop production systems, from low-yielding, dry, rainfed conditions to high-yielding, irrigated conditions. Conservation agriculture aims to boost agricultural production by optimizing the use of farm resources and helping to reduce widespread land degradation through the integrated management of available soil, water, and biological resources combined with external inputs. Mechanical tillage is replaced by biological mixing of the soil, whereby soil micro-organisms, roots and other soil fauna take over the tillage function and soil-nutrient balancing. Soil fertility (nutrients and water) is managed through soil cover management, crop rotations, and weed management.

2.1.1. Benefits of conservation agriculture

Several benefits arise from the implementation of conservation agriculture, some of which become obvious once the system reaches stability (such as improved yields, biodiversity, etc.).

- The organic carbon stock, biological activity, above- and below-ground biodiversity, and soil structure are all improved. Higher biological activity results in the formation of well-connected, mostly vertical soil macro-pores that increase water infiltration and resistance to severe packing. Soil degradation — in particular soil erosion and run-off — is greatly reduced, often leading to increased yields. Reduced soil and nutrient losses, in combination with more rapid pesticide breakdown and greater adsorption (due to the higher organic matter content and biological activity) also results in improved water quality. Carbon dioxide (CO₂) emissions are lowered as a result of the reduced use of machinery and increased accumulation of organic carbon. Conservation agriculture practices could sequester between 50 and 100 million tons of carbon annually in European soils, the equivalent of the emission of 70-130 million cars.
• Labor and energy inputs related to land preparation and weeding are greatly reduced.
• Fertilizer requirements and soil-restoration interventions are reduced.
• Highest economy: Highest mechanical efficiency, less time for land preparation, less machinery deterioration, and less fuel consumption.
• Climate protection: Minimal use of fuel, less CO₂ addition into the atmosphere and fixation of carbon via mulch degradation.
• Water protection: Increased water-holding capacity of soil, higher infiltration rate, decreased leaching of nutrients, and reduction of evaporation.
• Soil fertility: Highest soil stability, undisturbed fauna and flora, natural soil structure, increased organic matter, and reduced erosion.

2.1.2. Implementation of CA
Conservation agriculture is typically implemented through the following steps, each of which lasts for two or more years:
• First phase: Inversion plowing is stopped, and reduced or zero tillage techniques are implemented instead. At least a third of the soil surface has to remain covered with crop residues, and cover crops should be introduced following the harvest of the main crop. Disc, spike or rotary harrows are used (direct drills in case of zero tillage). Yield reduction may occur.
• Second phase: Natural improvement of soil conditions and fertility occurs due to the origination of organic material from the natural degradation of residues. Weeds and pests tend to increase and must be controlled chemically or by other means.
• Third phase: Diversification of the cropping pattern (crop rotations) may be introduced. The overall system stabilizes progressively.
• Fourth phase: The farming system reaches equilibrium and yields may improve in comparison with conventional farming. This reduces the need to use chemicals for weed and pest control, or to supplement fertility. Farmers need training for each phase. Experience may be acquired in the field, but yields and profits may be lower in the short term. The system is unsuitable for compacted soils, which may first require loosening.

2.1.3. Steps in zero tillage adoption:
Some critical factors that should be considered before starting CA:
• Improve knowledge about all aspects of the system especially in weed control
• Analyze soil and if necessary incorporate lime and correct nutrient deficiencies
• Avoid soils with bad drainage
• Level the soil surface if this is rough for any reason
• Eliminate soil compaction using chisel plows or subsoilers
• Produce the highest amount possible of mulch cover
• Buy a zero tillage machine
• Use crop rotations and green manure cover crop to get the full benefits of the system
• Be prepared to learn constantly and be up-to-date with new developments

So, we need to:
• Convince farmers of the need to concentrate their efforts so that they are able to manage the crop well
• To show farmers that leaving residues on the surface reduces the risk associated with drought and enables them more security to produce their food needs on a smaller area. i.e., start incorporating CA into their production system.

2.1.4. Strategy for CA based agricultural development
• Sensitizing farming community with impact of CA
• Motivation/mobilization of farmers through demonstration to adopt CA
• Capacity building and technical support for adoption of CA
• On-farm technology validation through farmer participatory approach
• Coordination with other partners for adoption-oriented research to get true outcomes of the collaborative efforts
• Adoptive research on region specific ecosystems
• Policy and institutional support
• Networks of farmer groups and scientists and ensuring availability and access to machinery

2.2. Conservation agriculture based mechanization in Bangladesh
It is widely recognized that low productivity is the primary underlying constraint, not only to agricultural development and allied activities, but also to the rural, non-agricultural sector in Bangladesh. As the number of landless and sub-marginal farm households has proliferated, the area available for cultivation has shrunk. The challenge is to facilitate the shift to more productive farm and non-farm activities that will require less land, and will focus on the output for which domestic, and possibly export, demand is known to be expanding.
During the past decade, agricultural mechanization, particularly the use of single axle tractors and power tillers, has been advancing at an impressive pace in Bangladesh. This development under conventional farming systems had the risk of causing soil degradation, which could be further aggravated in view of the climate change occurring in the country. This danger, however, could be offset by introducing specialized equipment and mechanization solutions, along with the introduction of CA approaches.

Conservation agriculture is a vital option to face the double challenge of increasing productivity and preserving the natural resource base, simultaneously. Conventional agriculture often involves intensive tillage and has been claimed to cause soil degradation (particularly when practiced in areas of marginal productivity). Conservation agriculture includes a set of integrated soil management practices that aim at minimizing the negative effects of intensive farming. Practices such as direct sowing, zero tillage or minimum tillage, and the establishment of cover crops help protect organic matter, soil moisture, and soil fertility.

The concepts of CA were introduced in Bangladesh by the Rice Wheat Consortium, the International Maize and Wheat Improvement Center (CIMMYT), and the Food and Agriculture Organization of the United Nations (FAO), through the Technical Cooperation Program project called TCP/BGD/2902, which targeted rice-wheat growing systems. With the country supplying as many farmers as possible with the required equipment and technology for CA, this new farming system approach proved to work, and achieved its envisaged results on several farms. To expand the application of CA in the country, a program that aims at enhancing the capacity of the rural population to ensure food security and reduce poverty is proposed. It is expected that such a program will achieve the following objectives: (1) Identification of potential areas, blocks, and collaborating farmer groups willing to adopt conservation agricultural practices; (2) Capacity-building of farmer groups so they can better face the challenges of an open market economy in the context of CA; (3) Appropriate location specific conservation technologies/innovations for agricultural and natural resources management to be generated, improved, and promoted; (4) Appropriate stakeholder information, communication, and learning systems to be developed and enhanced; and (5) Appropriate policy and institutional options for CA to be developed and adopted.

2.3. Opportunities for the dissemination of CA technology
- Intercropping of maize with potato
- Rice super bag for storage of different crop seeds
- Introduction of the zero tillage mechanical rice transplanter
- Relaying of sugarcane in T. Aman rice fields, followed by wheat-mungbean or potato–mungbean
- Alternate wetting and drying (AWD) technology in Boro rice
- Nutrient management for rice/wheat/maize
- Creating institutional (private and public) linkage for rapid dissemination of technology
- Zero/strip tillage
- Laser land leveling

2.4. The following must be considered and researched for the successful dissemination of CA:
- Machineries suitable for DSR/zero/strip tillage in Boro/T. Aman/T. Aus rice
- Varietal differences for the cultivation of Boro rice/T. Aman/Wheat
- Application of appropriate herbicide for T. Aman/Boro/T. Aus rice for CA
- Water management technology for Boro/T. Aus rice for CA
- Fertilizer management technology for CA based rice/other crop production.
- The incorporation of residues in wheat-mungbean-T. Aman cropping pattern under minimum tillage/strip tillage conditions
- Seed rate/plant population for DSR/zero tillage/strip tillage under CA

2.5. Encouraging farmers to adopt CA
2.5.1. Bed planting of wheat
An experiment was conducted in Melandah, Jamalpur, during the Rabi season of 2009-2010 to determine the effects of bed planting on wheat yields in rice–wheat cropping systems. Bed planting was done in wide beds with three plant rows per bed under the conventional method. Seventy five cm-wide beds increased wheat grain yield up to 21% compared to the conventional method. It increased the number of panicles, number of grains, and 1,000-grain weight of wheat. Sterility percentage was lower in the bed method than the conventional method. Weed infestation was lower in bed planting. It saved 41-48% irrigation water. The cost of cultivation was lower and gross return: gross margin and benefit-cost ratio were higher in bed planting than under the conventional method. The results are presented in Table 5.
2.5.2. Wheat cultivation by power tiller operated seeders
An experiment was conducted in the medium highland under irrigated conditions at Elenga, Tangail, during the Rabi season of 2009-2010, to evaluate the performance of different tillage systems along with wheat varieties under farmers’ field conditions (Fig. 6). Two tillage systems such as PTOMTS and conventional tillage were placed in the main plot: four varieties of wheat namely Prodip, Bijoy, Sufi, and Satabdi were placed in the sub-plot. The PTOMTS tillage system gave the higher grain yield (3.71 t/ha) over the conventional method (3.50 t/ha). Among the varieties, Prodip provided the highest grain yield (3.77 t/ha). However, both PTOMTS along with Prodip produced the highest grain yield of 3.92 t/ha. The PTMOTS has promising prospects regarding reduction of production costs and minimizing the tillage period of land. Therefore, it should be demonstrated for large scale production next year.

2.5.3. Sugarcane as relay crop with rice and mixed intercropping
Rice is the staple crop and can be grown two to three times a year. Farmers cannot sacrifice rice to grow sugarcane. In order to sustain profitability of sugarcane cultivation there is a need for technology to grow rice for farmers’ primary requirements. Therefore, an attempt was made to accommodate rice in the sugarcane-based system.

Table 5. Wheat yield when grown by Bed planter, power tiller operated seeder (PTOS) and conventionally in Jamalpur

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bed Planter</td>
<td>3.37</td>
</tr>
<tr>
<td>PTOS</td>
<td>2.78</td>
</tr>
<tr>
<td>Conventional</td>
<td>2.38</td>
</tr>
</tbody>
</table>

Sugarcane seedlings were transplanted, both the single row and double row system, and rice was established in the space between sugarcane rows through the unpuddled transplanting method. This system worked very well to prove that sugarcane and irrigated Boro rice can be grown in the same field. Rice yield was on average 6.5 t/ha. However, one important lesson learnt is that if sugarcane is planted in November or earlier, and Boro rice is transplanted in December through unpuddled transplanting method, it is quite possible to grow irrigated Boro rice using AWD with sugarcane in the same field. Farmers will be motivated to grow rice, the staple food as their primary requirement and also the cash crop sugarcane, which usually occupies land for about 12 months, which is why farmers have previously disliked growing sugarcane. On the other hand, different types of vegetables, pulses, spices, and oil seeds are also cultivated as intercrops with sugarcane (Fig. 7 & 8). This practice covers about 25-35% of sugarcane land in Bangladesh.
2.5.4. Direct-seeded Boro rice plus mustard
Mixed cropping of Boro rice and mustard under zero/surface seeding conditions is a unique example of CA practiced by the farmers of Chandpur and Bandor Upazila, Narayangonj (Fig. 9 & 10). Direct seeding of rice is not altogether a new technology for rice, though mechanization was not in place. There are scattered examples of such practice in farmers’ fields. The CSISA team members at the Central East Bangladesh Gazipur hub were looking for an avenue to introduce DSR in the hub domain. The age-old practice of surface seeding of rice was made redundant long ago as it has many disadvantages especially weed problems. The CSISA team members at CE Bangladesh Gazipur hub were eager to use DSR as an entry point. The CSISA intervention in Bandar Upazila started through the experience of the farmers’ innovated technology and details of crop variety and management. It was learned that farmers grew BRRI dhan 29, a high-yielding Boro rice, but the mustard variety was a local one yielding hardly 700-900 kg/ha. CSISA provided the farmers with a high-yielding mustard variety BARI Sharisha 15 and quality seeds of BRRI dhan 29 as a replacement of their traditional mustard variety Tori 7 and own Boro rice seed, respectively. The result was encouraging because the mustard that CSISA supplied (BARI Sharisha 15) yielded 2.3 t/ha, whereas the farmers’ variety yielded 1.32 t/ha. Boro rice yield was 6.41 t/ha with intervention.
and 6.05 t/ha without intervention. Boro rice was broadcast and there was no line sowing. The sales proceeds of 2.3 t/ha of BARI Sharisha 15 were USD $1,166. The farmers’ conventional variety produced 1.32 t/ha. The sales proceeds were USD $645. The extra yield of paddy (0.36 t/ha) earned USD $91. Thus the intervention of CSISA doubled the income of farmers in the Bandar upazila of Narayangonj district. Now, power tiller operated seeders (PTOS) are used for seeding of Boro rice, and line sowing will improve yields. The success will open up an avenue to introduce DSR to other places of the hub domain where land is usually flooded. This flooded ecosystem is very important for weed control in DSR fields.

2.5.5. Evaluation of the PTOS in Boro-T. Aman rice-cropping systems
The PTOS was fitted with both Dongfeng and Sifeng power tillers (12HP) replacing the rotary part of the tiller. It performs the following functions in a single pass: tilling, seeding in line, seed covering, and land leveling. The experiment to establish DSR with PTOS commenced in Rabi season 2009-10 with rice at farmers’ fields, Mear Bazer. Four crop establishment options viz. T1: strip (DSR) seeding, T2: full-till DSR seeding, T3: strip transplanting and T4: farmers’ practice. No non-selective herbicide was applied in the field due to less weeds. Pendimethalin, a pre-emergence herbicide, was applied after four days of direct seeding by the PTOS machine. Generally 48 tines were used in full tillage by PTOS. The PTOS was operated in the field with strip tillage arrangement (24 tiller tines or blades with special arrangement). Recommended doses of fertilizers were applied before seeding operations. In the DSR plot urea was applied in 4 splits: 20 DAS, 40 DAS, 60 DAS, and booting stage. Seedling performance, area coverage per unit time, plant establishment, fuel consumption, irrigation amount, and crop yield were recorded.

As stated previously, the PTOS performs shallow tilling, seeding in line, seed covering and land leveling in a single pass. It maintains uniform seeding depth, uniform seed distribution, and better seed soil contact, which enhances plant establishment and yield. The field capacity of the PTOS was 0.15 ha/hr. In T1 the irrigation water required was less than conventional method (T0). Crop yield was not significantly higher in T1 (conventional practice) than T0 (strip DSR). No crack formation was observed in T0, T2 and T3. It is environmentally-friendly, there was minimum disturbance of soil, and it saved diesel fuel.

3. Conclusions
Due to high cropping intensity, improper cropping sequence, lack of balanced use of fertilizers and faulty management practices, the soil fertility of Bangladesh is decreasing gradually. If appropriate measures are not taken, crop productivity will continue to decline. Conservation agriculture is an important method that can sustain and increase soil fertility and crop productivity. Research and development work on CA show that it is possible to sustain the soil fertility if appropriate measures are taken. Farm machinery required for conservation tillage, like minimum tillage seeders, bed planters, zero tillage seeders, and strip tillage seeders, have been developed locally. It is also necessary to attain collaboration from other disciplines, especially agronomy, plant breeding, entomology, farm machinery, and post-harvest technology, to strengthen CA. It is expected that strengthening the CA program will help soil fertility and crop productivity to increase. Key issues to be addressed to promote CA are changes in mindset, adaptive research and demonstration efforts, policy and institutional support, networks of farmer groups and scientists, and ensuring availability and access to machinery.

References


Chapter 2. Conservation agriculture in rice-based cropping systems

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Abstract

This review paper presents an overview of factors that influence crop growth and yields in rice-based cropping systems under conservation agriculture (CA). The materials were compiled based on studies on no-tillage cultivation, various residue management techniques and crop rotations, as well the impact of CA on the crop’s nutrient-use efficiency, pest and disease outbreaks, and soil chemistry. Most studies were conducted based on CA principles with rice and wheat systems, particularly in the Indo-Gangetic Plains area. Among the tillage operations, strip tillage gave the best yields. Zero tillage rice cultivation kept the nitrogen availability constant and increased the availability of phosphorus and potassium. Overall, pest incidence is less in zero tillage rice crops compared to that of the conventionally transplanted rice.

Keywords: conservation agriculture, zero tillage, residue management, nutrient-use efficiency, Oryza sativa

1. Introduction

Rice (Oryza sativa L.) is an important staple food. Rice is grown both on irrigated and rainfed conditions. Irrigated rice accounts for about 71 million hectares, and consumes about 50% of the irrigation water in Asia. Rain fed rice is grown on about 46 million hectares, which accounts for about 20% of the total rice growing area of Asia. Rice diverged from other Gramineae before grasses moved from the forest floor to more open, highly irradiated environments (Kellogg, 2001; Lafitte and Bennett, 2002). Since it evolved from a semi-aquatic ancestor, rice is more susceptible to water-limited conditions as compared to other crops such as maize, sorghum, wheat, and barley (IRRI, 1982; Inthapan and Fukai, 1988; Monneveux and Ribaut, 2006).

Farmers usually adopt intensive tillage operations for rice with the main intention of controlling weeds, minimizing the percolation rate of water, and preparing a soft bed for crop establishment. This system results in high-energy consumption, drudgery of labor, and high cultivations. Recently, there has been a growing effort to reduce the cost of cultivation by minimizing the cost of land preparation (AICRIP, 1998).

1.1 What is conservation agriculture?

Conservation agriculture (CA) aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water, and biological resources combined with external inputs. It contributes to environmental conservation as well as to enhanced and sustained agricultural production. It can also be referred to as resource-efficient or resource-effective agriculture (FAO, 2010).

CA is often confused with conservation tillage, but the FAO defines the latter as a set of practices that leave crop residues on the surface, which increases water infiltration and reduces erosion (FAO, 2010). The practice of conservation tillage is used in conventional agriculture to reduce the effects of tillage on soil erosion. However, it still depends on tillage as the structure-forming element in the soil. Nevertheless, conservation tillage practices such as zero-tillage can be transition steps towards CA. In other words, conservation tillage uses some of the principles of CA, but it involves more soil disturbance.

**FAO has characterized CA as follows:**

Conservation agriculture maintains a permanent or semi-permanent organic soil cover. This can be a growing crop or dead mulch. Its function is to protect the soil physically from sun, rain and wind and to feed soil biota. The soil micro-organisms and soil fauna take over the tillage function and soil nutrient balancing. Mechanical tillage disturbs this process. Therefore, zero or minimum tillage and direct seeding are important elements of CA. A varied crop rotation is also important to avoid disease and pest problems (FAO, 2010).
CA does not mean implementing minimum, or zero tillage, and then keeping all other conditions the same. It is a holistic system that involves interactions among households, crops, and livestock, since rotations and residues have many uses within households; the result is a sustainable agricultural system that meets farmers’ needs.

To practice CA one must adhere to the following three principles: reduced tillage, keeping a residue cover on the soil, and suitable crop rotations. These principles need to be followed continuously for all the crop rotations. The second principle is especially key as the land must be kept covered with crop residues for CA to be successful. Note that CA can be done on flat or on raised beds; in both cases the three pillars of CA are followed (Sayre and Hobbs, 2004).

There have been several studies on zero tillage with rice crops, residue management on rice fields, and crop rotation in rice-based systems. In most cases, the experiments were tried in individual treatments or with a combination of either two of the above. CA insists on following the above mentioned three principles to achieve better results in the system. This paper reviews the impact of zero tillage compared to conventional tillage, and different residue management practices, as well as their implication on crop growth, nutrient-use efficiency and pest and disease incidences in these environments.

2. CA in India and the world with rice-based systems

Most of the CA-based work done on rice, study the rice-wheat systems in the North Indian Plain or the Indo-Gangetic Plains. There, the rice is grown under heavy tillage and puddling conditions and the wheat is grown under the zero tillage by keeping the rice stubbles on the field.

Zero tillage cultivation was initially implemented in rice production in southern China, although it has been commonly practiced in upland crops for more than half a century (Feng, 2006). In the zero tillage cultivation, rice seeds are sown on the soil after previous crops, mainly wheat and oil rape. It is predicted that more and more farmers will adopt zero tillage cultivation as it is less labor intensive (Huang, 1997). It is well documented that soil tillage affects nutrient availability in soil and plant growth, which in turn is closely related to nutrient uptake and utilization (Hargrove, 1985). In general, zero tillage influences crop growth and nutrient uptake by changing the soil’s physical and chemical properties directly, for instance, soil compaction, water content, and bulk density (Anikwe et al. 2007).

Yet, other regions of the world have made progress in fostering farmer use of these practices. Zero tillage and direct sowing of crops has become especially widespread in the Southern Cone of South America. Work on resource CA has also been done in Mexico and Mesoamerica with some success. The use of CA is being explored in areas of sub-Saharan Africa and is making good progress in China and Central Asia. Furthermore, there are substantial areas covered by CA in the U.S., Canada, and Australia.

3. Nutrient use pattern in rice-based cropping systems

The nutrient uptake of a crop is influenced by both the properties of rhizosphere and crop physiology. Lavado et al. (1999) reported that the distribution pattern of nutrients in the topsoil layer is usually modified by tillage systems. According to Blevins et al. (1983), zero tillage cultivation may improve some soil properties, such as organic matter content or pH, leading to increased bioavailability of nutrients for crops (Alvear et al. 2005). In their experiments on nutrient change under zero tillage cultivation, Halvorson et al. (1999) and Wienhold et al. (1998) found that soil alkali hydrolysable nitrogen (N) content was kept constant, while soil-available potassium and phosphorous contents were increased in the zero tillage soils in comparison with those under conventional tillage. However, according to Puustinen et al. (2005), zero tillage systems increased surface runoff of dissolved nutrients including nitrogen (N), phosphorus (P), and potassium (K), thus posing an environmental issue in addition to the reduction of nutrient-utilization efficiency. One explanation for the reduction of nutrient efficiency is that nutrients are mainly accumulated in the topsoil in a zero tillage field, because applied fertilizers are not inserted into the deep soil profile (Tebrügge and Düring, 1999). Hence, it may be assumed that nutrient uptake and accumulation of plants will be markedly affected by zero tillage. However, little research has been done to compare the difference. Moreover, the nutrient uptake, accumulation, and remobilization in rice plants during growth have not been characterized for zero tillage cultivation.
The influence of tillage methods on nitrogen concentration and accumulation, on the whole, varied depending on the plant tissues. Nitrogen concentrations in the stem and panicle in zero tillage were lower than those in conventional tillage in all measurements, irrespective of year and location. However, leaf nitrogen concentration was relatively higher in the plants under zero tillage before maturity stage, whereas at the maturity stage the two cultivations had the same nitrogen concentrations.

According to Ebelhar (1984), the total amount of nitrogen fertilizer was reduced in the zero tillage cultivation with legume mulch to maintain the yield, indicating that zero tillage systems increase the nutrient-uptake ability of crop plants. Franzleubbers et al. (1999) found that potential soil carbon mineralization was faster in tillage systems than in zero tillage systems, and the difference between tillage systems would last several months, thus causing less nitrogen mobilization in tillage systems. More application of nitrogen fertilizers may increase the risk of nitrogen leaching and emissions, thus leading to a deteriorated environment and reduced nutrient-use efficiency, although more fertilizer could improve plant growth and yield formation (Mackenzie and Cadrin, 1998). A study on the effect of tillage systems in semi-arid areas showed that nitrogen-use efficiency and nitrogen harvest index of wheat were greater in conventionally-tilled plants than in zero tilled plants (Lopez-Bellido and Garrido, 2001). This study also found that zero tilled plants had lower nutrient-use efficiency, which may be partly attributed to higher nutrient concentration in leaves and stems at maturity stage. However, nitrogen and potassium harvest index was significantly higher in the zero tilled plants than in conventionally-tilled plants, indicating more nitrogen and potassium were accumulated in the grains, which is favorable for improvement of rice nutrition quality (Chen et al. 2008).

Bed planting increased the grain number panicle\(^{-1}\) and reduced sterility of both wheat and transplanted Aman rice. Nitrogen-use efficiency such as partial factor productivity and agronomic efficiency were higher in bed planting than for the conventional method and it saved about 20% nitrogen without affecting yields in wheat and transplanted Aman rice (Mollah et al. 2009)

Strip tillage drilling provided the highest rice yield, net returns, benefit : cost (B: C) ratio and energy output: input ratio, and lowest specific energy and specific cost compared to other planting methods. Next in decreasing order were rotary-tillage drilling, zero tillage drilling, bed planting, and conventional sowing. The advantages in strip-tillage drilling were 8.2% in yield, 27.3% in net returns, 27.1% in B: C ratio, 31.3% in energy output: input ratio, 21.6% in specific cost and 24.0% in specific energy, respectively compared to conventional sowing. These advantages in rotary-tillage drilling were 6.1% in yield, 21.5% 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 as compared to conventional sowing. The advantages in zero-tillage drilling 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 as compared to conventional sowing. The weed dry matter was, however, lowest under bed planting followed by strip, rotary and zero tillage drilling and conventional sowing (Singh and Sharma, 2005).

The maximum rice yield (6.3 tons per hectare) was obtained under in-situ incorporation of wheat straw that was, respectively, 11% and 7% higher than residue removal and burning treatments. 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. Different straw management practices in wheat indicated that incorporation of straw in soil was a good straw management practice for improving the physio-chemical properties of the soil, instead of burning and removing the straw. This practice provided a lower soil cone index value and a higher mean weight diameter of soil aggregates. It caused a reduction in bulk density and an improvement in moisture content of the soil during the crop growth period. It also increased the fertility status of soil through the increase of organic C, available N, P\(_{2O_5}\) and K\(_{2O}\). The increase in soil organic carbon (OC) and mean weight diameter (MWD) under the straw incorporation treatment was 14.5% and 9.1%, respectively, compared to straw burning, and 23.5% and 9.6%, respectively, compared to the straw removal treatment (Singh and Sharma, 2005).
Zero tillage direct seeded rice in the heavy soils of south Bihar was found to save nearly 35% of irrigation water when compared to puddle-transplanted rice. Water savings by avoiding puddling was up to 10-12 cm. Frequency of irrigation in zero tilled direct seeded rice was 25 days as compared to 10 days in puddled transplanted rice in the silty loam soil of Bihar. There was saving of two irrigations up to the tilling stage in zero tilled direct seeded rice, besides saving 10-12 cm of water for puddling. Rice cultivation under furrow irrigated raised bed systems saved up to 40% water. In the farmers’ fields of Barh, Patna, during kharif 2004, which was a drought year, 13 irrigations were needed for puddled transplanted rice, while it was reduced to 5 irrigations under zero tillage direct seeded rice (Sikka et al. 2005). There was a saving of 72% in irrigation water with zero tillage direct seeded rice, due to cracking of soils and more irrigation needed at fewer intervals in conventionally puddled transplanted rice. The yield gain was also 700 kg per hectare under zero tilled direct seeded rice. Total saving in irrigation was estimated to be USD $220 per hectare due to zero tillage direct seeded rice. Rainwater utilization efficiency is enhanced with zero tillage direct seeded rice and the need for irrigation water is reduced by timely sowing. Implementing other water conservation practices, such as raising bund height and irrigation scheduling, could further enhance the efficiency of rainwater and irrigation water in zero tillage areas (Sikka et al. 2005).

4. Pest management under conservation agriculture

There is every indication that innovative cultural practices involving CA systems will continue to be developed because of the host of benefits these are expected to yield. These practices will be refined and may possibly replace conventional agriculture practices of crop production in large areas in the near future. The rapid changeover to reduced tillage systems is exemplified by the wheat crop. The abundant plant residues resulting from the reduced tillage operations mean that insects affect the rice-wheat differently than in conventional tillage. Thus, reduced tillage has benefits and risks for the rice crop, which are as follows:

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Conserves natural enemies</td>
<td>a. Pests from the rice stubble may survive and shift to the wheat crop (pink borer, Chilo sp.) or to early sown rice nurseries, ratoon sprout, etc.</td>
</tr>
<tr>
<td>b. Reduces the pest risks by enhancing natural control (monophagous species)</td>
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<tr>
<td>c. Makes the ecosystem more stable</td>
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<tr>
<td>d. Creates species diversity</td>
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<td>e. Reduces the cost of pest control</td>
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<td>f. Environmentally-friendly and ecologically-sustainable</td>
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</tbody>
</table>

(Source: Saroj Jaipal et al. 2005)

5. Conclusions

CA systems in rice were extensively studied in the rice-wheat systems in the Indo-Gangetic Plains. The studies show that rice can be grown in zero-tillage conditions using direct seeding methods. Nutrient-use efficiency and pest and disease resistance are better under no-tillage conditions compared to that of conventional puddle transplanted rice. Thus, there is a lot of scope to grow rice in zero-tillage direct seeded conditions. The interaction between no-tillage and nutrient-use efficiency of rice has not been studied much and future research is needed on this aspect. The residue cover and crop rotations are other aspects which require more research attention. Currently, rice-wheat systems are considered the major crop rotation and crops that yield better economically should be tried with rice in rice-based cropping systems, to make this a farmer-friendly process.

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References


Chapter 3. Can conservation agriculture improve the land productivity of smallholder farmers in Eastern Tigray, Ethiopia?

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1. Introduction

Ethiopia is located in the Horn of Africa and is bordered on the North and northeast by Eritrea, on the East by Djibouti and Somalia, on the South by Kenya, and on the West and southwest by Sudan. The country has a high central plateau with altitudes that vary from 1,800 to 3,000 meters (6,000 ft.-10,000 ft.) above sea level, with some mountains reaching 4,620 meters (15,158 ft.). Elevation is generally highest just before the point of descent to the Great Rift Valley, which splits the plateau diagonally. A number of rivers cross the plateau — notably the Blue Nile flowing from Lake Tana. The plateau gradually slopes to the lowlands of the Sudan on the West and the Somali-inhabited plains to the southeast.

The climate is temperate on the plateau and hot in the lowlands. At Addis Ababa, which ranges from 2,200 to 2,600 meters (7,000 ft.-8,500 ft.), the maximum temperature is 26°C (80°F) and the minimum temperature is 4°C (40°F). The weather is usually sunny and dry with the short (belg) rains occurring February-April and the big (meher) rains beginning in mid-June and ending in mid-September.

The Ethiopian economy is based on agriculture, which contributes 45% of its GDP and more than 80% of its exports, and employs 85% of the population. The major agricultural export crop is coffee, providing approximately 35% of Ethiopia's foreign exchange earnings, down from 65% a decade ago because of the slump in coffee prices since the mid-1990s. Other traditional major agricultural exports are leather, hides and skins, pulses, oilseeds, and the traditional “chat,” a leafy shrub that has psychotropic qualities when chewed. Sugar and gold production have also become important in recent years (Ethiopia, 2009, www.traveldocs.com/et).

Ethiopia's agriculture is plagued by periodic drought, soil degradation caused by inappropriate agricultural practices and overgrazing, deforestation, high population density, undeveloped water resources, and poor transport infrastructure, making it difficult and expensive to get goods to market. Yet agriculture is the country’s most promising resource. The potential exists for self-sufficiency in grains and for export development in livestock, flowers, grains, oilseeds, sugar, vegetables, and fruits. (Ethiopia, 2009 www.traveldocs.com/et)

1.1. The Tigray Region

Tigray, the northermmost state of Ethiopia, has a population of 4.7 million, of which 86% is rural, and 14% live in urban areas. It consists of 6 administrative zones, 35 woredas and 74 towns. It shares common borders with Eritrea in the North, the state of Afar in the east, the state of Amhara in the south, and the Republic of the Sudan in the west (Bureau of Agriculture and Rural Development of Tigray).

Tigray is made up of a central highland plateau bordered on the East and West by lowland plains. The highland region has the highest population density in the country and, like most parts of the country; the region has been hit by recurrent droughts. Based on the type of livelihood the region is classified into 16 livelihood zones. These are shown in Fig.1 (Bureau of Agriculture and Rural Development of Tigray).

Meher is the most important season in the Tigray region. More than 95% of the crop is produced during this season. The meher season is classified into Azmera and Tsidiya. Azmera rains, which are essential for long cycle crops such as sorghum, maize and millet, normally start in mid March. Tsidiya rains which are important for the short cycle crops such as barely, wheat, ‘Hfanfets’ (mixture of wheat and barely) and ‘teff’ starts normally around mid June (Bureau of Agriculture and Rural Development of Tigray).
2. Agriculture problem statement

As is mentioned in the introduction, 85% of Ethiopia’s inhabitants depend on agriculture for their livelihoods. The recurrent drought, together with rising population pressure, has people living in absolute poverty (below one US dollar per day). The eastern part of Tigray is a highly populated and drought-affected area. It is in this area that arable land is very scarce; that is, an average of 0.5 hectares per household, to an average of 5 family sizes per household. In addition to the land scarcity, unsuitable topography that causes land degradation is another issue. As a result of these and other combined effects, crop production and productivity is low.

Production is low because of limited arable land, and unsustainable exploitation of the land has resulted in reduced organic biomass, biodiversity and water infiltration, and increased runoff and soil erosion. This leads to environmental degradation and low agricultural productivity, thereby contributing further to poverty and food insecurity.

The yield that is gained from a small land plot will only feed a household for six months. The remaining six months are usually a danger season, and families have various coping strategies that they resort to during periods of hunger. Some families will sell their assets, migrate for work opportunities, borrow from neighbors, collect wild fruit (such as cactus), or sell firewood and charcoal.

The government has designed short-term and long-term projects all over the country to help solve this recurring problem. Short-term projects address areas that are in need of immediate help, and especially areas with infant malnutrition problems. Long-term projects aim to bring sustainable development and try to limit food shortages, for example through initiatives like Productive Safety Net Program (PSNP), as well as different non-governmental organizations that are also involved in the reduction of the drought impact. For example, the Ethiopian Catholic Church’s Social and Development Coordinating Office of Adigrat (ECS-SADCO) is a non-profit, religious, locally-based organization. These initiatives especially aid the poorest and most marginalized communities through the provision of access to irrigation water, and help them enhance the productivity of their farmland.

The PSNP program was launched in 2005, and is an important policy initiative by the government and donors to shift millions of chronically food-insecure rural people from recurrent emergency food aid to a more secure and predictable, and largely cash-based, form of social protection (www.Odi.Org.uk, report of March-September 2006).

The eastern zone of Tigray is also one of the areas that is highly affected by food shortages and benefits from the PSNP program. For example,
in the last two years many non-governmental organizations have made crop assessments, and the number of beneficiaries from the program is shown in Table 1.

To switch from the existing situation, that is, from a traditional and backward agricultural farming system that results in low agricultural production, to a sustainable and profitable agricultural system, which is conservation agriculture (CA), is very crucial to the area.

3. What is conservation agriculture?

CA is defined as a farming practice/system that does away with regular plowing or tillage and promotes permanent soil cover and diversified crop rotation to ensure optimal soil health and productivity (FAO, 2010).

The idea was introduced some 25 years ago. It is now practiced on 100 million hectares of land all over the world. It originated mainly in:
1. Sub humid to humid regions of North America
2. Latin America and some areas in Asia (rice-wheat systems of South Asia)

Currently, it is spreading in many African countries including Burkina Faso, Cameroon, Chad, Tanzania, Mozambique, Ghana, Kenya, Mali, South Africa, Uganda, Zambia, Madagascar, Mozambique, Lesotho, Swaziland, Eritrea, etc.

The goal of CA is to maintain and improve crop yields and resilience against drought and other hazards, while at the same time protecting and stimulating the biological functioning of the soil (FAO, 2010).

Three essential features of CA are zero tillage, maintenance of a cover (or live or dead vegetative materials) on the soil surface, and proper crop rotation. Crops are seeded or planted through this cover with special equipment. It should be noted that zero tillage is an essential feature of CA, but the use of zero tillage by itself does not qualify as CA. If a farmer plows for at least one crop within the rotation or does not maintain a permanent soil cover, he or she does not practice CA properly.

The three principles of CA are as follow:

**Continuous minimum mechanical soil disturbance** — Direct seeding involves growing crops without mechanical seedbed preparation and with minimal soil disturbance since the harvest of the previous crop. The term direct seeding is understood in CA systems as synonymous to no-till farming, zero tillage, no-tillage, direct drilling, etc. Planting refers to the precise placing of large seeds (maize and beans for example); whereas seeding usually refers to a continuous flow of seeds, as in the case of small cereals (wheat and barley for example). The equipment penetrates the soil cover, opens a seeding slot and places the seed into that slot. The size of the seed slot and the associated movement of the soil are to be kept at the absolute minimum possible. Ideally, the seed slot is completely covered by mulch again after seeding and no loose soil should be visible on the surface.

Land preparation for seeding or planting under zero tillage involves slashing or rolling the weeds, previous crop residues or cover crops; or spraying herbicides for weed control, and seeding directly through the mulch. Crop residues are retained either completely or to a suitable amount to guarantee the complete soil cover, and fertilizer and amendments are either broadcast on the soil surface or applied during seeding.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Districts</th>
<th>No. of PSNP beneficiaries</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern</td>
<td>Kite Awlaello</td>
<td>79,840</td>
<td>The modality is in the form of cash or grain. Grain was 3 kg/day/person and cash was 8 birr/day/person (less than 1 USD).</td>
</tr>
<tr>
<td>Tigray</td>
<td>Atsbi wonberta</td>
<td>69,933</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S/Tseda Emba</td>
<td>73,299</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ganta Afeshum</td>
<td>65,207</td>
<td>From the 2009 report of the agriculture office</td>
</tr>
<tr>
<td></td>
<td>Gulomekeda</td>
<td>61,783</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hawzen</td>
<td>61,117</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irob</td>
<td>21,627</td>
<td></td>
</tr>
</tbody>
</table>


NB. 1 US dollar is equivalent to approximately 16.4336 Ethiopian birr (October 29, 2010).
Crop residue retention in the soil surface — A permanent soil cover is important to protect the soil against the harmful effects of exposure to rain and sun, to provide the micro and macro organisms in the soil with a constant supply of “food,” and to alter the microclimate in the soil for optimal growth and development of soil organisms, including plant roots. Cover crops need to be managed before planting the main crop. This can be done manually or with animal or tractor power. The important point is that the soil is always kept covered (FAO, 2010).

Effects of soil cover (FAO, 2010):
- Improved infiltration and retention of soil moisture resulting in less severe, less prolonged crop water stress and increased availability of plant nutrients.
- Source of food and habitat for diverse soil life: creation of channels for air and water, biological tillage and substrate for biological activity through the recycling of organic matter and plant nutrients.
- Increased humus formation.
- Reduction of impact of rain drops on soil surface resulting in reduced crusting and surface sealing.
- Consequential reduction of runoff and erosion.
- Soil regeneration is higher than soil degradation.
- Mitigation of temperature variations on and in the soil.
- Better conditions for the development of roots and seedling growth.

Means and practices of soil cover (FAO, 2010):
- Use of appropriate/improved seeds for high yields as well as high residue production and good root development.
- Integrated management and reduced competition with livestock or other uses e.g., through increased forage and fodder crops in the rotation.
- Use of various cover crops, especially multi-purpose crops, like nitrogen-fixing, soil-porosity-restoring, pest repellent, etc.
- Optimization of crop rotations in spatial, timing, and economic terms.
- “Targeted” use of herbicides for controlling cover crop and weed development.

Diversified crop rotation — This is not only necessary to offer a diverse “diet” to the soil micro organisms, but as they root at different soil depths, they are capable of exploring different soil layers for nutrients. Nutrients that have been leached to deeper layers and that are no longer available for the commercial crop can be “recycled” by the crops in rotation. This way the rotation crops function as biological pumps. Furthermore, a diversity of crops in rotation leads to a diverse soil flora and fauna, as the roots excrete different organic substances that attract different types of bacteria and fungi, which in turn, play an important role in the transformation of these substances into plant-available nutrients. Crop rotation also has an important phytosanitary function as it prevents the carryover of crop-specific pests and diseases from one crop to the next via crop residues.

Effects of crop rotation (FAO, 2010):
- Higher diversity in plant production and thus in human and livestock nutrition.
- Reduction in and reduced risk of pest and weed infestations.
- Greater distribution of channels or bio-pores created by diverse roots (various forms, sizes and depths).
- Better distribution of water and nutrients through the soil profile.
- Exploration for nutrients and water of diverse strata of the soil profile by roots of many different plant species resulting in a greater use of the available nutrients and water.
- Increased nitrogen fixation through certain plant-soil and improved balance of N/P/K from both organic and mineral sources.
- Increased humus formation.

Means and practices of crop rotation (FAO, 2010):
- Design and implementation of crop rotations according to the various objectives: food and fodder production (grain, leaf, stalks); residue production; pest and weed control; nutrient uptake and biological subsurface mixing/cultivation, etc.
- Use of appropriate/improved seeds for high yields as well as high residue production of above-ground and below-ground parts, given the soil and climate conditions.

In general, CA is a farming system that is characterized by the principles mentioned above, as well as some other practices that are vital in implementing the technique. Some of the additional key features of CA are as follows:
- No plowing, disking or soil disturbance;
- Retaining crop and cover crop residues on the soil surface;
- No burning of crop residues;
- Replicating the closed-, nutrient-recycling system of the forest;
- Applying lime and, sometimes, fertilizers;

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- No burning of crop residues;
- Replicating the closed-, nutrient-recycling system of the forest;
- Applying lime and, sometimes, fertilizers;
• Use of specialized equipment as needed by farmers;
• Continuous cropland use;
• Crop rotations and cover crops are used to maximize biological controls (i.e., more plant and crop diversity) as seen in FAO-case studies in Latin America and Africa.

4. The objectives of introducing conservation agriculture to the area

Generally speaking, the objective of CA is to improve agricultural production by adopting economically, ecologically, and socially sustainable methods. Conservation agriculture aims to conserve, improve and make more efficient use of natural resources. It contributes to environmental conservation as well as to enhanced and sustained agricultural production for farmers. In the Ethiopian context agricultural production and productivity are very small. It is vital that measures be taken to provide food for the country’s fast-growing population in a sustainable and ecologically-safe way. Conservation agriculture can play role in boosting productivity in a sustainable and profitable pattern. The practical objectives of introducing the technique to the area are as follows:

- To introduce and demonstrate the system for smallholder farmers.
- To increase crop production while reducing erosion and reversing soil fertility.
- To improve the livelihood of the population and restore the environment.

5. The importance of implementing conservation agriculture

Shifting towards this new agricultural method will cause some conflicts, as it contrasts with the current production system. Yet, it is up to the professionals to show farmers how the system works and to determine the best methods for the area in question.

CA is the way through which sustainable and profitable agricultural production can be achieved, especially in areas that have little rainfall like the eastern part of Tigray. Its positive impact can be seen in different aspects, some of which are:

5.1 Agronomic importance

- Buildup of organic matter will be enhanced (soil fertility and soil structure will be improved).
- Soil and water will be conserved (soil loss will not exceed the rate of soil formation).
- Water infiltration and holding capacity will be improved.
- Rooting environment and nutrient cycling and retention will be increased.
- Natural flora and fauna in the soil will be enhanced.
- Crop productivity will be increased in a sustainable way through time and input efficiency.

5.2 Economic benefits

- CA saves time and reduces labor requirements from 30% to 40%. A farmer in Ethiopia might have to plow his/her field at least three times, depending on the crop. This plowing is usually done with an ox-drawn plow (Fig. 2).
- CA reduces input utilization. During the first two to three years, inputs for CA are vital; herbicide and fertilizers are needed in the beginning, but in the long run weed infestations decline and buildup of organic matter will be enhanced, increasing fertility.
- CA minimizes the cost of animal feed and veterinary needs. If a farmer follows CA, it is only during the planting season that oxen are needed for field operations, so oxen are not needed the whole year. Also, since children are expected to keep the livestock, less need for animals will reduce other social problems like poor school attendance.
- CA reduces fuel and machinery maintenance costs for large-scale farmers.
- CA also allows for carbon credit income to be obtained in the long run.

Figure 2. The traditional practice is very energy and time consuming (Source: photo of women and Agriculture by ECC-ADCS- FSP Project)
5.3 Environmental and social benefits

Conservation agriculture has both direct and indirect environmental and social benefits that include:

- A high soil infiltration which keeps soil erosion at a minimum. As a result, sedimentation (due to soil water erosion) will be reduced and lakes, dams for electric generation etc, will not be silted up. Thus there will be no flooding, less irrigation problems, and interruption of electric supply will be reduced.
- Due to minimum runoff and leaching with CA implementation, water quality will also be improved.
- Since there is minimum tillage there is less emission of greenhouse gases and elements from soil surface to the atmosphere; as a result, air pollution will be decreased.
- Biodiversity and landscape will be maintained or improved.
- Carbon sequestration will be enhanced.

6. Challenges to introducing conservation agriculture in the eastern part of Tigray

CA clearly contrasts with current farming practices and no technology is 100% efficient. As such some of the challenges that could arise are:

- Farmers might be slow to adopt this unfamiliar practice.
- The source of animal feed will be controversial since CA mixes types of agriculture that include crop production and cattle ranching.
- Limited knowledge and information of the technique.
- Small-scale farming equipment or farm tools are not readily available.
- Free grazing can also contribute its negative impact in the adoption of the technology.
- Weed infestation during the first two to three cropping seasons.

7. Some control measures to deal with the challenges

Firstly, and most importantly, extension workers and farmers must be provided with knowledge and capacity-building regarding CA.

In mixed agriculture, both crop production and animal ranching are important means of livelihood with similar focuses. In eastern Tigray both are important, but the existing livestock rearing is not specialized. This means that farmers have five livestock animals on average per household, but due to low feed quality, animals do not receive good food products. In such conditions, instead of having five animals with fewer products it is better to have one or two good breeds so the harvest can have a high quantity and quality. Thus, the area must be de-stocked. Next to de-stocking there needs to be a focus on the quality of animal feed, as well as producing animal feed crops with a good biomass, nutrients, and palatable varieties (triticale, alfalfa, and other fodder crops). There is a significant difference in biomass production between CA and conventional agriculture.

The other option in the area is the promotion of the watershed management and good natural resource management approach started by the Ministry of Agriculture and other development actors like the Adigrat Diocese Catholic Secretariat (ADCS). Some initiatives that look promising are the rehabilitation of gullies and the opportunities they offer as sources of feed, hillside closure, physical and biological treatment to the degraded area and area closure. Other projects include applying “cut and carry” systems to avoid free grazing and minimizing soil compaction by subtracting livestock pressure onto the farmland. This is also a good condition to retain crop residue on the farmland for CA.

Implementation of CA requires a shift in mindset and inputs like appropriate machinery, fertilizers, and herbicides. For the eastern part of Tigray, the appropriate machines would be the Matraca, the dual purpose two-wheel tractor seeder, and the bed maker. Smallholder farmers may be unable to purchase the two-wheel tractor but can obtain the tractor by being part of a cooperative. The Mekelle University mechanical engineering department is modifying the tractor’s prototype. Thus, it is good to strengthen the relationship among all stakeholders to promote the development of new technologies.

At the beginning, using fertilizers and herbicides is mandatory. Farmers use fertilizers thanks to the subsidy provided by the government. Herbicide application is also crucial, and although it is expensive, the risk of weed infestation will be high due to the no-plowing approach. If you calculate the economic expense and the return using CA along with herbicide, it is higher than under conventional agriculture. It is a matter of taking economic return into consideration to accept and achieve CA goals.
8. Farm tools and inputs needed to implement conservation agriculture techniques

Research on CA and CA-based resource-conserving technologies in Ethiopia generally fits into two major paradigms: (1) flat seedbeds with the use of herbicides and one surface tillage operation (Ito et al. 2007); or (2) surface shaping using various (often heavy and complex) tools (Hussein et al. 2000; Abiye et al. 2002; Gebreyesus et al. 2006; McHugh et al. 2007 and many others). In both cases, indigenous in situ soil and water conservation tillage technology, if recognized, is merely mentioned anecdotally (Gebreyesus et al. 2006; McHugh et al. 2007), and even considered as an interference with the experiment (Hussein et al. 2000; Ito et al. 2007).

All over the country, farming practices are dominated by ox plowing systems. This method has been implemented for the last two centuries. In the eastern part of Tigray it is also similar. Culturally, it was believed that men are responsible for plowing and women are expected to do share cropping and straw with men.

CA does not necessarily need sophisticated and expensive equipment. It can also work with locally-available materials and be successfully implemented as long as the three principles are fulfilled.

The land holding size is very small in the eastern part of Tigray and the topography is undulated. As such small machinery with easy operation (such as the “matraca” and the two-wheel tractor) is needed to achieve CA techniques.

8.1 The traditional “Maresha”

Animal traction has been an integral part of most agricultural systems in Ethiopia for thousands of years. There is evidence that cattle were first used for plowing in the latter part of 3000 BC (Goe, 1987). Today, the traditional cattle economy is directed mainly towards supplying draught oxen.

It is not certain when animal-drawn tillage implements began to be used for agriculture. It has been conjectured that the Ethiopians inhabiting the highland areas of the country were introduced to the ard by Semitic-speaking invaders from South Arabia between 1000 and 400 BC (Goe, 1987). Recent archaeological evidence, however, suggests that it may have been used even before the Semitic invasion by Cushitic-speaking peoples from an ancient Nubian region in northeastern Sudan (Goe, 1987). Regardless of who introduced it, the ard (“maresha”) has remained the traditional animal-traction implement in Ethiopia and has contributed to crop-livestock integration in the country.

The “maresha” consists of a metal point or tine fastened to a long pole, at the opposite end of which is fastened a wooden neck yoke. At each side of the metal point are two wooden wings that push the soil aside (Fig. 3). The traditional implement, together with the yoke, weighs between 17 and 26 kg (Goe, 1987), and is therefore light enough to be transported easily by one person to and from the fields and over difficult terrain. With the exception of the metal tine, which the farmer buys from the blacksmith, the “maresha” is homemade. It is a versatile implement and can be used on all soil types. Depending on the

Figure 3. Maresha (Source: photo of women and Agriculture by ECC-ADCS- FSP Project)
crop and soil types, two to five cultivations using the “maresha” are necessary before a field is ready for planting. It is also used to cover crop seeds with soil, except for *Eragrostis tef*. (Astatke and Matthews, 1980).

Until farmers adopt appropriate farm tools that suit CA; it is possible to use the “maresha” to refresh the bed at planting, combined with broadcasting or hand planting by rows (Fig. 4; Nyssen et al. 2010).

8.2 The “matraca”

It is a farm tool used for simultaneous seed planting and fertilizer application. It consists of two pots that hold seeds and fertilizer; when blowing into the soil it will plant and fertilize at the same time (Fig. 5). It is crop specific and may also be fertilizer specific.

The simpler arrangement is to have an implement for opening the furrow (the “maresha” in the eastern part of Tigray) then seeding by using the “matraca” and finally closing the furrow and compressing the soil.

In the eastern part of Tigray crops like maize, wheat, barley, ‘hanfets’ (a mixture of wheat and barley), ‘teff’ (*Eragrostis tef*), and legumes such as broad beans, field peas, amongst others, are important. These crop seeds have different sizes, so the “matraca” should be designed in a way that is adapted to all common crop types. At the same time, the area is very much known to be scarce of nitrogen and phosphorous therefore it should also be designed to fit both these fertilizers.

8.3 Weed control measures

Weeds are any type of plants that grow in unwanted areas and times. They compete with cultivated crops for nutrients, water, sunlight and space. They shelter pests and diseases that can cause damage to the crops. They reduce crop production and farmers’ income. The longer they are left in the field, the harder they are to control.

In conventional farming practices, tillage (turning over the soil) is used to control weeds. Farmers plow repeatedly to suppress weeds through exposing the seeds to the sunlight and wind, and thus interrupting the weeds’ life cycle. Weeds can be a big problem at the beginning of CA. Controlling weeds during the first couple of cropping seasons is important to avoid the production of their seeds. If done properly, weeds will become less problematic later on. In CA there are different methods to manage weed seeds, such as:

1. **Agronomic management** – it starts with pure seed selection for planting, proper spacing to suppress the weed seeds, proper crop rotation, using mulching, intercropping, and soil cover.
2. **Weeding by hand** – it is possible to pull out weeds by hand, sickle, and slasher. It is also common to use the hand hoe for weeding, but this might disturb the soil surface.

3. **Herbicides** – They are quick and easy to apply, and don’t disturb the soil. Not all herbicides are efficient in controlling weeds; some are specific like 2-4-D for broad leaves only and others are effective for all types of weeds such as glyphosate. Not all smallholder farmers use herbicides because they are expensive and hard to find. They also need special equipment like sprayers and its accessories.

In CA using herbicides is vital in the first years. The correct amount must be applied with the right equipment.

9. **The potential of conservation agriculture**
   - The government’s agricultural policy supports CA techniques. There are full extension service technicians that are well equipped to provide support farmers to enhance crop production and productivity from the federal level to the ‘tabia’ (the lowest level of districts).
   - Programs for grazing land enrichment and watershed management are a precondition for the implementation of CA in the area. If grazing lands are enriched and farmers use “cut and carry” systems there will not be livestock free grazing and farmlands can be kept with retained crop residues on the soil’s surface. Soil compaction due to livestock pressure will also be minimized.

10. **Future perspective of conservation agriculture**
    As with any other businesses, producers and conservationists are always looking towards the future. In this case, CA is a very important process to be looked at in order for future generations to have a chance to survive. As of today there are many organizations that have been created in order to help educate and inform producers and conservationists regarding CA. These organizations can help to inform, conduct research and buy land in order to preserve animals and plants (New Standard, 1992).

    Another way in which CA is looking to the future is through prevention. According to the European Journal of Agronomy, producers are looking for ways to reduce leaching problems in their fields. These producers are using the same principles as in CA as they are leaving cover on their fields in order to save fields from erosion and stop the leaching of chemicals out of fields (Kirchmann and Thorvaldsson, 2000). Such processes and studies allow for a better understanding of resource conservation and finding ways to put back something that may have been lost before.

    Further improvements in conservation-effective agriculture are indeed possible as seen by the growing number of positive results in both mechanized and non-mechanized agriculture on small and large farms and in temperate and tropical zones. Farmers will adopt CA practices and experience such benefits if they are cost effective in the short term.

    Circulation of plant nutrients can be a vital way of conserving resources for future use. An example of this would be the use of animal manure, spread out over a particular area. This process has been done for quite some time now, but in the future we must look towards handling and conserving the nutrients within manure for a longer period of time. But besides the use of animal waste, food and urbanized waste are also being considered as a way to aid growth under CA systems (Kirchmann and Thorvaldsson, 2000). Turning these products from waste to fertilizers and yield improvers is something that would be beneficial for both conservationists and producers.

11. **Conclusion**
    In areas like the eastern part of Tigray, conservation agriculture is the best means to reduce land degradation, protect and conserve the environment, and reverse low yield status in a sustainable and profitable way. It is obvious that there will be some resistance from both farmers and extension workers at the beginning (due to lack of awareness of this farming practice) but through experiences in demonstration areas the confusion will be lessened. To my understanding, it might be difficult for farmers to automatically jump into a CA based system, but it is a step-by-step process that in a way will help farmers understand and start practicing the new system.

    It is good to keep in mind that population growth is increasing at a steady rate. Yet, at the same time, production is declining. Global warming is also becoming a big issue, as well as the increasing price of crops. Unless we turn towards systems
that can bring higher yields, in economical viable, sustainable, and profitable ways, it will be a challenge to survive. The solution is to use CA based resource-conserving technology, since it is a practice that can ensure food security in a sustainable way, while attaining higher yields and causing less damage to the environment.

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References
FAO. 2010. What is Conservation Agriculture?

Chapter 4. Conservation agriculture in Pakistan

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Abstract
The concept of conservation agriculture is outlined in a series of principles and practices; it is an application of modern agricultural technologies that improve production, while concurrently protecting and enhancing the land resources on which production depends. The application of conservation agriculture promotes the concept of optimizing yields and profits while ensuring the provision of local and global environmental benefits and services. Zero tillage, along with other soil conservation practices, is the cornerstone of conservation agriculture. About 47% of the 95 million hectares of zero tillage is practiced in South America, 39% in North America, 9% in Australia, and 3.9% in Europe, Asia, and Africa (Hobbs, 2010).

Key words: conservation agriculture, zero tillage, erosion

1. Introduction to conservation agriculture
Conservation agriculture (CA) is a concept that entails resource-saving agricultural crop production, which strives to achieve acceptable profits together with high and sustained production levels, while conserving the environment. CA is based on enhancing natural biological processes above and below the ground. Interventions, such as mechanical soil tillage, are reduced to an absolute minimum, and the use of external inputs, such as agrochemicals and nutrients of mineral or organic origin, are applied at an optimum level and in a way that they do not interfere with, or disrupt, the biological processes of the soil. CA is characterized by three principles that are linked to each other, namely:
- Continuous minimum mechanical soil disturbance.
- Permanent organic soil cover.
- Diversification of crop species grown in sequence or associations.

In contrast to this, conventional agriculture is normally based on soil tillage as the main operation. The most widely known tool for this operation is the plow, which has become a symbol of agriculture. Soil tillage has in the past been associated with increased fertility, which was thought to originate from the mineralization of soil nutrients as a consequence of soil tillage. This process leads in the long term to a reduction of soil organic matter. Soil organic matter not only provides nutrients for the crop, but it is also, above all else, a crucial element for the stabilization of soil structure. Therefore, most soils degrade under prolonged intensive arable agriculture. This structural degradation of the soil results in the formation of crusts and compaction, finally leading to soil erosion. The process is dramatic under tropical climatic situations, but can be noticed all over the world. Mechanization of soil tillage, allowing higher working depths and speeds and the use of certain implements, like plows, disk harrows, and rotary cultivators, have particularly detrimental effects on soil structure.

Soil erosion resulting from soil tillage has forced us to look for alternatives to reverse the process of soil degradation. The logical approach to this has been to reduce tillage. In a soil that is not tilled for many years, the crop residues remain on the soil surface and produce a layer of mulch. This layer protects the soil from the physical impact of rain and wind, but it also stabilizes the soil moisture and temperature in the surface layers. Thus, this zone becomes a habitat for a number of organisms, from larger insects down to soil-borne fungi and bacteria. These organisms macerate the mulch, incorporate and mix it with the soil and decompose it so that it becomes humus, and it contributes to the physical stabilization of soil structure. At the same time, soil organic matter provides a buffer function for water and nutrients. Larger components of the soil fauna, such as earthworms, provide a soil-structuring effect, that produces very stable soil aggregates as well as uninterrupted macro pores leading from the soil surface straight to the subsoil and allowing fast water infiltration in case of heavy rainfall.

Changes in pest and weed management become necessary with CA. Burning plant residues and plowing the soil is mainly considered necessary for phytosanitary reasons, as it entails a way of controlling pests, diseases, and weeds. In a system with reduced mechanical tillage based on mulch
cover and biological tillage, alternatives have to be developed to control pests and weeds. Thus, integrated pest management becomes mandatory. One important element to achieve this is crop rotation, which interrupts the infection chain between subsequent crops and makes full use of the physical and chemical interactions between different plant species. Synthetic chemical pesticides, particularly herbicides, are inevitable in the first years, but have to be used with great care to reduce the negative impacts on soil life. As the farmer learns to manage the cropping system, the use of synthetic pesticides and mineral fertilizer declines to a level below that of the original, “conventional” farming system, and a new balance can be established between the organisms of the farm-ecosystem, pests, beneficial organisms, crops, and weeds. The aim of crop rotation is to employ economically viable, diversified crops to help moderate/mitigate possible weed, disease, and pest problems.

Conservation agriculture provides a truly sustainable production system, conserving natural resources and increasing the variety of soil biota, fauna, and flora in agricultural production systems, without sacrificing yields. As CA depends on biological processes to work, it enhances the biodiversity in an agricultural production system on a micro and macro level. Zero tillage or minimum tillage fields act as a sink for CO₂ and conservation technology could provide a major contribution to control air pollution in general. Farmers applying this practice could eventually be rewarded with carbon credits. Plowing the soil is the major operation in which energy is consumed. By not tilling the soil, farmers can save between 30% and 40% of their time, labor and, in mechanized agriculture, fossil fuels, as compared to conventional agriculture. By using CA technologies, water infiltration capacities are increased due to increased porosity, and surface runoff and soil erosion decrease, while groundwater resources are enhanced. More moisture is retained in the soil by increasing its water-holding capacity. In many areas it has been observed that, after some years of CA, natural springs that had dried in previous years started to flow again. The potential effect of a massive adoption of conservation farming on global water balances is not yet fully recognized. For the farmer, conservation farming is mostly attractive because it allows a reduction of the production costs, reduction of time and labor (particularly at times of peak demand, such as land preparation and planting) and, in mechanized systems, it reduces the costs of investment and maintenance of machinery in the long-term (FAO, 2010).

2. About Pakistan

2.1. Geography and population

Pakistan has a total area of 796,100 km² and is located in southern Asia. It is bordered by India on the East, China on the northeast, Afghanistan on the North and northwest, Iran on the southwest and the Arabian Sea to the South. Pakistan is divided into four provinces, namely the Punjab, Sindh, North West Frontier Province (NWFP), and Balochistan. The country can be divided into five physiographic regions:

- **The Himalayan mountain ranges** in the northwestern part on the border with India and China. The highest peak, the Godwin-Austin (7,610 m) is part of the Trans-Himalayan Range.
- **The Hindu Kush and the Western Mountains** in the North on the border with Afghanistan. The Tirichmir (7,690 m) is the highest peak in the Hindu Kush range.
- **The Potwar Plateau**, just south of Islamabad (the elevation varies from 300 to 600 m); and South of the Potwar Plateau is the Salt Range;
- **The Indus Plain**, stretching from the Salt Range to the Arabian Sea. This flat plain is largely made up of alluvium, is over 300 m deep, and was deposited by the Indus River and its tributaries.
- **The Balochistan Plateau** in the southwest of the country, which has an average altitude of about 600 m. Dry hills run across the plateau from northeast to southwest. A large part of the northwest is desert.

The total cultivable area is estimated to be around 21.7 million hectares, which is 27.22% of the total area, and is mainly concentrated in the Indus plain. The total irrigated area is estimated at almost 16.2 million hectares, or 77.2% of the total cultivable area and remaining area is rainfed.

The total population is 169.7 million of which 65% is rural. The average population density is 177 inhabitants per km², but the population is mainly concentrated in the Indus plain. The average annual population growth is estimated at about 3.2%. In 1992, agriculture accounted for 26% of gross domestic product (GDP) and provided employment to 48% of the labor force. It supplies most of the country’s food, but is also the source of raw materials for major domestic industries, particularly for cotton products which account for 80% of export earnings.
2.2. Climate
Pakistan lies in the subtropical arid zone and most of the country is subjected to a semi-arid climate. June is the hottest month in the plains and July in the mountainous areas, with temperatures over 38°C, while the mean monthly minimum is only 4°C in December/January. Average annual precipitation is estimated at 494 mm, but is uneven over much of the Indus basin. It reaches up to 1500 mm in the north. Most of the rainfall in Pakistan originates from summer monsoons.

3. Objectives of the paper
• To evaluate how common CA techniques are being implemented in the country.
• To foster the adoption of CA with its appropriate component technologies, and in a way that best fits the requirements of the country.
• To improve crop production and productivity for farmers in rural communities.

4. Cropping systems in Pakistan
The major cropping system in Pakistan is cotton–wheat. The cotton is sown in May and the last pick is done in December. The wheat is planted in December after the cotton, but the ideal time for wheat sowing is between 01 November and 15 November. After that the grain yield decreases gradually at 25 kg/day/ha.

For cotton, there is intercropping of mungbean, vegetables, melon, and watermelon. The other systems are:
• Wheat-rice
• Wheat-maize
• Potato-rice-potato
• Sugarcane (in sugarcane intercropping of canola, vegetables, pulses, melon, and watermelon can be done (Fig. 1))
• In rainfed areas chickpea is the main crop.

5. Present status of conservation agriculture in Pakistan:
Zero tillage was introduced in Pakistan in the Indo-Gangetic plains for wheat sowing as zero tillage machines were imported from New Zealand. Conservation agriculture technology was introduced at the Rice-Wheat Consortium (RWC) in Pakistan but there was no significant adoption of this technology due to misunderstandings between projects and some research departments.

The bed planting seed drill is now being used in Pakistan and was designed by the Directorate of Water Management Research Centre, from the University of Agriculture in Faisalabad. The bed planter makes two beds while sowing wheat in one pass. The width of one bed is 86 cm and four rows of wheat are sown on one bed (Fig. 2). In this way the number of wheat rows remains the same as in the conventional method of sowing. By using this technology, up to 25%-30% water can be saved, and if the field is laser leveled up to 50% water can be saved.
Wheat has been planted under zero tillage, (Fig. 3 & 4) at the Postgraduate Agricultural Research Station (PARS) at the University of Agriculture, Faisalabad. By using this technology, fossil fuels, labor, and time can be saved, and the wheat can be planted at a suitable time.

The Government of Pakistan is providing laser-leveling units to farmers on a 50% subsidized basis. Simultaneously, the government is providing laser-leveling services to the farmers at subsidized rates. A government project to provide high-efficiency irrigation system equipments to farmers has also been started.

The Water Management Research Centre, from the University of Agriculture in Faisalabad, is running a project in an area of three distributaries called “On-farm research and development component for rehabilitating the lower Chenab canal systems (Part-B) Faisalabad” in which they are promoting laser land leveling, zero tillage, and bed planting.

Some farmers are already adopting CA technologies since the RWC was introduced in Pakistan. Progressive farmer Bilal Shah, a resident of Bilal Nagar district in the village of Sheikhupura has sown wheat on raised beds as well as on the flat and his yields were higher on the field where his wheat was sown on beds, as compared to on the flat (Table 1). Likewise a farmer named Muhammad Mushtaq, from Faisalabad district, planted wheat under zero tillage technology, as well as under conventional practices, and had higher yields from the zero tillage field (Table 2).

6. The Cereal System Initiative for South Asia in Pakistan:

The Cereal System Initiative for South Asia (CSISA) in Pakistan has one hub. Its office is at the Ayub Agricultural Research Institute in Faisalabad. The area covered by this hub includes four Punjab districts (Faisalabad, Sheikhupura, Kasur, and Okara). In Pakistan, at the moment, CSISA is at a pilot project stage.

CSISA is promoting CA by introducing laser-leveling, tilled raised beds, zero tillage, direct-seeded rice (DSR), intercropping, and relay cropping (Fig. 5), etc.

CSISA started its activities in Pakistan in August of 2009. Research associates were recruited in October 2009. Its aim is to promote CA technology among farmers and to provide farmers with capacity-building in CA technology and seed production. Meanwhile, the Technical Working Group (TWG) has been formed, and its meeting has been called.

<table>
<thead>
<tr>
<th>Name of Farmer</th>
<th>Address</th>
<th>RP Ton/ha</th>
<th>FP Ton/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bilal Shah</td>
<td>Bilal Nagar</td>
<td>5.0</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>Sheikhupura</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name of Farmer</th>
<th>Address</th>
<th>ZT Ton/ha</th>
<th>FP Ton/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muhammad Mushtaq</td>
<td>Pindi Sheikh Musa</td>
<td>4.8</td>
<td>4.2</td>
</tr>
</tbody>
</table>

*Table 1. Comparison of wheat yields on raised beds (RP) vs. flat planting (FP) (2009)*
The members of the TWG are top officials from the agriculture department, including the vice chancellor of the University of Agriculture in Faisalabad, some agricultural machinery manufacturers, and a few progressive farmers.

CSISA has partnered with some research departments including the Directorate of Rice Research Institute Kala shah Kaku, in Lahore, Punjab; the Directorate of Adoptive Research, in Punjab; the Maize and Millet Research Station, in Yousafulwala, Sahiwal, Punjab; and the Ayub Agricultural Research Institute, in Faisalabad. The Department of Agriculture Extension in Punjab is also cooperating with CSISA to promote CA in our hub. Punjab wheat was planted on permanent beds at different adoptive research stations during the last season (2009-2010) to check yield and water saving as compared to conventional practices. The yield was high for fields where wheat was sown on permanent beds, except for one station, as compared to conventional agriculture. Water saving ranged from 25%-30% and a higher yield was obtained when wheat was planted on permanent beds (Table 3).

When CSISA started its activities in Pakistan, the wheat planting season was about to start. We consulted the farmers about adopting CA technologies during the wheat-sowing season (i.e., to plant wheat on beds and to use zero tillage technology). Although it was late to start sowing wheat, we succeeded in convincing a few farmers to adopt CA technologies, and they planted their wheat under CA, and are now happy using this system. Meanwhile, we got lists of the farmers of our hub domain who had received laser levelers on a subsidy basis from the government and we organized meetings with them so we could provide them with capacity-building in various aspects of CA. They were persuaded to buy the CA implements, and then to act as service providers in their village or surrounding area.

At the same time, we conducted meetings with machinery manufacturers and asked them to fabricate a planter which could plant crops on beds and that could also work as a zero tillage machine, so that farmers could purchase a multipurpose machine for the price of one machine. The prototype of this machine is ready and is in the final stages of testing.

To promote the adoption of the DSR technology in paddies, CSISA has been training farmers since kharif 2010. For this purpose, we have prepared a pamphlet in which DSR technology is described briefly from soil preparation to harvesting of the crop. Farmers have expressed their satisfaction and

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**Table 3. Comparison of wheat yields planted in permanent raised beds (PB) vs. flat planting (FP) (2009)**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Adoptive Research Station (Pak)</th>
<th>PB Ton/ha</th>
<th>FP Ton/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R.Y. Khan</td>
<td>4.6</td>
<td>5.3</td>
</tr>
<tr>
<td>2</td>
<td>Vehari</td>
<td>4.7</td>
<td>3.9</td>
</tr>
<tr>
<td>3</td>
<td>Kehror Pacc</td>
<td>4.0</td>
<td>3.7</td>
</tr>
<tr>
<td>4</td>
<td>Sheikhupura</td>
<td>2.6</td>
<td>2.3</td>
</tr>
<tr>
<td>5</td>
<td>Gujranwala</td>
<td>4.0</td>
<td>3.7</td>
</tr>
<tr>
<td>6</td>
<td>Sargodha</td>
<td>4.2</td>
<td>3.7</td>
</tr>
</tbody>
</table>

**Table 4. Comparison of wheat yields planted on raised beds (PB) vs. flat planting (FP) (2009)**

<table>
<thead>
<tr>
<th>Name of Farmer</th>
<th>Address</th>
<th>PB Ton/ha</th>
<th>FP Ton/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ayub Agricultural Research Institute</td>
<td>Faisalabad</td>
<td>4.0</td>
<td>3.7</td>
</tr>
</tbody>
</table>

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Figure 5. Relay cropping
they are adopting this technology eagerly. The labor shortage and cost of puddling have fueled the rapid adoption of this technology. CSISA has also given capacity-building to 500 female farmers, 526 male farmers, 392 researchers, and 115 agronomists/field assistants in CA technology, seed production, laser-leveling, and DSR (Table 5).

Table 5. Capacity-building delivered by CSISA, Pakistan to farmers, researchers, and extension agents

<table>
<thead>
<tr>
<th>Date</th>
<th>Training Topic</th>
<th>Village/Location</th>
<th>Site of training</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.08.2009</td>
<td>Training of women farmers</td>
<td>University of Agriculture Faisalabad</td>
<td>FSD PAK</td>
<td>Women: 500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faisalabad</td>
<td></td>
<td>Men: 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faisalabad</td>
<td></td>
<td>Researchers: 100</td>
</tr>
<tr>
<td>20.08.2009</td>
<td>CA technology</td>
<td>Tonalca</td>
<td>FSD PAK</td>
<td>Women: 16</td>
</tr>
<tr>
<td>18.11.2009</td>
<td>CA technology</td>
<td>Pun Piran</td>
<td>FSD PAK</td>
<td>Men: 75</td>
</tr>
<tr>
<td>06.01.2010</td>
<td>CA technology</td>
<td>Ayub Agricultural Research Institute</td>
<td>FSD PAK</td>
<td>Women: 200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faisalabad</td>
<td></td>
<td>Men: 200</td>
</tr>
<tr>
<td>28.01.2010</td>
<td>LASER Land Leveling</td>
<td>Sheikhupura</td>
<td>FSD PAK</td>
<td>Women: 115</td>
</tr>
<tr>
<td>03.02.2010</td>
<td>Extension staff capacity-building</td>
<td>Faisalabad</td>
<td>FSD PAK</td>
<td>Men: 15</td>
</tr>
<tr>
<td>08.02.2010</td>
<td>CA technology</td>
<td>62 RB</td>
<td>FSD PAK</td>
<td>Women: 43</td>
</tr>
<tr>
<td>10.02.2010</td>
<td>LASER Land Leveling</td>
<td>Kasur</td>
<td>FSD PAK</td>
<td>Men: 43</td>
</tr>
<tr>
<td>11.03.2010</td>
<td>Seed production</td>
<td>Ayub Agricultural Research Institute</td>
<td>FSD PAK</td>
<td>Women: 32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faisalabad</td>
<td></td>
<td>Men: 32</td>
</tr>
<tr>
<td>15.03.2010</td>
<td>Capacity-building for service providers</td>
<td>Office of Okara EDO (Agri.)</td>
<td>FSD PAK</td>
<td>Women: 55</td>
</tr>
<tr>
<td>18.03.2010</td>
<td>Lecture on “Climate change and crop production compulsion”</td>
<td>NIAB</td>
<td>FSD PAK</td>
<td>Men: 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Farmers: 45</td>
</tr>
<tr>
<td>08.04.2010</td>
<td>Capacity-building for staff training Lecture</td>
<td>Plant Protection Institute (AARI)</td>
<td>FSD PAK</td>
<td>Women: 10</td>
</tr>
<tr>
<td>14.04.2010</td>
<td></td>
<td>Punjab Forest Research Institute Delpur</td>
<td>FSD PAK</td>
<td>Men: 10</td>
</tr>
<tr>
<td>26.04.2010</td>
<td>DSR</td>
<td>Okara</td>
<td>FSD PAK</td>
<td>Women: 50</td>
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<tr>
<td>29.04.2010</td>
<td>DSR</td>
<td>Ayub Agricultural Research Institute</td>
<td>FSD PAK</td>
<td>Men: 20</td>
</tr>
<tr>
<td>09.05.2010</td>
<td>DSR</td>
<td>Sacha Sauda</td>
<td>FSD PAK</td>
<td>Women: 30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sheikhupura</td>
<td>FSD PAK</td>
<td>Men: 30</td>
</tr>
<tr>
<td>10.05.2010</td>
<td>DSR</td>
<td>Jaranwala</td>
<td>FSD PAK</td>
<td>Women: 85</td>
</tr>
<tr>
<td>13.05.2010</td>
<td>DSR</td>
<td>Kangan pur</td>
<td>FSD PAK</td>
<td>Men: 60</td>
</tr>
<tr>
<td>14.05.2010</td>
<td>DSR</td>
<td>Ayub Agricultural Research Institute</td>
<td>FSD PAK</td>
<td>Women: 40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jaranwala</td>
<td>FSD PAK</td>
<td>Men: 40</td>
</tr>
<tr>
<td>31.05.2010</td>
<td>DSR</td>
<td>Lundianwala, Jaranwala</td>
<td>FSD PAK</td>
<td>Women: 45</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Men: 5</td>
</tr>
</tbody>
</table>

CA = conservation agriculture; DSR = direct seeded rice; FSD = Faisalabad
The adoption of DSR technology has spread thanks to meetings with and capacity-building provided to farmers, and farmers have planted rice under this technology. Some farmers in the CSISA hub domain have sown paddy crops with this technology (Fig. 6, 7).

At the same time, farmers are adopting intercropping, like Rana Zahid Farooq of Faisalabad district, who planted canola after his sugarcane, and is getting an extra benefit along with the sugarcane crop (Fig. 1).

### 7. Conclusion

Crop production in the next decade will have to produce more food from less land by making more efficient use of natural resources, and causing minimal impact on the environment. Only in this manner will food production keep pace with demand, while the land’s productivity is preserved for future generations. This is a tall order for agricultural scientists, extension personnel, and farmers. The use of productive but more sustainable management practices (as described in this paper) can help to solve this problem. Crop and soil
management systems that improve soil health parameters (physical, biological, and chemical) and reduce farmer costs are essential. Development of appropriate equipment will allow these systems to be successfully adopted by farmers, and is a prerequisite for success. Overcoming traditional mindsets about tillage by promoting farmer experimentation with this technology in a participatory way will help accelerate its adoption. Encouraging donors to support this long-term, applied research with sustainable funding is also an urgent need. It has been observed that crops planted on beds can save between 25%-30% water and laser leveling a field can provide up to 50% water savings. DSR technology can also result in 8%-10% water savings and 75%-80% labor savings.

The disadvantages in the short term are the high initial costs of appropriate machinery, which require high management skills and a learning process by the farmer. Long-term experience with conservation farming all over the world has shown that conservation farming does not present more or less problems to the farmer, but rather different problems arise that can all be resolved. Nature is a good example of CA as it does not plow or irrigate the soil, yet, there are thousands of plants that have existed, and exist, naturally without any external aid.

Acknowledgements

My advanced training course “Conservation agriculture: Laying the groundwork for sustainable and productive cropping systems” at CIMMYT El Batán and Toluca station in Mexico, from 24 May to 25 June, 2010 was sponsored by the Cereal System Initiative for South Asia (CSISA). I am thankful to CSISA for granting me this opportunity.

References


Chapter 5. Conservation agriculture in Iran

M. R. Mehrvar

1Cereals Agronomist in the Cereals Research Department of the Seed and Plant Improvement Institute (SPII), Iran

Abstract

The farmers of Iran should make a step-by-step shift from the traditional intensive crop production and management to the conservation agriculture (CA)-based technology as a national cropping program. This shift would be in accordance with the agro-climatic and economic conditions of the main or selected provinces with irrigated wheat production. The change in the “one crop” viewpoint (regardless of other crops in the sequence or in rotation with wheat) to an integrated cropping system requires the multidisciplinary joint efforts of the Agricultural Research, Education, and Extension Organization (AREEO) of the Ministry of Jihad Agriculture and the agricultural service centers which can be used as “hubs” for direct communication with farmers. This collaboration will allow for the preparation of quality, feasible agronomic packages for irrigated wheat-based cropping systems under CA principles. The role of research, education, and extension would be to cooperate with agricultural service centers and farmers to facilitate the implementation of CA-based technology.

Keywords: conservation agriculture, cropping system, cropping pattern, CA hub, wheat, maize

1. Introduction

Crop yields have increased dramatically in developing countries thanks to the adoption of new agricultural technologies, the intensification of agriculture, and improved crop varieties (Gupta and Seth, 2007). However, modern society demands cropping systems that not only aim at stable and high yields, but also maintain soil fertility, reduce negative environmental impacts, and are economically sound (Lal, 1997).

Farmers concerned about the environmental sustainability of their crop production systems combined with ever-increasing production costs have begun to adopt and adapt improved management practices for their cropping systems that lead toward sustainable conservation agriculture (CA) solutions. CA combines the following basic principles:

1. **Minimum tillage**: The objective is the application of zero tillage or controlled tillage seeding systems that normally do not disturb more than 20-25% of the soil surface.

2. **Maximum possible retention of crop residues and surface cover on the soil**: The objective is to maintain an adequate soil cover through the retention of sufficient crop/cover-crop residues on the soil surface to protect the soil from water/wind erosion, water run-off, and evaporation. This soil cover improves water productivity and enhances soil physical, chemical, and biological properties associated with long-term sustainable productivity.

3. **Use of crop rotations**: The objective is to employ economically viable, diversified crop rotations to help moderate/mitigate possible weed, disease, and pest problems and offer economically sound cropping alternatives to help minimize farmer risk. These CA principles seem to be applicable to a wide range of crop production systems including low-yielding, dry rainfed systems as well as high-yielding irrigated conditions. However, how these principles are applied will depend on the situation and will need a flexible approach for different production systems. Obviously, specific and compatible management components (weed control tactics, nutrient management strategies, and appropriately-scaled implements) will need to be identified through adaptive research with active farmer involvement to facilitate the adoption of appropriate CA-based technologies for contrasting agro-climatic/production systems. As such, the movement toward CA-based technologies normally involves step-by-step changes in cropping system management that lead to improved productivity and sustainability. Reduced tillage is initially applied in combination with the retention of sufficient amounts of crop residue on the soil surface, with the assumption that appropriate crop rotations can be included or maintained to achieve an integrated, sustainable production system. Local soil and environmental conditions will determine if zero tillage, strip tillage, permanent raised bed planting, or any other reduced tillage system is the best alternative. Local market conditions, crop production level, the farming system, and the environment will determine the strategies but adequate residues must be retained for marked reductions in tillage to be feasible over the long term.
Conservation agriculture is a concept for resource-saving agricultural crop production. It strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment (FAO, 2008). CA is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes. CA consists of different crop cultivation practices such as zero tillage, sowing of crops on permanent beds, strip tillage, plant residue management, and adequate crop rotation management amongst others (Tursunov, 2009).

Research on different aspects of CA is being conducted by many scientists in different parts of the world. The area of crops under zero tillage systems has increased significantly in recent years. According to Derpsch and Friedrich (1999), the area under zero tillage in 1999 was about 45.5 million hectares. But recent studies on CA systems show a rapid spread of these systems, and by 2008 the area had increased up to 105.9 million hectares; the area under zero tillage in North and South America is approximately 90 million hectares (Derpsch and Fredrich, 2009). The reason for this extensive uptake of zero tillage systems is that this technology has many advantages compared to conventional methods, including: (i) reduced production costs, (ii) sharply reduced energy requirements, (iii) better moisture retention, (iv) reduced rainfall runoff, (v) less wind and water erosion, (vi) less soil damage from machinery use, (vii) better timing in planting and harvesting, (viii) lower labor costs, (ix) reduction of some weather risks, and (x) lower fuel use in agriculture. Another advantage of this method is that land that may have become inaccessible for conventional tillage (due to wet soil conditions) is usually accessible for direct seeding of crops. Using a zero tillage system approach, the crop can be sown in one pass of machinery. In Pakistan and India, the number of irrigated crops under zero tillage has increased over the last 10 years (Khan, 2002, Indo-Gangetic Plain Bulletin, 2006). According to the Indo-Gangetic Plains (IGP) Bulletin (2006), the area under zero tillage in India has reached 2 million hectares. The reason for this continuous increase is that the farmers have seen this system in practice and have been convinced that it improves yields, raises water and fertilizer efficiency, and reduces weed germination.

Investigations done on CA practices under different climatic and soil conditions have shown that, in general, the following basic criteria must be observed for the approach to provide full benefits: 1) minimum soil disturbance (i.e., less machinery needed for crop production), 2) appropriate crop residue management (i.e., the amount of retained crop residues should correspond to the subsequent crop so that the sown crops can germinate and rise up through the retained layer of crop residues), and 3) suitable crop rotation, which in many respects defines the success of this system (Tursunov, 2009).

2. Conservation agriculture: A perspective from the International Maize and Wheat Improvement Center in Mexico

Effective development and extension of complex, multi-component, locally-relevant CA practices best occurs through “innovation systems,” in which researchers, farmers, input supply companies, extension staff, and farm implement manufacturers, among others, test and share ideas and products (Govaerts and Sayre, 2010). The International Maize and Wheat Improvement Center (CIMMYT) is establishing decentralized learning “hubs,” modeled after those operated by international airline carriers to foster such “innovation systems” for the maize and wheat-based farming systems and agro-ecological zones where CIMMYT works in Mexico. At such hubs, the different airline routes come together and there is intense contact and exchange of information, before passengers and planes head for particular destinations. The CA hubs are intended to serve a similar organizational aim: technology development and extension activities are concentrated in a few defined locations representative of certain farming systems, rather than pursuing less intensive, wide-scale efforts. Each hub provides:

- Benchmark sites for research on the impacts of CA on crops and the environment in prevalent cropping systems of a region.
- A focal point for regional (agro-ecological) capacity-building and scaling out of research and innovation systems. Through research and training, regional CA networks are established to foster CA innovation systems and research on/extension of technologies.
- A setting for multiple actors in a production system (farmers, scientists, machine-builders, decision-makers, input suppliers, among others) to work and learn together, allowing subsequent, intensive scaling out.
- Working examples of CA systems that help break down the culture of the plow.
2.1. Hubs

Hubs link to a strategic science platform in Mexico, fostering a shared, global understanding of CA and its adaptability in different environments, cropping systems, and farmer circumstances. Hubs are operational or under development in Mexico (irrigated intensive systems for wheat, highland mixed systems), Uzbekistan (cotton-wheat based systems), the IGP (rice-wheat based systems), and southern Africa (high-risk, rainfed maize-based systems).

2.2. Basic research: Results of long-term trials

Since 1990, CIMMYT has been conducting long-term sustainability trials comparing CA and conventional practices at three experimental stations in Mexico: the central highlands (El Batán, 19°N, and 2240 meters above sea level (masl), Toluca, 19° N, 2640 masl, both in the state of Mexico) for mixed, rainfed systems; and Ciudad Obregón (27°N, 39 masl), in the state of Sonora, in northwestern Mexico, for irrigated wheat-based systems (Govaerts and Sayre, 2010).

Adequate management of permanent beds with residue retention provides yields roughly on par with those for conventionally-tilled beds with incorporation of residues, but the farmer’s income increased significantly due to reduced costs (Govaerts and Sayre, 2010).

2.3. The role of farm implements

Access to the right machinery is essential for the adoption of CA. A lack of suitable implements, particularly sowing equipment, has limited the extension and adoption of the permanent bed planting system, particularly for small grains like wheat and small-to-medium-scale farmers in developing countries. CIMMYT has focused on developing multi-crop/multi-use implements that can easily be reconfigured to reform beds, for basal or post-emergence fertilizer applications, and for sowing small- or large-grain crops (Fig. 1). Use of this type of planter markedly reduces farmers’ production costs. A prototype developed in Mexico is now ready for production by local machinery manufacturers.

![Figure 1. Left-Multi-crop/multi-use implement configured for reshaping permanent beds and applying basal fertilizer; Right-Same implement configured for bed reshaping, fertilizing, and maize planting.](image-url)
2.4. An example of step-by-step implementation of CA in irrigated wheat-based cropping systems.

The step-by-step implementation of CA for irrigated wheat-based cropping systems can be seen in the Yaqui Valley in Sonora state in northern Mexico (Fig. 2), (Govaerts et al. 2009). The region is characterized by a desert climate, mostly sunny and dry, with a total yearly rainfall of about 381 mm, with 255 mm during the summer cycle (May-Oct). The Yaqui Valley has about 255,000 ha of irrigated land using primarily gravity irrigation systems fed by canals (over 80% of irrigation water) and deep tube wells (around 20% of irrigation water). Crops planted during the winter cycle include wheat (November to May); safflower (January-June); winter maize (September-February); and chickpea (December-April). During the summer cycle the most common crops are summer maize (May-October); sorghum (March-July); and dry beans (March-May).

There have been three main shifts in farming system practices during the last decades: (1) in 1981, the majority of the farmers were planting with “melgas” (crop seeds in flat planting and basin irrigation) (Fig. 3), with only 6% of farmers in the valley planting on raised beds (Fig. 4), then 90000 hectares of crops in the valley were shifted to bed planting. The great benefits from bed planting include reduced production costs and irrigation water; enhanced field access, which facilitates weeds and pest control; and timely and efficient application of nutrients, reduced tillage, and crop residue management. (2) The second remarkable change in farming practices has been crop residue management: in the 1992-1993 cycle, residues were burned by 95% of the farmers, but by 2001, 96% of the farmers no longer burned but incorporated crop residues. (3) Recently there has been growing interest to take the next logical step in making raised bed planting more sustainable by reducing tillage and leaving crop residues on...
the surface by reusing permanent raised beds with only superficial shaping in the furrows between the raised beds as needed before the planting of each succeeding crop (Fig. 5). Therefore in 1991 the crop management team at CIMMYT started research on permanent beds to offer opportunities for farmers to further reduce production costs and increase the sustainability of the system through the positive effects on chemical, physical, and biological soil quality (Govaerts et al. 2009).

2.5. CIMMYT and conservation agriculture worldwide: Examples
• During 1994-2001, CIMMYT helped promote zero tillage and crop rotations in Bolivia and organized, with local partners, a network of research institutions, farmer associations, and progressive farmers. By 2000, farmers were using the new practices on 300,000 hectares.
• More than 300 million people in South Asia depend on the rice-wheat system for food and livelihoods. Through the efforts of the CIMMYT-led Rice Wheat Consortium (RWC) for the IGP, farmers were using zero tillage systems on more than 2 million hectares in 2004, and obtained a net profit of more than USD $100 million that year.
• In sub-Saharan Africa, CIMMYT is helping smallholder maize farmers in Malawi, Mozambique, Zambia, and Zimbabwe to test and adopt CA practices through participatory demonstration plots and machinery evaluations, meetings to inform communities, and training for extension agents and researchers.

3. Conservation agriculture in Iran
Iran has about 8.7 million hectares of irrigated lands of which about 2.4 million hectares is under irrigated wheat cultivation (Jalal Kamali et al. 2009). According to the principles of CA, this technology is feasible for any condition in Iran and it seems to have no limitations. But the agronomic and economic package is different for each location and should be fulfilled for any specific area based on the cropping pattern of agricultural and horticultural plants considered for that location by the government. According to the definition of the cropping pattern as an economical and sustainable agricultural system based on country policies, indigenous knowledge of farmers and optimum utilization of the regional potentials, we see that the cropping pattern is influenced by many factors. Some of these include the amount of water available during drought periods, technology advancements, the extent to which agricultural mechanization is being followed, the field area of the land, the economic value of the crops, crop management changes feasibility, and agricultural inputs. Change is dependent on farmers and can be facilitated by government support; if change is not adopted then improvement to the agricultural systems cannot be successful within the country.

At the moment, we have two big programs in Iran called “the improvement of field cropping patterns and horticultural crops program” (happening all through the country) and “the conservation agriculture program” (for 3 million hectares of land).
These two programs are somewhat related to each other, but they should be related completely, which means the improvement in cropping patterns should be in the context of CA and not in the context of the traditional methods or farmers’ experience. Full implementation of CA means considering all three principles of CA under the context of wheat-, maize-, and rice-based cropping systems as the dominant cropping systems in Iran, managed traditionally but not based on the CA principles. The successful transition from the traditional way of thinking about crop production to the CA-based technology needs much more research, education, and extension, which can be achieved through the cultural, economic, and social development programs now running in Iran.

Wheat, a strategic crop in Iran, has been continuously in need of improvement in domestic production. In the 2008-2009 crop seasons, the area and production of wheat in irrigated fields were about 2.4 million hectares and 9 million tons, respectively. The country’s average grain yield was 3,673 kg/ha, with the maximum of 5,352 kg/ha for Tehran, and the minimum of 2,446 kg/ha in the Bushehr Province. The reported complete crop failures for irrigated wheat in the provinces of Khuzistan, Fars, and Isfahan were 117,647, 41,261, and 12,584 hectares, respectively. The causes for crop failure and lower grain yield of irrigated wheat in Iran seem to be many. But the most important ones include biotic and abiotic stresses, such as weeds (for instance, in the Golestan province); diseases in high humid areas in the North and some parts of the South; drought stress through the entire growth period (especially in terminal growth stages) in most parts of Iran except in the Northwest and some west provinces; freezing stress through the mid-growing season (especially in the Northwest and some cold areas near the West of Iran); and saline soil and water in some provinces in the central plateau of Iran. Sometimes the aforementioned stresses overlap partly or completely, which in most cases have synergistically negative effects on the final yield of the crop (Office of Statistics and Information Technology, 2009).

According to some studies, the wheat/maize double cropping is the dominant intensive cropping system in Iran, by which the land is conventionally tilled and crop residues are burned or removed (partly or totally) for cattle feed. High diesel fuel consumption, more traffic and horse power (used for seedbed preparation through intensive crop production), result in soil degradation (physically, chemically, and biologically), low soil organic matter, soil compaction, high soil bulk density, low water-holding capacity and low cation exchange capacity (CEC).

3.1. Conservation agriculture or conservation tillage?

Conservation tillage in irrigated and dryland agriculture has been in demand for many years due to the many problems related to conventional tillage for crop production in Iran. The reduced tillage has been practiced as the first tillage strategy by some farmers using chisel plows instead of moldboard plows. Afterwards, in some irrigated lands, the farmers decided to practice agriculture using chisel cultivator plows, which minimize machinery passes and production costs. This practice has helped farmers to solve some problems, such as high crop production costs, long turnaround time (especially in wheat/maize double-cropping), crop yield reduction, high fuel consumption and labor/tractor use for land preparation and high soil compaction. Yet, it is definitely not a solution for other problems concerned with soil erosion; the progressive loss of fertility or soil quality with all its components (such as low soil organic matter content); CEC; nutrient availability; soil biological fertility and water-holding capacity; as well as low water productivity and efficiency use for the system and the crop. In fact, the irrigated drylands in Iran need a sustainable agricultural system and new cropping system that can aim at increasing productivity and improving the use of natural resources. Conservation agriculture approaches may help to address these aims.

The government of Iran has decided to conduct many projects, such as encouraging raised bed planting systems, improved field management, conservation tillage management, and recently, CA. In fact, the efforts being done in Iran are mainly based on minimum tillage using chisel-cultivators (a type of conservation tillage, but not CA) to reduce the machinery traffic and planting with seeders and/or combinations, leaving no (or low) amounts of residue. The results have been tremendously good in some parts, especially in the Fars province. The CA resource-based technologies fulfill the requirements needed for a stable cropping system based on the dominant crop of any specific location. The CA based cropping system is an integration of CA principles (crop rotation, crop residue retention and low or minimum soil disturbance) that takes into account agronomic, technical, environmental and socio-economical issues. The introduction of suitable CA based cropping systems is necessary to stabilize the field crop production in Iran. These practices include diversified crop rotations, diverse crop residue retention, minimal soil disturbance and should ultimately be based on the local
requirements and economic considerations of each production environment. The problems seen with intensive crop production in Iran are the result of the components of a fragile or unsustainable environment. The basic ideas in the current intensive crop production in Iran are limited to non-optimum use of inputs, especially water, nutrients, and machineries. Under this philosophy, the final target of the farmer is maximum output, without consideration of other consequences, such as soil exhaustion and degradation, low crop quality, resistances to chemicals, and environmental fragility and un-sustainability.

Since Iran is found in the global drought belt, and water is the most important determinant of final yield, there should be much more attention put on water productivity and its economy. Water shortages may partly explain the big difference in grain yield in the drylands vs. the irrigated wheat environments. Furthermore, the long-term data of wheat grain production in Iran has been in much fluctuation; this is partly due to weather condition variability and partly due to the unstable, different environments found in Iran. The CA resource based technologies provide stable water harvesting methods by increasing soil water-holding capacity, upgrading soil quality by enhancing biological activity of the soil, increasing carbon sequestration and organic matter content, and optimizing the ecological niche for the crop.

3.2. Problems
The first and most important problem embedded in the intensive irrigated wheat production environments of Iran, is the lack of definition for irrigated wheat production environments, based on the cropping system viewpoint and in the context of CA resource based technology.

3.3. Limitations
There has been some resistance by farmers to accept the improvement of the cropping pattern, and the program being introduced by the Ministry of Jihadé Agriculture. This means that, for each province and the farmers of that province, there would be a share to fulfill by the farmers based on the new cropping pattern program considered. The Ministry has stated that, by accepting the rules of the new cropping pattern, there would be many advantages, such as subsidiary inputs, monetary funding, and negotiations with factories to provide support with buying products.

Another issue related to the successful implementation of CA resource based technology, is the shortage of special CA implements since we are currently in the first stage of evaluating some imported implements. The next stage will be to fabricate these implements internally, based on the farmers’ requests for each specific location. The land area of each farmer who needs special CA implements should also be considered. In fact, the CA implements should be in coordination with the farmers’ coefficient of utilization or mechanization.

3.4. The National Cropping Pattern Program in Iran
There are many goals related to the implementation of the National Cropping Pattern Program in Iran, such as:
1. The provision of suitable cultivation, food security, and stability of production.
2. The conservation of basic resources and increased productivity of production.
3. The coordination and cooperation with the Ministries of Energy, Agriculture, and Commerce.
4. The use of optimization models for making decisions and policies.
5. Production resources must be used logically so that water and soil can be saved for future generations.
6. Water productivity and use efficiency must be upgraded and the side effects of drought (as a key limiting factor) be reduced.
7. The agro-climatic conditions throughout the country must be considered, so that the proper cropping pattern ensures sustainability.
8. Successful implementation of the appropriate cropping pattern will require national commitment.
9. The implementation of appropriate cropping pattern is supported by appropriate laws and regulations.
10. Farmers and agricultural producers have a key role.
11. Support of legislation parliament is a prerequisite.
13. Joint cooperation of all the agricultural sub-sectors.

The most important of these are production stability, natural resource conservation, increasing productivity, optimizing models, farmers’ cooperation, food security, sustainable development, and drought mitigation.
These issues imply the appropriate cropping pattern should be based on the principles of CA resource based technology, and not on the traditional, or experience-based mindset of intensive crop production. Through this approach all the above goals can be fulfilled, provided that CA is considered as a context or an infrastructure fully covered by its principles. Because the mentioned principles of CA are interwoven and completely related, ignoring any of them means the long-term approach will fail (partly or totally).

3.5. Factors affecting successful CA based cropping systems
Successful CA based cropping systems technologies may seem to be related to many parameters such as farmers’ behavior, sustainable agriculture knowledge, literacy level, achievement motivation, wheat production total area, wheat production technical knowledge, economic policy, wheat cropping model, the amount of supervision by agricultural service centers, and educational services provided by extension agents. So it seems the role of agricultural service centers in transferring the predefined technologies based on CA is paramount, because they should be considered as the hubs. The agricultural research, education, and extension organization (AREEEO) in Iran has the key role of holding seminars, workshops, and training programs for the agricultural service centers and they are the persons responsible for transferring the technologies to the farmers. Agricultural researchers have to prepare and conduct research projects to define the CA based cropping systems according to all issues and policies for a specific location. The agricultural extension system has to prepare the extension documents for CA technology designed specifically for the farmers and coordinated with the agricultural service and research centers. The agricultural education system should prepare and run the programs for training agricultural engineers and students.

4. Recommendations
1. Stepwise change of the traditional or experience-based mindset of crop production and management, especially wheat and other crops in rotation (mainly maize) to CA, according to the agro-climatic and economic conditions of the main or selected provinces of irrigated wheat production.
2. To change the “one crop” viewpoint regardless of other crops in the sequence or in rotation with wheat vs. a cropping system based mindset in the context of CA.
3. To prepare the superior agronomic package for irrigated wheat based cropping systems based on CA principles with the required modifications, in consideration of the limitations for each province.

5. Conclusions
The CA resource based technology should be globally accepted as a feasible approach to replace the traditional mindset of intensive crop production and all its consequences (such as soil degradation and environmental un-sustainability). The next logical step to make CA part of the culture is to define specific agronomic and economic crop based packages for any crop production environment, specifically the irrigated lands in Iran. CA technology would be a suitable way to solve the problems of field crop production since the proper National Cropping Pattern Program and the CA plan are running over the irrigated lands of Iran for the next years. CA technology must be implemented through the multidisciplinary joint cooperation of agricultural research, education, and extension with agricultural service centers as hubs all over the country. The agricultural service centers are directly connected to farmers and have a key role in transferring the CA resource based technology to them.

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References


Chapter 6. Direct-seeded rice: A way toward conservation agriculture in Punjab

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Abstract

The Western Indo-Gangetic Plains are considered the grain basket of India. Unfortunately, the Plains and Punjab area in particular face natural resource degradation and agricultural labor shortages. Continuous puddling of the rice crop has eroded soil and water resources greatly. Conservation agriculture (CA) can help sustain the productivity of the rice and wheat system, mitigate environmental pollution, and improve soil quality and the declining water table. CA could be introduced through direct-seeded rice (DSR), which may play an important role in the conservation of natural resources. Research efforts have been made in Punjab to develop the optimal management practices for DSR. A seed rate of 20 kg/ha and a seed depth of 2-3 cm was found optimum for rice in non-puddled fields. One or two weeks prior to historical onset of the monsoon was observed as the optimal sowing time. Pre-emergence application of pendimethalin (1 kg a.i. /ha) and post-emergence application of bispifyribac 25-30 days after seeding (DAS) (25 g a.i. /ha) was found to be the best for weed management. Inclusion of other technologies including laser land levelling, crop rotations, and crop diversifications can sustain the natural resource base for a longer time. Direct-seeded rice in laser-leveled fields offered an average of 40% water savings and 18% less methane emissions as compared to conventional puddled transplanted systems. In addition to substantial reductions in water consumption, direct seeding also results in significant cost reductions of about USD $138/ha for the farmer. Thus, CA principles can clearly make agriculture sustainable and profitable.

Keywords: crop establishment, soil aggregates, green house gases, brown manuring, soil degradation, labor scarcity

1. Introduction

Rice (\textit{Oryza sativa}) is a principal source of food for more than half of the world’s population, especially in South and southeast Asia and Latin America. It is grown on approximately 153 million hectares globally, of which 134 million hectares are in Asia (Rao et al. 2007). Rice is the lifeline of Asia and more than 90% of the world’s total rice crop, or around 570 million tons of the estimated 630 million tons of global rice production in 2006-2007, was produced in Asia (FAO, 2007; USDA, 2007). The Green Revolution improved rice productivity across monsoon Asia through a combination of new high-yielding varieties with increased input use, like stable water supplies from new irrigation systems, and fertilizer (Hossain and Fischer, 1995). Because of this increased productivity, and an increase in the cropped area, total rice production over the last 40 years has efficiently kept pace with the tremendous population growth in Asia, and now stands at about 550–600 million tons annually (Maclean et al. 2003). To fight poverty and provide food security, rice production must increase dramatically in spite of climate change. The rotation of rice and wheat, for example, is a major agricultural production system, which accounts for approximately 30% of the area on which rice and wheat are grown in South Asia (Timsina and Connor, 2001; Ladha et al. 2003). More recently, the area of rice and wheat was estimated at 10 million ha in India, and 13.5 million ha for the Indo-Gangetic Plains (IGP), which includes Bangladesh, India, Nepal, and Pakistan (Ladha et al. 2003) (Fig. 1). Increased productivity and profitability also contributed to food security and poverty reduction among farmers with irrigated land (Dawe, 2000). However, there has recently been a significant slowdown in the productivity growth rate, and the sustainability of this important cropping system is at stake. The decline in soil productivity (particularly organic C and N); the deterioration in soil physical characteristics; the delay in sowing of wheat; decreasing water availability; depletion of groundwater; increased soil salinity; water logging; increased pest incidence; and the evolution of new,
more virulent pests are often suggested as the causes of this slowdown in productivity. Climate change will also have adverse impacts on the productivity of this important cropping system, posing a real threat to food security in Asia.

In Asia, more than 80% of the developed freshwater resources are used for irrigation purposes, about half of which are used for rice production (Dawe et al. 1998). In Asia, 17 million hectares (Mha) of irrigated rice areas may experience “physical water scarcity,” and 22 Mha may have “economic water scarcity” by 2025 (Tuong and Bouman, 2002). The challenge is to develop novel technologies and production systems that will allow rice production to be maintained or increased in spite of declining water availability. Rice is generally grown in flooded fields whereas the ensuing wheat crop requires well-drained soil conditions. This fundamental difference in the growing conditions entails distinct properties of both crops as far as green house gas (GHG) emissions are concerned. While anaerobic conditions in wetland rice fields foster the emission of CH$_4$, the upland conditions during wheat production could act as a net-sink for this gas. However, the biggest threat to sustaining or increasing the productivity of rice-wheat systems of South Asia is probably water shortage.

1.1 Rice in Punjab

The Punjab state has only 1.5% of the country’s geographical area, but it produced about 20% of its wheat, 11% of its rice, and 9.5% of its cotton during 2007-2008. The Punjab state, which has earned a reputation as the country’s “food basket” and/or the “granary of India” has provided 40% of the country’s rice and 50-70% of its wheat for the last two decades. The Punjab state produces 1% of the world’s rice and 2% of its wheat and cotton.

1.1.1 Contributions by Punjab

The wheat crop showed a significant increase in contribution to the national cereal central pool from 1998-1999 to 2006-2007 (from 49% to 75%; Fig. 2). On the other hand, rice contribution to the national cereal central pool decreased from 2002-2003 (49%) to 2006-2007 (31%).

Figure 1. Rice–wheat cropping systems in the Indo-Gangetic plains along a West–East transect.

![India-10 M ha Bangladesh- 0.8 M ha Pakistan- 2.2 M ha Nepal- 0.5 M ha](image)

Figure 2. Rice and wheat contribution of the Punjab state to the central pool (in percentage).
(Source: PAU handbook)
In the last 15 years, the overall contribution of wheat ranged from 50% to 75%; in rice, the contribution to the central pool varied from 30% to 50%.

1.1.2 Climatic variations
Climate change has many facets, including changes in long-term trends in temperature and rainfall regimes, as well as increasing variability in extreme events. The impacts of these changing conditions on agriculture are already being seen, yet there are still considerable gaps in our knowledge of how agricultural systems will be affected by both short- and long-term changes in climate, and what implications these changes will have for rural livelihoods, particularly among the most vulnerable.

The present agriculture cropping pattern in the state is dominated by the rice-wheat rotation (approximately 65% of the area of Punjab) causing degradation in soil fertility and lowering of the underground water table. In Punjab, rice is mostly grown during the monsoon season (July to October). Rice production in the state has gone up to 5.8 tons per hectare. But high rice yields have affected the water levels. Groundwater levels are declining rapidly in the northwest Indo-Gangetic Plains (Pingali and Shah, 1999; Singh, 2000). Thirty years ago, the groundwater level was between 4 to 5 m deep and today it is 30 m deep at places. Under dry conditions, rice needs to be irrigated 24 to 28 times, constituting 37% of the total water demand of Punjab. Soil and climate conditions in the whole state don’t favor rice i.e., central Punjab has very little heavy clayey soil which is essential for rice cultivation. The current pattern of farming includes a rotation of wheat and rice. This has led to heavy use of groundwater, especially in the central districts. Over 70% of the tubewells in the state are in the central districts, and about 85% of the land is used for rice during the kharif season. Areas irrigated by tubewells have gone up from 0.2 million to 2.4 million ha in the last decade. Only 1.8 million ha of Punjab are suitable for the rice crop which gets recharged from rainfall, streams, and canals. Punjab has exhausted its upper layer of groundwater, and farmers are now using high-horsepower pumps. The central plain districts of the Punjab state show the maximum concentration of rice. Agro-climatologically, this zone falls in the low rainfall zone of 400 mm–800 mm. Groundwater reserves are being fully exploited, so that this area is showing a sharp decline in the groundwater table, averaging 20 cm per annum (Narang and Gill, 1994). In spite of this, an increase in the rice area has continued because stable high yields of rice are harvested with liberal use of fertilizers (120 kg–150 kg N/ha or more), an overall favorable growing condition during most of the active growth period of rice, and a continuous replenishment of irrigation water. Although costly, operating an additional diesel pump over and above the electric pumps, along with the availability of canal water, makes rice the most productive and the only crop choice for farmers during the kharif season. It requires 1500 mm of irrigation water to be applied over 100–110 days for the active crop-growing phase besides the 330 mm of average normal effective rain received during the growing season (Narang and Gulati, 1992). The water application consists of scheduling 20–25 cm of water at land preparatory tillage, puddling, and transplanting. Water is then kept ponded for about 6-8 weeks. Irrigation is discontinued about two to three weeks prior to harvest.

2. Puddled transplanted rice
In Punjab, there are three main cropping systems: rice-wheat (64%), cotton-wheat (15%) and maize-wheat (5%). Rice is cultivated by sowing seeds in a small nursery, where they germinate into seedlings. The 4-5 week old seedlings are transplanted manually in puddled fields in standing water (4-5 inches). This level of water is maintained for 6-8 weeks after transplanting, mainly to prevent weed growth. Almost 98% of Punjab was under puddled transplanted rice (PTR) method in the rice season. The following are some necessary steps for PTR:

2.1 Nursery, puddling, and transplanting
Traditionally, rice is grown by transplanting one-month old nursery seedlings into the puddled and continuously flooded soil. Puddling requires lots of scarce water at a time when there is little water in the reservoirs, destroying soil structure and adversely affecting soil productivity. Puddling is achieved by intensive tillage under ponded water conditions, which breaks down soil aggregates, reduces macro-porosity, disperses the clay fraction, and forms a dense zone of compaction i.e., plow pan. In addition to facilitating the transplanting process, puddling also fulfils other functions, including weed control, and reduces deep percolation losses of water. Although physical changes on the soils from puddling can be favorable for rice cultivation, they can also be very detrimental to the growth of subsequent non-rice crops by causing temporary water logging, poor crop emergence, and restricted root development. High water losses occur through the puddling process, surface evaporation, and percolation. Water resources, both at surface and underground, are shrinking and water may
become a limiting factor in the future. Moreover, transplanting operations are usually performed by expensive hired labor. Puddling for rice induces high bulk density, high soil strength, and low permeability in sub-surface layers (Sharma and DeDatta, 1986; Aggarwal et al. 1995; Kukal and Aggarwal, 2003), which can restrict root development and water and nutrient use from the soil profile for wheat after rice (Sur et al. 1981; Gajri et al. 1992). However, the impact of puddling for rice on the performance of wheat after rice is variable across sites and years (Sharma et al. 2003).

Important environmental impacts associated with transplanted rice are GHG emissions, including the three main agricultural contributors to climate change: carbon dioxide (CO$_2$), methane (CH$_4$), and nitrous oxide (N$_2$O). Atmospheric concentrations of these gases have been increasing in recent decades due to human activity, including agriculture, and they have been shown to contribute to increases in average global temperatures (Houghton et al. 2001). Rice cultivation with traditional flooded irrigation is one of the main reasons for methane (a gas which damages the ozone layer 23 times more than CO$_2$) emissions in the country.

3. Direct-seeded rice

Direct-seeded rice (DSR) is directly seeded on a prepared bed without being grown in a nursery, and there is no puddling or transplanting done through manual labor. Direct-seeding of rice can overcome the problem of seasonality in labor requirements for rice nursery raising and transplanting operations. Resource-conserving technologies (RCTs) are increasingly being adopted by farmers in the rice and wheat belt of the IGP, specifically because they require less labor, water, and natural resources (Gupta and Sayre, 2007). Input water savings of 35%–57% have been reported for DSR sown into non-puddled soil, as compared to PTR with continuously flooded paddies (Sharma et al. 2003; Singh et al. 2003).

3.1 Laser land levelling

Laser land levelling is the most important first step in DSR. Precision land levelling helps germination and reduces the mortality of young tender rice seedlings due to uneven distribution of water during an irrigation event. Laser land levelling improves crop establishment and also enables the farmer to apply uniform irrigation, leading to improved weed control and nutrient-use efficiencies.

3.2 Sowing time

DSR should start about 10-12 days before the historical onset of the monsoon. Direct seeding after the onset of the monsoon is difficult due to problems related to machinery field access in wet soil conditions. Under such conditions, there are also problems with depth control of the drills/planters, clogged seed tubes, and other issues that result in poor crop establishment. Direct seeding of rice during the optimal time saves water and energy.

3.3 Seed rate, seed depth, and machinery:

Good cultivars, proper seed placement, and water management are the key factors needed for good crop establishment. The cultivars with medium fine grain, seed rates of 15-20 kg/ha are optimum planters that have precise seed-metering systems. Suitable cultivars for DSR in Punjab include PAU 201, Arize 6129, and Pusa 1121. High seed rate (i.e., more than 20 kg seed per hectare) increases the chance of lodging, increases N deficiency, and affects tillering of the rice plant. Seed priming can improve germination because the seed is sown in dry conditions, especially at lower seed rates; fluted roller mechanisms are not ideally suited for DSR because they often damage the rice seed coat and do not maintain adequate plant spacing within the row. Direct seeding of rice requires perfect machinery for seeding in non-puddled fields. Seed depth plays a pivotal role in early germination and the emergence of seedlings in the DSR system. The seed depth should be approximately 2.5 cm; too deep or too shallow placement of seeds adversely affects the dynamics of seedling emergence. Seed depth can be adjusted with the depth control wheels fitted to most drills/planters. Planking after seeding can also create better seed-soil contact, which is especially important when seeding is done after pre-sowing irrigation in the absence of rain.

3.4 Irrigation management

Pre-sowing irrigation depends upon the soil moisture conditions of the field. Pre-sowing irrigation controls the weed establishment and enhances seed germination and early growth. In Punjab, rice is generally transplanted in June–July during dry spells, when soil moisture losses are higher due to annual high evaporation, so irrigation becomes necessary after planting, so that there is good emergence. Vigorous early growth of rice crops before the arrival of the monsoon rains reduces seeding mortality due to submergence and, by hastening crop development, makes it easier to ensure timely planting of succeeding crops after the rice harvest. Puddled fields
show soil cracking behavior very early if adequate water levels are not maintained in the field, whereas DSR soils generally do not crack as substantially on drying. From the perspective of water stress, rice does not require continuous submergence across the growing season, but any attempt to reduce irrigation should not be at the cost of yield penalty. Therefore, water stress must be avoided two weeks after seedling emergence at tiller, panicle initiation, and flowering growth stages. The practice of intermittent flooding after the disappearance of ponded water has been suggested.

3.5 Weed control

Weeds are a major concern for high productivity of the DSR. Effective weed management in DSR depends on several factors including the timeliness of the control operations during the early crop growth stages and, in some cases, good control in preceding crops. Integrated approaches to weed management combine multiple tactics and knowledge of site-specific field conditions are essential to increase the efficacy and sustainability of weed control. Individual tactics for weed management in DSR are described below. The focus of weed management should ideally combine agronomic practices that increase crop competitiveness with the judicious use of chemical and other methods of direct weed control.

3.5.1 Cultural weed control methods

These include stale seed bed, surface mulch and cover crop and brown manuring.

3.5.2 Chemical weed control

The chemical weed control method is an excellent way to control weeds. The right herbicide for DSR depends on the weed flora present in a given field; individual herbicides have strengths and also weaknesses. Rotational use of herbicides with different modes of action is also desirable to check the possible development of herbicide-tolerant or herbicide-resistant weed biotypes. The control efficacy of herbicides is also contingent on the use of proper spray techniques. For example, it is better to use flat fan nozzles in combination with multiple nozzle booms to achieve spray uniformity across the field. Guidelines on the use of chemical molecules for efficient weed management in DSR are described below:

- Pre-sowing herbicide e.g., (i) Glyphosate (1 kg a.i/ha mixed with 500 L water, (ii) Paraquat (0.5 kg a.i/ha mixed with 400 L water.
- Pre-emergence herbicides e.g., (i) Pendimethlin (Stomp) 1 kg a.i/ha, (ii) Pyrazosulfuron 20 g a.i/ha
- Post-emergence herbicides e.g., (i) Bispyrabac (Nominee gold) 25 g a.i/ha (ii) 2-4 D 500 g a.i/ha and Fenoxaprop (Whip super) 60 g a.i/ha

4. Results and discussion

4.1. Farmers’ field data

4.1.1 Rice yield

Last year, more than 200 hectares of land were under DSR in the Punjab state. DSR trials were conducted with farmer participatory mode in different districts. Physical and chemical characteristics of soils vary from district to district in Punjab. The main objective of the CSISA project is to develop technologies that increase food security, reduce water scarcity, promote sustainable agriculture, and improve the productivity and profitability of the farming system. Direct seeding of rice offers benefits over PTR through reductions in production costs and methane emissions, and by preserving soil and water. The performance of DSR under different conditions is

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Variety</th>
<th>DSR (kg/ha)</th>
<th>PTR (q/ha)</th>
<th>DSR (kg/ha)</th>
<th>PTR (kg/ha)</th>
<th>Yield Gain/loss in DSR over PTR (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pusa-44</td>
<td>3,000</td>
<td>3,100</td>
<td>7,500</td>
<td>7,750</td>
<td>-250</td>
</tr>
<tr>
<td>2</td>
<td>Arize-6129</td>
<td>2,910</td>
<td>2,800</td>
<td>7,275</td>
<td>7,000</td>
<td>+275</td>
</tr>
<tr>
<td>3*</td>
<td>Pusa-11121</td>
<td>1,700</td>
<td>2,800</td>
<td>4,250</td>
<td>7,000</td>
<td>-2,750</td>
</tr>
<tr>
<td>4</td>
<td>Syngenta-3325</td>
<td>1,900</td>
<td>2,200</td>
<td>4,750</td>
<td>5,500</td>
<td>-750</td>
</tr>
<tr>
<td>5</td>
<td>Mota</td>
<td>2,200</td>
<td>2,200</td>
<td>5,500</td>
<td>5,500</td>
<td>----</td>
</tr>
<tr>
<td>6</td>
<td>Mota</td>
<td>2,100</td>
<td>2,200</td>
<td>5,250</td>
<td>5,500</td>
<td>-250</td>
</tr>
<tr>
<td>7*</td>
<td>Pusa-11121</td>
<td>1,500</td>
<td>2,100</td>
<td>3,750</td>
<td>5,250</td>
<td>-1,500</td>
</tr>
<tr>
<td>8</td>
<td>Pusa-11121</td>
<td>1,950</td>
<td>2,100</td>
<td>4,875</td>
<td>5,250</td>
<td>-375</td>
</tr>
<tr>
<td>9*</td>
<td>Pusa-11121</td>
<td>1,500</td>
<td>1,800</td>
<td>3,750</td>
<td>4,500</td>
<td>-750</td>
</tr>
<tr>
<td>10</td>
<td>Pusa-11121</td>
<td>2,100</td>
<td>2,300</td>
<td>5,250</td>
<td>5,750</td>
<td>-500</td>
</tr>
</tbody>
</table>

* Intercropping of direct-seeded rice in poplar

DSR = direct seeded rice; PTR = puddled transplanted rice.
given in Table 1, during kharif, 2009. The results of DSR show that rice yields under DSR are not higher than PTR. Rather DSR yields are on par or less than PTR, but the production cost is less for DSR and it is more sustainable as compared to PTR. An additional benefit of DSR is that rice can be grown in poplar plantations for the first two years as additional crops, because there is no need for puddling in DSR. In Table 1, some data are presented from poplar fields; the yield is less than PTR but there are extra crops in poplar fields. The yield of DSR in some fields is less due to improper seed germination (seed depth) and lack of weed control.

Similar work on DSR was also conducted in the neighboring state of Haryana by CSISA. In Haryana DSR was done at five districts with the following varieties: CSR-30, Pusa-1121, and Arize 6129 (Hybrid). CSR-30 performed very well in Haryana and yield gain was more in DSR as compared to PTR and gain in income under DSR over PTR was $180 USD/ha. For Pusa 1121, the yield was a little bit less under DSR, but the financial gain was $128 USD/ha under DSR due to reduced costs. The gain in income under DSR over PTR was $237 USD/ha in different hybrids. These trials were under farmer participatory mode across five districts of Haryana. The saving of irrigation water under DSR over PTR was 35-40%/ha. In addition to the effects of climate change, agriculture is confronted with other rapid socioeconomic changes that result in labor shortages, rising energy costs, and so on. Thus, DSR is the most important soil-conserving step in the rice-growing states.

### 4.1.2 Cost of production

The economics of different crop establishment methods were calculated with the following price parameters presented in Table 2:

- Sale price of paddy = USD $24/q;
- Savings due to no puddling in DSR = USD $44;
- Labor savings under DSR = USD $138/ha;
- Savings stemming from not raising a nursery under DSR = USD $34/ha;
- Additional cost of herbicides and extra manual weeding under DSR = USD $78;
- Savings for total cultivation costs under DSR = USD $138/ha.

In puddled transplanted rice, labor shortages for transplanting are becoming a major problem which may affect the timely transplanting and maintenance of optimum plants, considered key factors to harvest optimum yield. Puddling in flooded fields increases the cost of production, increases fuel consumption, and deteriorates the soil’s physical and chemical quality.

### 4.1.3 Weed flora

In DSR, the field is prepared without flooding and puddling, and this is followed by a change in the weed flora. This is the main problem in DSR; weeds suppress the germination of rice and compete with it. Different types of weeds are presented in Table 3, but these weeds are manageable by proper herbicides applied at the proper time.

### 4.1.4 Water savings

This study focuses on the improvement and evaluation of sustainable practices for increased crop production and the conservation of natural resources in Punjab. Traditionally, rice is transplanted after

### Table 2. Effect of different crop establishment methods on grain yield of rice in Punjab

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grain yield (q/ha)</th>
<th>Gain/ loss in DSR over PTR (USD/ha)</th>
<th>Saving in cost of cultivation (USD/ha)</th>
<th>Total gains/ loss (USD/ha)</th>
<th>Water saving DSR over PTR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSR</td>
<td>72.5</td>
<td>+60</td>
<td>138</td>
<td>198</td>
<td>35</td>
</tr>
<tr>
<td>PTR</td>
<td>70.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DSR = direct seeded rice; PTR = puddled transplanted rice

### Table 3. Weed spectrum in direct seeding rice in the Indo-Gangetic Plains

<table>
<thead>
<tr>
<th>Botanical Name</th>
<th>Local Name</th>
<th>Type</th>
<th>Herbicides</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Leptachloa chinensis</em></td>
<td>Red sprangletop</td>
<td>Grassy weed</td>
<td>Pyrazosulfuron and Fenoxaprop</td>
</tr>
<tr>
<td><em>Cynodon dactylon</em></td>
<td>Doob</td>
<td>Grassy weed</td>
<td>Glyphosate and Fenoxaprop</td>
</tr>
<tr>
<td><em>D. aegyptium</em></td>
<td>Makra</td>
<td>Grassy weed</td>
<td>Fenoxaprop</td>
</tr>
<tr>
<td><em>Echinochloa crusgalli</em></td>
<td>Swank</td>
<td>Grassy weed</td>
<td>Bispyribac (Nominee gold)</td>
</tr>
<tr>
<td><em>Cyperus rotundus</em></td>
<td>Motha</td>
<td>Sedge</td>
<td>Glyphosate</td>
</tr>
<tr>
<td><em>Cyperus compressus</em></td>
<td>Motha</td>
<td>Sedge</td>
<td>Pyrazosulfuron</td>
</tr>
<tr>
<td><em>Caesalia axillaris</em></td>
<td>Grhilla</td>
<td>Broad leaf</td>
<td>Bispypribac</td>
</tr>
<tr>
<td><em>Sphenoclea zeylanica</em></td>
<td>Sanni</td>
<td>Broad leaf</td>
<td>Bispypribac</td>
</tr>
<tr>
<td><em>Eclipta alba</em></td>
<td>Jalbangra</td>
<td>Broad leaf</td>
<td>Pyrazosulfuron</td>
</tr>
</tbody>
</table>
puddling and wheat is sown after pulverizing the soil. This reflects an edaphic conflict in traditional soil management for rice and its consequent harmful effects on the soil environment for the succeeding wheat, and other upland crops. After three decades of intensive farming, however, the productivity and sustainability of this system are deteriorating (Byerlee et al. 2003; Ladha et al. 2003; Pathak et al. 2003). Total seasonal water input to rice fields is up to two or three times more than for other cereals (Tuong et al. 2005). NH$_3$ volatilization from the application of urea fertilizer is the major pathway of N loss in flooded rice systems, often causing losses of 50% or more of the applied urea N in tropical transplanted rice (Buresh and De Datta, 1990). Water for agriculture is becoming increasingly scarce, which is another challenge for rice production (Rijsberman, 2006). Tuong and Bouman (2003) estimated that, by 2025, 15–20 million ha of irrigated rice will suffer some degree of water scarcity. Overexploitation of groundwater during the last decades has caused serious problems in northern China and South Asia (Postel, 1997; Singh, 2000), affecting rice–wheat growing areas. Groundwater tables have dropped on average by 1–3 m year$^{-1}$ in the North China Plain; by 0.5–0.7 m year$^{-1}$ in the Indian states of Punjab, Haryana, Rajasthan, Maharashtra, and Karnataka. In a field experiment in the central Philippines, direct seeding reduced CH$_4$ emissions by approximately 18% as compared to transplanting (Corton et al. 2000). The rate of water-table decline is as high as 100 cm per annum or even more; with the consequence that sustainability of rice cultivation is at risk. Global water scarcity, and especially scarcity of agricultural water (Vörösmarty et al. 2000) will result in water stresses occurring more frequently (Anon., 2000), but should also favor the development of water-saving irrigation technologies, including direct-seeding methods (Bhuiyan et al. 1995; Bhuiyan et al. 1998), as well as land-levelling technologies, and intermittent irrigation.

4.1.5. Can rice cultivation be like wheat cultivation?
Direct-seeded rice removes puddling and the drudgery of transplanting the young rice seedlings provides an option to resolve the edaphic conflict and enhance the sustainability of rice and wheat cropping systems. On the one hand, shortage of agricultural labor (Pingali and Hossain, 1998) favors the adoption of direct-seeding technologies, in replacement of traditional, labor-intensive transplanting (De Datta, 1986; Olofsdotter et al. 1998). In addition to reducing fuel and labor costs, these conservation tillage systems may reduce soil erosion, improve soil physical and chemical properties and conserve soil moisture (e.g., Chauhan et al. 2006a).

5. Conclusions and future perspectives
Punjab is the most productive state of India. Increasing pressure on land, water, and labor resources threaten the sustainability of the rice production base. The availability of soil water is the most important limitation to productivity in the semi-arid area of Punjab. Direct-seeded rice holds an enormous potential for rice and wheat systems by making them less resource-intensive and more sustainable. Soil structure is a key factor in soil functioning and evaluation of the sustainability of crop production systems. As such, DSR is one alternative to puddled-transplanted rice, which saves soil structure, reduces water consumption, and reduces methane emissions. Apart from resulting in substantial reductions in water consumption, direct seeding also results in significant cost reductions of about USD $138/ha for the farmer. The critical success factors for direct seeding are proper seed germination, management of micronutrient deficiency, along with management and control of weeds. In order to save water and labor, and promote conservation agriculture, with zero- and/or reduced tillage, it is absolutely essential to replace puddled transplanting with direct seeding. Direct seeding with minimum tillage has been shown to improve the soil quality, and support the rice and wheat systems. The identification of pre-and post-emergence herbicide molecules has opened the window for practicing CA in irrigated rice–wheat systems.

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References


Chapter 7. Intercropping in sugarcane for resource conservation

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Abstract

The productivity and profitability of sugarcane based cropping systems in the northern Indo-Gangetic Plains (IGP) must be improved. The planting time of sugarcane must be optimized in this rice-wheat dominated area as 30-40% of sugarcane is planted after harvest of the wheat crops. It is important to intensify the sugarcane-based systems through intercropping practices, by using furrow irrigated raised bed systems (FIRBS). Sequential planting of sugarcane and wheat was compared with simultaneous planting of autumn sugarcane and wheat in FIRBS in Yamuna Nagar, from 2004-2005 to 2009-2010. The yield of sugarcane was higher (18.5t/ha) in the sugarcane and wheat intercropping system, compared to sequential planting of wheat-sugarcane. The sugarcane and wheat-ratoon-wheat cropping system gave more returns (USD $1,295/ha) than the wheat-sugarcane-ratoon-wheat cropping sequence. Maximum net returns (USD $5,744.2/ha) were obtained from the sugarcane and garlic intercropping system; whereas only sugarcane gave minimum returns of USD $4,244.7/ha.

Keywords: autumn intercropping, sugarcane equivalent yield, natural resources, economic gain

1. Introduction

1.1. Sugarcane production

Sugarcane (Saccharum officinarum L.) is a very important cash crop which plays a major role in the Indian agricultural economy. Sugarcane is cultivated on an area of 5.04 million hectares (Mha) with sugar production of 26.4 M tons and productivity is 6.75 t/ha. In Haryana, sugarcane is grown on a 0.12 Mha area and average productivity is 70 tones per hectare. The sugarcane growing districts, Yamuna Nagar, Kurukshetra, Ambala, and Karnal, contribute 60% of sugarcane production in Haryana. The limited growth period is the main reason for low productivity of sugarcane in the northern states. The late planting of sugarcane has been practiced in western Uttar Pradesh. Farmers in Haryana have adopted this practice out of convenience rather than it being a good agronomic practice. This practice also uses excess water for the establishment of the sugarcane crop. This loss in the productivity of sugarcane in Haryana is definitely associated with late planting.

Sugarcane planted after wheat has to face an unfavorable season and a limited period for vegetative growth and cane development. This area should be weaned away in favor of autumn planting. The farmer does so because he is not ready to sacrifice the wheat crop. His concern can be adequately addressed by taking wheat as an intercrop in the autumn planted sugarcane. Autumn planting of sugarcane and wheat, and sowing at the end of October will be beneficial for the crops, as both crops will get sufficient time for growth and development. Ladha (2003) has reported adverse effect on grain yield of wheat when sown after 15-20 November.

Intercropping has a chance to be a successful practice even with spring planted sugarcane. The catch/zaid and moong/mash crops planted during the summer are the best fit that ensures resource conservation, cost recovery through additional income, and even fewer weed problems. As part of the conservation agriculture (CA) strategy, sugarcane (which uses excess water in the hot months of May and June) may be avoided, and this space can be filled up with summer moong. The inclusion of moong in the summer can also help in displacing summer rice. In some parts of Yamuna Nagar the mash crop (Vigna mungo) can be introduced in summer. These crops can serve the purpose of cover crops, in addition to being green manure. A good cover can help to reduce the recruitment of weed seed banks in the long run. The advantage of green manure will be an addition to the grain yield advantage of such crops. The Krishi Vigyan Kendra (KVJ) system has evolved and accelerated this practice in rice-wheat cropping systems.
The optimization of planting time in sugarcane has to be an integral part of the varietal balancing exercise. To ensure the availability of cane to the sugar mills for at least six months, the area should be equally divided among early-, mid-, and late-season varieties. There is a contradiction in the industry’s priorities and farmer preferences. The mills vie for early varieties due to better recovery and early beginning of the crushing season. These varieties have a comparatively smaller yield in terms of cane yield and are also prone to insect-pests and disease complexes. But farmers strongly favor late varieties due to their high tonnage and high degree of tolerance to insect-pests. However, the mills are reluctant to purchase them due to poor recovery on account of high fiber content. The price policy of sugarcane is designed in a way to encourage the early varieties, often procured at premium prices. Intensification of the sugarcane based cropping systems through intercrops and resource conservation, therefore, has the potential to address the above discussed issues and contradictions.

The furrow irrigated raised bed system (FIRBS) has been rated as one of the potential technologies that could lead to major water savings in all cropping systems. These technologies have been successfully demonstrated in sole crops. This practice has also been proposed as a means of increasing the productivity, profitability, and sustainability of rice-wheat in the Indo-Gangetic Plains (IGP). However, farmers did not accept bed planting in sole crops mainly because profitability in the sole crops could not be established on a regular basis. The hypothesis that bed planting would save water was further enhanced by exploring the virtues of the technology in intercropping systems in sugarcane based cropping systems.

Bed planting is an agronomic intervention where intercrops are sown on beds. The setts of sugarcane are placed end to end in the furrows. The setts are immediately covered with a thin mass of soil (1 inch) through a locally designed Pyramid shaped raker, then, light irrigation is given in the furrows of the FIRBS. The exercise focused on sugarcane and wheat as the majority of the farmers have a general preference for the wheat crop during the rabi season.

1.2. Objectives
1. To investigate the benefit of sugarcane and wheat intercropping systems compared to sequential planting of wheat-sugarcane.
2. To focus on intercropping-based strategies for increasing the productivity and profitability from sugarcane based intercropping systems while saving water and other natural resources based on bed planting.
3. To encourage multiple land use to sustain the advantages of bed planting.
4. To calculate the economics of different intercropping systems.

2. Materials and methods
2.1. Experimental site
A large un-replicated block of field trials was conducted at multiple locations in the Yamuna Nagar district (Haryana) from 2004-2005 to 2009-2010. The soil at the experimental sites was sandy loam in texture, low in available N, low to medium in available P and medium in available K. The trials had only two treatments. One treatment was the sequential planting of sugarcane and wheat. The second treatment was simultaneous planting of autumn sugarcane in furrows and wheat on beds. Wheat sowing in the first treatment was done in the second week of November and planting of sugarcane was done in the last week of April to the first week of May. In the second treatment, sowing of both the crops was done simultaneously in the last week of October to the first week of November, with the help of a bed planter. The sugarcane was planted in furrows at a spacing of 90 cm and three rows of wheat were sown on beds. One pre-sowing irrigation was given in the treatment, where both the crops were grown simultaneously, while two pre-sowing irrigations were given where two crops were grown sequentially. The number of tillage operations ranged from 5 to 6 in treatment II, while in treatment I there were 10 to 12 tillage operations. Fertilizer application was the same in both the treatments. Data was reported as the sugarcane equivalent yield for two years. Other possible intercrops like raya, garlic, onion, and potato were also grown as intercrops in autumn sugarcane. All the recommended packages and practices were followed for sugarcane and intercrops. The economics of all the intercropping systems has been calculated.

3. Results
The yield of wheat was at par in the sugarcane and wheat (Fig 1) and wheat-sugarcane treatments. The yield of sugarcane (plant crop) was higher when planted simultaneously in intercropping systems, compared to sequential planting in the wheat-sugarcane rotation. Based on the average of six years, the sugarcane yield was 18,500 kg/ha higher in the intercropping system than in the sequential planting
of sugarcane in the wheat-sugarcane rotation (Table 1). The yield of sugarcane ratoon and the subsequent crop of wheat was also at par in both the systems. The results showed the mean of sugarcane crops to be the equivalent yield gain of 21,580 kg/ha in sugarcane and wheat-ratoon-wheat compared to wheat-sugarcane-ratoon-wheat cropping sequences. Economic gain calculated at a sugarcane price of USD 60/t was USD 1,295/ha in two year cropping sequences, consequently conserving the natural resources on account of bed planting and sugarcane vis-à-vis the rice-wheat cropping system.

The economics of different intercropping systems (presented in Table 2) clearly show the advantage of intercropping systems over the sole cropping of

![Figure 1. Intercropping of sugarcane with wheat in Yamuna Nagar, Haryana.](image-url)

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Yield (kg/ha)</th>
<th>Sugarcane Equivalent Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sugarcane</td>
<td>Wheat</td>
</tr>
<tr>
<td>2004-2005 to 2006-2007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sugarcane+wheat - ratoon -wheat</td>
<td>90,000</td>
<td>4,300</td>
</tr>
<tr>
<td>wheat -sugarcane-ratoon -wheat</td>
<td>75,000</td>
<td>4,400</td>
</tr>
<tr>
<td>2005-2006 to 2007-2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sugarcane+wheat - ratoon -wheat</td>
<td>99,500</td>
<td>4,500</td>
</tr>
<tr>
<td>wheat -sugarcane-ratoon -wheat</td>
<td>77,500</td>
<td>4,500</td>
</tr>
<tr>
<td>2006-2007 to 2008-09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sugarcane+wheat - ratoon -wheat</td>
<td>97,000</td>
<td>4,550</td>
</tr>
<tr>
<td>wheat -sugarcane-ratoon -wheat</td>
<td>73,000</td>
<td>4,620</td>
</tr>
<tr>
<td>2007-2008 to 2009-2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sugarcane+wheat - ratoon -wheat</td>
<td>95,000</td>
<td>4,750</td>
</tr>
<tr>
<td>wheat -sugarcane-ratoon -wheat</td>
<td>75,000</td>
<td>4,850</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. The economics of the sugarcane based intercropping system.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercropping system</td>
</tr>
<tr>
<td>---------------------------------------</td>
</tr>
<tr>
<td>sugarcane+garlic</td>
</tr>
<tr>
<td>sugarcane+onion</td>
</tr>
<tr>
<td>sugarcane+potato</td>
</tr>
<tr>
<td>sugarcane+wheat</td>
</tr>
<tr>
<td>sugarcane+raya</td>
</tr>
<tr>
<td>sugarcane sole</td>
</tr>
</tbody>
</table>
Among different intercropping systems, sugarcane and garlic (Fig. 2) gave maximum net return of USD $5,744.2 per ha, followed by sugarcane and onion (USD $5,702 per ha). The net returns obtained from sugarcane and vegetables depend on prevailing market prices. Net returns obtained from sugarcane and wheat crops were USD $4,866.6 per ha which were higher than the sole cropping of sugarcane (USD $4,244.7).

4. Discussion

4.1. Intercropping of autumn sugarcane

The intercropping of autumn sugarcane with wheat recorded higher sugarcane equivalent yields and better economic gains than wheat grown in winter followed by planting sugarcane. The positive effect on sugarcane yield might be attributed to longer growth periods. The intercrops of wheat emerge, as usual, within a week, whereas the emergence of sugarcane commences two to three weeks after planting. Sugarcane crops remain dormant during the winter months and offer no competition during the grand growth period of wheat. This crop offers no competition during wheat maturity because of its slow growth behavior up to wheat harvest. Even the mechanical harvesting of wheat is not affected by sugarcane, which starts its re-growth from the end of March. Sugarcane itself is widely spaced and very slow-growing during the winter period, and poses no competition for the wheat crop. Both crops grow in a complementary manner. It is possible to get the potential yield of the wheat crop with no significant effect on the cane yield. Moreover, the intercropping of wheat with sugarcane will be helpful in the longevity of the crop period. The longevity of the sugarcane crop period by autumn planting translates into yield gains and the early maturity of the cane in the case of autumn planting is always welcomed by the sugar industry, which ensures a longer crushing period. This intercropping system will be helpful in discouraging the late (May) planting of sugarcane. The sugarcane and wheat is planted in the FIRBS which ensures the uniform germination of both the crops. Ultimately, the better yield in the FIRBS here or in any crop situation saves water and ensures a proper moisture regime to the crop. This is a kind of resource-conservation technology (RCT) permitted in one or the other system. However, the field should be laser-leveled prior to the adoption of the FIRBS. This makes management easy by reducing the infiltration opportunity time and ensures quick flow in the furrows with no chance of water stagnation.

The sugarcane crop is planted at a wider spacing of 90-105 cm, and remains dormant during the winter months, thus posing no competition during the grand growth period of crops grown as intercrops. Because of this, any vegetable crop that fits in the system can be taken up. In the six years of the study, vegetable based intercropping systems were found more profitable, sugarcane and garlic being the highest, followed by sugarcane and onion, as well as sugarcane and potato. Jat et al., (2006) also reported higher returns from the intercropping of vegetables with maize compared with the sole crop of maize. The contribution of the vegetable component is responsible for a certain edge over the sugarcane and wheat. Despite the favorable economics, we must not underestimate the fact that vegetables are perishable commodities and often exhibit wild price fluctuations. Consistent with the general inflation

Figure 2. Intercropping of sugarcane with garlic in Yamuna Nagar, Haryana.
in the economy during the last three years, all horticultural crops showed price increases with a reasonable degree of stability. The sustainability of this price trend may be a problem in the future. So, this economic trend needs to be analyzed with caution. Wheat is our principal food crop. Keeping in view of the global trends and food availability within the country, wheat prices are most likely to increase in the coming years. Therefore, sugarcane and wheat may be a good option. Any piece of technology can generate tangible benefits if adopted at a certain volume. Even marginal increases in widespread technology may contribute much more to the economy of the farmer and the country, rather than a technology with handsome returns but restricted to few people. There is a limit to horizontal expansion of vegetable based intercropping systems. But there is no restriction as far as wheat is concerned. The saturation in sugarcane and wheat cropping systems, if it comes at all, will be because of sugarcane. There is no chance of landing in crisis even if every acre of autumn planted sugarcane is intercropped with wheat. Even though the sugarcane and wheat intercropping had slightly lower yields than the other treatments during the three successive years, it would be worthwhile to pursue it as the most viable options for the farmers.

Labor for agricultural purposes is a constraint in industrial hubs. The state of Haryana is witnessing an industrial revolution. All agrarian work is dependent on the migratory workforce from Bihar and adjoining states. The vegetable based intercropping systems are labor intensive. These are good options for employment generation in case there is surplus manpower. But the costly labor and restricted availability can create logistical problems, such as timely operations not being done, meaning a loss of production and profit margin. This issue has relevance in any plan of horizontal expansion of these crops. Conversely, there is no such problem in sugarcane and wheat intercropping systems. Moreover, the technology has flexibility. If sugarcane planting is not possible in the month of October-November, it can be safely done in January-February as the furrows are clear for sett placement. This system is equally good in productivity. Hence, under the circumstances sugarcane and wheat intercropping systems will be tagged options in the pursuit of multiple land use systems.

4.2 Intercropping in spring sugarcane

In spring, planted cane intercropping of legume crops, like moong and mash, may be good options to pursue. Two rows of short duration moong or mash may be sown between two rows of sugarcane in the FIRBS. This system will be helpful in sustaining the soil health, besides providing additional income from the intercrop.

In the Allahar village of the Yamuna Nagar district May planting of sugarcane was done until now. Recently, over 50 demonstrations were planted, which proved to be a worthwhile intervention. The yield of wheat raised on beds was at par with the yield obtained in the case of sole crop of wheat. Simultaneously, an increase in the yield by 22,200 kg per ha was recorded for sugarcane. This is a paradigm shift as sugarcane and wheat can be grown together with no yield penalty to wheat or sugarcane. That is how we can make multiple uses of land, especially when we introduce, garlic, wheat, and raya.

An impact analysis revealed that the area under May-planted sugarcane had gone down from 80 ha to nil. The technology found peripheral expansion in hinterlands. An additional 126 ha were brought to autumn planting under FIRBS that was supposed to be planted in the month of May.

The results of trials on autumn sugarcane and wheat conducted at farmers’ field in the Kurukshetra district reveals that the sowing of sugarcane in the last week of October to the first week of November registered 87-100 tons of cane yield (Kamboj et al. 2008). The yield of wheat sown as an intercrop ranged from 4.5 to 5.5 t/ha which was as good as the yield obtained from the sole crop of wheat. Sugarcane and onion intercropping systems gave a cane yield of 105 t/ha (2004-2005), 87.5 t/ha (2006-2007) and the onion yield obtained was 27.5 t/ha and 35 t/ha during 2004-2005 and 2006-2007, respectively.

![Figure 3. Sugarcane yield of trials conducted in the three villages during 2006-2007 in the Jind district.](image-url)
The sugarcane equivalent yield obtained was much higher than the sole crop of sugarcane in the Jind district. The results of the trials conducted in the three villages during 2006-2007 in the Jind district (Fig. 3) revealed that maximum sugarcane equivalent yield was obtained from sugarcane and onion (139.4 t/ha) followed by sugarcane and wheat (106 t/ha), sugarcane and raya (102.1 t/ha), and a minimum yield of 82.5 t/ha was obtained from sole sugarcane planted in autumn (Kamboj et al. 2008).

5. Lessons learned
Farmers must be a part of the planning and implementation process in deciding the evolution and acceleration of technologies. We must articulate and identify opportunities for enhancing the applicability of those technologies that increase both the productivity and the conservation of resources at the same time. That is why bed planting was accepted after value addition and covering risk through intercropping which was not possible in a sole crop.

6. Impact
The intercropping of wheat with sugarcane through bed planting was well accepted by the farmers in the district of Yamuna Nagar, and in the other sugarcane-growing districts of Haryana and the adjoining states of Punjab and Uttar Pradesh. The area under this RCT in Yamuna Nagar district during the current year has been estimated as 2,500 ha, and it will likely exceed 5,000 ha in the next year. The area under May planting of sugarcane has gone down.

7. Conclusions
The sugarcane crop planted in autumn with wheat and vegetable crops will improve the tonnage and quality of the cane, help in advancing the crushing season of the sugar mills, generate additional returns from intercrops, and grant extra income for the farmers. Bed planting techniques have made the system feasible, economically viable and proved helpful in water saving, minimizing the yield gaps in cane yield besides providing additional income from wheat as an intercrop. The most important thing is that wheat could be retained as a rabi crop in the system.

8. Limitations
- Chemical weed control sometimes becomes a problem. Atrazine is the recommended herbicide for sugarcane, but it is fatal to wheat.
- Depth of sowing should be maintained for intercrops to have optimum crop stand.

9. Future strategy
The multiple land use system of the autumn planted sugarcane can ensure economic advantages and resource conservation. The objective is to eliminate the May planting of sugarcane and ensure at least 50% of the sugarcane area in autumn planting is with wheat as an intercrop in the next five years. This strategy is compatible with the objective of the food security mission. Intercropping in autumn sugarcane with vegetable crops will be popularized depending on the availability of labor and other resources. The FIRBS technology will be integrated with laser leveling for better acceptability among farmers.

Acknowledgements
Special acknowledgement is given to the Cereal System Initiative for South Asia who sponsored Baldev Raj for the conservation agriculture training course in Mexico, and thanks in particular to Dr. Raj K. Gupta and M.L. Jat for sponsoring my name for CA training and supporting me in conducting the research. We thank Dr. Ken Sayre and Dr. Bram Goeraerts for their important suggestions regarding conservation agriculture. I am highly thankful to the Vice-Chancellor and Director of Extension Education and the Chaudhary Charan Singh Haryana Agricultural University, Hisar for financial help and cooperation in conducting present trials.

References
Chapter 8. Conservation agriculture: Strategies for long-term weed management in the eastern Indo-Gangetic Plains of India


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Abstract

Conservation agriculture (CA) can work to sustain the productivity of cropping systems in India. The principles of CA are minimum soil disturbance, keeping a permanent soil cover combined with adequate crop diversification or rotation. This paper will discuss how these principles are helpful for managing the diverse weed flora in different cropping systems and future management strategies. The implementation of permanent zero tillage could reduce the weed seed bank as compared to disturbed soils, and less weeds could emerge in the succeeding year. Residue retention, or the inclusion of cover crops, like sesbania, cowpea, and mungbean, has added the advantage of weed control under zero tillage. Crop residue and cover crops reduce weed germination and emergence by altering the soil temperature, release of phytotoxins, soil pH and sunlight (intensity and quality), and by increasing the population of beneficial insects that consume weed seeds. Cover crops suppress the weed growth by competing for common growth factors (water, nutrients, sunlight, etc.).

Crop rotations effectively manage parasitic weeds and crop associated weeds, and facilitate the use of a wide range of herbicides in different cropping systems. Intercropping of leguminous and graminous grain crops and mixed cropping of these fodder crops produced more biomass, less weed problems, and improved soil fertility. Employing the combinations of these CA principles can reduce the entire reliance on herbicides and can delay the development of herbicide resistance.

Keywords: Direct-seeded rice, legumes, brown manuring, mulching, crop establishment methods

1. Introduction

In recent years, most of the nations across the world, particularly developing countries, have confronted problems related to maintaining sustained growth in food production to achieve food security. This was done while trying to avoid ecological degradation due to the overexploitation of natural resources, so that the rightful natural heritage of future generations can be preserved. Similar to other parts of the world, India is depleting its natural resources day-by-day to provide adequate shelter, food, and other amenities to an ever increasing population.

The benefits of the Green Revolution in India were confined to the western Indo-Gangetic Plains (IGP), and improved productivity of the rice-wheat cropping systems. The eastern part of the IGP still lags behind the western IGP in productivity of major crops. In the eastern IGP, rice is an important crop during the summer (rainy) season since it is mostly grown in rain fed conditions. Frequent flooding and droughts lead to uncertainty of rainy season crops. Wheat, maize, and potato are the important crops in irrigated ecosystems, and pulses are grown on residual soil moisture during the winter season. Traditionally, rice is grown by transplanting 25-30 day old seedlings after puddling. Puddling is achieved through the extensive plowing of fields in standing water, which creates an impervious layer of 10–15 cm below the soil surface. The purpose of puddling is to reduce percolation losses, to control perennial weeds and to make transplanting operations easier. Wheat, maize, potatoes, and pulses are grown by using extensive tillage operations. The traditional systems of hand-transplanting, hand weeding, and plowing are based on the premise of cheap and readily available labor. The country is currently experiencing
an impressive phase of economic development, which has dramatically reduced the availability of farm labor, including that used for rice transplanting. There is rapid labor migration occurring from rural to urban areas due to the emergence of industries, etc. Weeds are the bottlenecks for crop production in the region, especially weed resistance and shifting of weed flora. In traditional systems, puddling was one of the options for weed management. Now there are options for weed management through the development of selective herbicides, and by implementing conservation agriculture (CA) techniques. This issue has attracted the attention of farmers as well as researchers. There is a need for renewed research efforts to develop cost-effective and resource-efficient sustainable technologies, which will improve productivity and production of major crops or cropping systems while conserving natural assets. CA based principles may be the solution for sustained productivity and weed issues.

The CA principles (maintaining permanent soil cover and promoting minimal mechanical disturbance of soil through zero tillage systems) will ensure a sufficient living and/or residual biomass cover that will enhance soil and water conservation and control soil erosion. This will also improve soil aggregation, soil biological activity and soil biodiversity, water quality, and increase soil carbon sequestration. Permanent soil cover is maintained during crop growth phases as well as during fallow periods, by using cover crops and maintaining residues on the surface. These practices reduce the requirements for pesticides and herbicides, control off-site pollution, and enhance biodiversity. Crop rotations and associations can be implemented in the form of crop sequences, relay cropping, and mixed crops (Dumanski et al. 2006). Careful integration of these principles with modern technologies and efficient crops/cultivars can be helpful in long-term management of diverse weed flora of cropping systems. The effect of CA principles (i.e., minimum soil disturbance, crop residues left on the soil, cover crops, crop rotations and intercropping) on weed dynamics is reviewed in this manuscript.

2. Major weed flora in different cropping systems

The soils of the eastern IGP are very fertile, have an acidic to alkaline pH, benefit from good average rainfall and are found in low lands and upland ecologies that favor diverse weed flora. Wheat crops are mainly affected by grasses and broad leaf weeds. Phalaris minor, Polypogon monspelieensis and Cynodon dactylon are grassy weeds, whereas Chenopodium album, Solonum, Physalis anagalis, Melilotus, Rumex, Fumeria, Vicea, Lathyrus, and Circium are common broad leaf weeds of the region. Rice crops become commonly infested with Echinochloa, Bracharia, Eragrostis, Panicum grasses, Physalis, Digera, Cucumis, Celosia, Caesalia broadleas and Cyperuru, Fimbrystylis sedges (Table 1). In direct-seeded rice (DSR), weeds like Cyperus rotundus, Leptochloa, Fimbrystylis, and Cynodon dactylon are most dominant. Cynodon dactylon is a major problem in permanent zero tillage fields in the eastern IGP. In wheat crops, Oldenlandia and Oxalis are the newly-shifting weeds of the region.

3. Conservation agriculture principles and weed dynamics

3.1 Minimum soil disturbance

3.1.1 Zero tillage

The diversity and density of weed floras are, in general, a reflection of the cropping system management practices. Tillage exposes deeper soil weed seed banks to the soil surface which favors weed germination as it facilitates light and aeration (Brenchley and Warington, 1933; Egley and Williams, 1990; Yenish et al. 1992). Tillage practices change the soil residue cover, which affects soil insulation, temperature, and pH, which are all important factors that determine weed germination (Mulugeta and Stoltenberg, 1997). The soil temperature, aeration and light intensity, combined with soil depth are favorable factors for weed germination. Weed species and density may also be affected in disturbed and undisturbed soil (Froud-Williams et al. 1983; Pollard and Cussans, 1981). Laursen and Haas (1971) suggest that cultivation greatly influences the abundance or scarcity of individual weed species, and they put forward that deeper cultivation increases the frequency of annual dicotyledonous species, but decreases the frequency of perennials.

Zero tillage (ZT) sowing of wheat drastically reduced the population of P. minor (Table 2) in comparison to conventionally-tilled plots (Malik et al. 1998; Hobbs et al. 1998; Malik et al. 2000a; Brar 2002; Singh et al. 2002; Yaduraju and Mishra, 2002; Sharma et al. 2004 and Jat, 2008). Malik et al. (1998) observed that ZT reduces 30-40% of P. minor infestations. They have also speculated that a reduction in P. minor under ZT was the result of minimum soil disturbance, because Phalaris seeds lying 4-5 cm below the ground could not germinate. Hobbs et al. (1998) also found ZT helpful in reducing P. minor infestations in wheat. Higher populations of P. minor at 50 days after sowing (DAS) in conventional tillage (CT) than ZT was found by Sirohi et al. (1999). In a study on the effects of
tillage practices on weeds, Jat (2008) found that ZT effectively reduced the *P. minor* density (Fig. 1), which was the most dominant weed in the complex weed flora of wheat. The higher density of *C. album*, *M. indica*, *A. arvensis*, and other broadleaf weeds in ZT, may be due to reduced inter weed competition (less *P. minor*).

Kuipers (1991), Christian and Bacon (1990) and Singh et al. (2001) found that relative density of grassy weeds increased with the advancement of crop growth, while that of non-grassy weeds were reduced in ZT. This might be due to the higher competitive ability of grassy weeds over non-grassy weeds. Prasad et al. (2002) also supported their findings and stated that more grassy weeds were found in ZT, whereas CT had a significantly higher amount of broadleaved weeds. In contrast to this, Singh et al. (2002), Sharma et al. (2004) and Jat (2008) observed an increased intensity of broadleaved weeds and a reduction in *P. minor* in ZT over CT. Yaduraju and Mishra (2002) reported that the grassy weed *P. minor* density was lower under ZT, while, other grassy weeds, *Avena sterilis* and *Avena*

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**Table 1. The weed spectrum in cropping systems of the eastern Indo-Gangetic Plains.**

<table>
<thead>
<tr>
<th>Botanical Name</th>
<th>Cropping Systems and Seasons</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Summer Season</td>
</tr>
<tr>
<td><strong>Grassy Weeds</strong></td>
<td></td>
</tr>
<tr>
<td>Brancheria reptans</td>
<td>M²-W, R³-W, M³-W</td>
</tr>
<tr>
<td>Cynodon dactylon</td>
<td>M²-W</td>
</tr>
<tr>
<td>Dactyloctynium aegyptium</td>
<td>M³-W</td>
</tr>
<tr>
<td>Digitaria ciliaris</td>
<td>M²-W, M³-P+M-M³-P</td>
</tr>
<tr>
<td>Echinochloa colonum</td>
<td>R²-W, M³-W</td>
</tr>
<tr>
<td>Eleusine indica</td>
<td>M⁴-W</td>
</tr>
<tr>
<td>Ergagostis tenella</td>
<td>R⁶-W/M</td>
</tr>
<tr>
<td>Panicum repens</td>
<td>R⁷-W/M</td>
</tr>
<tr>
<td>Phalaris minor</td>
<td>R-W⁴</td>
</tr>
<tr>
<td>Polypogon monspeliensis</td>
<td>R-W⁵</td>
</tr>
<tr>
<td><strong>Broad leaf weeds</strong></td>
<td></td>
</tr>
<tr>
<td>Anagallis arvensis</td>
<td>R-W⁵, M-W⁶, M-P-M³, M-P³</td>
</tr>
<tr>
<td>Cannabis sativa</td>
<td>R-W⁶, M-W⁶, M-P-M², M-P²</td>
</tr>
<tr>
<td>Celosia argentea</td>
<td>R²-W, M³-W, R⁸-L</td>
</tr>
<tr>
<td>Circium arvense</td>
<td>R-W⁶, M-W⁶, R-L⁴, F-L⁴</td>
</tr>
<tr>
<td>Caesulia axillaris</td>
<td>R⁰-W/M, M⁴-W</td>
</tr>
<tr>
<td>Chenopodium album</td>
<td></td>
</tr>
<tr>
<td>Commelina bengalensis</td>
<td>M²-W, R⁰-W/M,</td>
</tr>
<tr>
<td>Cucumis spp.</td>
<td>R⁰-W/M, M³-W</td>
</tr>
<tr>
<td>Digitaria arvensis</td>
<td>R³-W, M³-W, M⁴W</td>
</tr>
<tr>
<td>Eclipta alba</td>
<td>R⁰-W/M, M³-W</td>
</tr>
<tr>
<td>Euphorbia hirta</td>
<td>M³-W</td>
</tr>
<tr>
<td>Lathyrus aphaca</td>
<td>R-L³, F-L³</td>
</tr>
<tr>
<td>Launaea nudicaulis</td>
<td>R-W⁵, M-W⁶</td>
</tr>
<tr>
<td>Lindernia crustaceae</td>
<td></td>
</tr>
<tr>
<td>Mellotus indica</td>
<td>R-W⁶, M-W⁶</td>
</tr>
<tr>
<td>Phylanthus niruri</td>
<td>M²-W</td>
</tr>
<tr>
<td>Physalis minima</td>
<td>R²-W, R³-M</td>
</tr>
<tr>
<td>Parthenium hysterophorus</td>
<td>R-W⁶, M-W⁷</td>
</tr>
<tr>
<td>Solanum nigrum</td>
<td>R-W⁶, M-W⁶</td>
</tr>
<tr>
<td>Stellaria media</td>
<td>R-W</td>
</tr>
<tr>
<td>Viciasativa</td>
<td>R-L⁴, F-L⁴, R-W⁶</td>
</tr>
<tr>
<td>Vicia hispida</td>
<td>R-L³, F-L³</td>
</tr>
<tr>
<td>Oxalis corniculata</td>
<td>RW⁴</td>
</tr>
<tr>
<td><strong>Sedges</strong></td>
<td></td>
</tr>
<tr>
<td>Cyperus iria</td>
<td>R²-W/M, M³-W</td>
</tr>
<tr>
<td>Cyperus deformis</td>
<td>R²-W/M, M³-W</td>
</tr>
<tr>
<td>Cyperus rotundus</td>
<td>M²-W, R²-W/M, M³-P+M-M³-M³-M</td>
</tr>
<tr>
<td>Fimbristylis milicea</td>
<td>R³-W/M</td>
</tr>
</tbody>
</table>

R=rice; W=wheat; P=potato; M=maize; S=sorghum; PP=pigeonpea; L=lentil; F=Fallow; C=Chickpea
ludoviciana, had a lower density under CT. They also observed that the broadleaf weeds, C. album and M. hispida, had a lower density under ZT. Chancellor (1964) showed an increased emergence of Raphanus, Viola, and Ranunculus species and a decreased emergence of Sonchus and Taraxacum species after soil disturbance.

Mishra et al. (2005) observed a lower density of Physalis minima and C. album under ZT than CT and furrowed irrigated raised bed systems (FIRBS). Blecharczyk et al. (1999) reported that reduced tillage promotes the establishment of grassy weeds, such as downy brome (Bromus tectorum) and quackgrass (Elymus repens). Experimental studies carried out in Sweden by Hallgren (1991) revealed that Matricaria inodora and Capsella bursa-pastoris had more density and dry weight in zero tillage, while Stellaria media and Viola arvensis were more abundant under conventional sowing.

Meelu et al. (1979) found a 21-28% higher weed population in tilled plots than ZT for wheat crops. A significant reduction of weed dry weight and density under ZT than CT was observed by Mishra (1984), Malik et al. (2000b), Bisn et al. (2002) and Sen et al. (2002). However, higher weed biomass under ZT was reported in wheat by Acciaresi et al. (2001). The higher weed density in CT than in ZT might be the result of better tillth and exposure of weed seeds to upper soil in CT (Singh et al. 2001). Franke et al. (2002), found 27% and 3% weed seed emergence in ZT and CT, respectively. Feldman et al. (1998) reported that less soil disturbing tillage systems (no tillage and chisel plowing) allowed the buildup of a more diverse community of weeds, whereas the most soil disturbing tillage system (moldboard plowing) prevented a high diversity in the weed community.

The real benefit of ZT for managing weeds depends more on long-term zero tillage as well as on adequate management practice. Banting et al. (1973) and Thomas et al. (1986) studied the effect of soil depth on weed seed viability and found that the seed viability increased with soil depth. More than 50% of green foxtail seeds were alive after two years when buried 10 cm into the soil, contrasting with a 10% survival rate of seeds that remained on the soil surface. Even when seeds were buried only 1 cm into the soil, survival was two-fold greater after two years, compared with seeds on the soil surface. This suggests that the seed bank of top soil can finish at a faster rate if the soil is kept undisturbed. Similarly, Egley and Williams (1990), Popay et al. (1994) and Anderson (1998) studied the weed emergence pattern in tilled and untilled soils; the experimental sites were naturally infested with weeds, but after the

![Figure 1. The effect of crop establishment methods on weed density (Adapted from Jat, 2008).](image)

Table 2. Weed density in undisturbed soil as compared to disturbed soil.

<table>
<thead>
<tr>
<th>Study</th>
<th>Technology</th>
<th>Weed species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mishra et al. 2005</td>
<td>ZT</td>
<td>Physalis minima, Chenopodium album</td>
</tr>
<tr>
<td>Blecharczyk et al. 1999</td>
<td>RT</td>
<td>Bromus tectorum, Elymus repens</td>
</tr>
<tr>
<td>Hallgren 1991</td>
<td>ZT</td>
<td>Stellaria media, Viola arvensis, Matricaria inodora, Capsella bursa-pastoris</td>
</tr>
<tr>
<td>Chancellor 1964</td>
<td>ZT</td>
<td>Raphanus, Viola, Ranunculus spp., Sonchus, Taraxacum</td>
</tr>
</tbody>
</table>

ZT = zero tillage; RT = reduced tillage
initiation of each study, further weed seed rain was prevented and seedling emergence was similar between tilled and zero tillage practices in the first year, whereas in the second and third years, two and eight fold higher population of weeds were recorded. The benefit of zero tillage in reducing seedling emergence increased across time.

Therefore, zero tillage systems help weed management by keeping weed seeds near the soil surface and exposing seeds to environmental extremes and predation (Sagar and Mortimer, 1976).

3.1.2 Direct-seeded rice
Weed species’ shifts in response to changes in rice crop establishment methods have been widely reported in tropical Asian countries, with the conversion from transplanting to wet seeding (Moody, 1995). Jat et al. (2010) in Bihar (India) observed less *Eragrostis* and broadleaf weed density and dry weight in puddled transplanted rice (PTR) than in ZT direct-seeded rice (DSR) 45 DAS. However, at 75 DAS, broadleaf weed density was higher in PTR. The grain yield was similar in PTR and DSR. Similarly, in another study, more weeds were observed in DSR plots than transplanted plots at the 40 days stage. However, in PTR, weed emergence at a later stage (75 days). At this stage, treatments with PTR had a lower number of grassy weeds, but a larger number of broadleaf weeds than ZT-DSR, resulting in similar weed dry weight. Crop residues were effective in reducing broad leaf population under DSR.

Chauhan and Johnson (2009), reported that seedling emergence of *Digitaria ciliaris*, *Echinochloa colona*, *Eleusine indica*, *Ageratum conyzoides*, *Eclipta prostrata*, and *Portulaca oleracea* was greater in zero-tillage systems, compared to either conventional or minimum tillage, where the seedling emergence was similar. The emergence of *Rottboellia cochinchinensis* was not influenced by the tillage system. A large proportion of the weed seed bank remains on or close to the soil surface after crop planting in ZT systems (Chauhan et al. 2006), which may promote greater emergence of weed species that require light to germinate. With CT, however, seedling emergence depends partly on the effect that tillage has on seed burial, since deeply buried seeds may not be able to emerge. In a pot study, for example, seedlings of *Digitaria ciliaris* (Retz.) Koel. (southern crabgrass), did not emerge from a seed burial depth of 6 cm (Chauhan and Johnson, 2008). Azmi et al. (2005) in Malaysia, reported that in 1989, the major weed flora in transplanted rice were *Monochoria vaginalis*, *Sphenoclea guyanensis*, *Fimbristylos miliae*, and *Leptochloa flav*a. In 1993, these were replaced by *L. chinensis*, *E. crus-galli*, *M. vaginalis*, and *E. colona* in areas where direct-seeding of rice was practiced. Similarly, in Vietnam, *E. crus-galli*, *L. chinensis*, and weedy rice were dominant weeds in the direct-seeded rice (Chin, 2000). In Thailand, *Sphenoclea zeylanica*, *Monochoria vaginalis*, and *Marsilea minuta* are dominant in the transplanted systems, whereas *E. crus-galli*, *L. chinensis*, *Cyperus iria*, and *C. difformis* are dominant in the wet-seeded areas (Vongsaroj, 1997). Some of the shifts in the importance of weed species (as a result of changes in crop establishment method from traditional transplanting (1970s) to DSR) are shown in Table 3. Weedy rice is difficult to control because of its similarity to the rice plant. It was

### Table 3. Weed shift from transplanting to the direct-seeding method (Azmi et al. 2005)

<table>
<thead>
<tr>
<th></th>
<th>Irrigated transplanting</th>
<th>Extensive direct seeding</th>
<th>Intensive direct seeding</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grasses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Isachne globosa</em></td>
<td></td>
<td><em>Echinochloa crus-galli</em></td>
<td><em>E. crus-galli</em></td>
</tr>
<tr>
<td><em>Leersia hexandra</em></td>
<td><em>Leptochloa chinensis</em></td>
<td><em>L. chinensis</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Ischaemum rugosum</em></td>
<td><em>I. rugosum</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Oryza sativa</em> (weedy rice)</td>
<td></td>
<td><em>O. sativa</em> (weedy rice)</td>
</tr>
<tr>
<td><strong>Broadleaf weeds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Limnocharis flav</em>a</td>
<td></td>
<td><em>L. flav</em>a</td>
<td><em>L. flav</em>a</td>
</tr>
<tr>
<td><em>Monochoria vaginalis</em></td>
<td><em>M. vaginalis</em></td>
<td><em>S. guyanensis</em>b</td>
<td></td>
</tr>
<tr>
<td><em>M. minuta</em></td>
<td><em>L. hyssophysa</em>a*</td>
<td><em>Sphenoclea zeylanica</em>b</td>
<td></td>
</tr>
<tr>
<td><em>Sphenoclea zeylanica</em></td>
<td><em>M. minuta</em></td>
<td><em>M. crenata</em>b</td>
<td></td>
</tr>
<tr>
<td><strong>Sedges</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Scirpus grossus</em></td>
<td><em>Cyperus iria</em></td>
<td><em>C. iria</em></td>
<td><em>F. miliacea</em>b</td>
</tr>
<tr>
<td></td>
<td><em>Fimbristylos miliae</em>a*</td>
<td><em>F. miliacea</em>b</td>
<td><em>C. difformis</em></td>
</tr>
</tbody>
</table>

*a* Biotypes with herbicide resistance against 2, 4-D and ALS-inhibitor herbicides.  
*b* Species/biotypes with herbicide resistance against 2, 4-D.
detected in Malaysia in 1988 (Azmi and Abdullah, 1998) and Vietnam in 1994 (Chin, 2000), and there has also been a rapid ingress of weedy rice in the DSR areas of the central region of Thailand in recent years. Recent weed surveys conducted in Malaysia found that weedy rice (Oryza sativa) had become a problem, and the weed is thought to be a serious threat to rice production (Azmi et al. 2003).

3.2 Permanent soil cover

3.2.1 Crop residues
Residue cover on the soil surface alters the soil temperature, moisture content, and sunlight (intensity and quality), which may change the weed emergence pattern of sensitive species. Since residue cover changes soil microclimate, it may also increase the population of beneficial insects than consume weed seeds. Wicks et al. (1994) reported that residues lying on the soil surface reduce establishment of weed seedlings; in the semiarid steppe, each 1000 kg/ha of winter wheat residues on the soil surface reduces weed seedling establishment by 14%. Retained crop residues, Sesbania coculture, and cover crops, like mungbean or cowpea, helped in reducing broadleaf and sedge weeds (Singh et al. 2009). Hence, cropping systems based on weed management strategies, like better water management, laser leveling, timely planting, and competitive rice cultivars, were found to be helpful in managing weeds under DSR. Moreover, weed surveillance may also prove beneficial in selecting suitable herbicides and weed management strategies in a region (Singh et al. 2009).

3.2.2 Cover crops
Legume cover crops in cereal based cropping systems improved soil fertility, nutrient availability and use efficiency, as well as suppressing weed establishment and growth, thereby reducing the number of weed seeds and vegetative propagates that infest succeeding crops. The purpose of using cover crops for weed control is to replace unmanageable weed populations with a manageable cover crop. Weed suppression will be effective when crop establishment occurs before weeds appear. Furthermore, harvest and deposition onto the soil also facilitates weed control because of the germination inhibition of cover vegetal residues. Atmospheric nitrogen-fixing legumes are the main cover crop species; however, several grasses and crucifers (usually sown together) are also used (Liebman et al. 2001). Cover crops grow very fast and compete with weeds for growth factors and changing environmental factors that affect weed germination and establishment by releasing phytoxins (Putnam and DeFrank, 1983; Mangan et al. 1995). Teasdale and Daughtry (1993) reported that the Vicia villosa cover crop reduced weed density by 70-78% and reduced weed biomass by 52-70%, compared with a fallow treatment. Measurements made after vetch had completed the majority of its growth, showed that an average of 87% of sites beneath the cover crop received <1% of unobstructed sunlight. Hairy vetch decreased the red by 660 nanometers (nm) to far-red (730 nm) ratio of transmitted light by 70% and reduced daily maximum soil temperature and diurnal soil temperature amplitude. Reductions in weed density and biomass were attributed to light extinction and changes in light quality and soil thermal regime. Weed suppression by cover crops can be directly proportional to cover crop growth and canopy production, as shown by data from McLenaghan et al. (1996), who sowed five winter cover crops or let ground lie fallow after plowing pasture. The quantity of ground cover produced by weeds was inversely proportional to that produced by the crops. In the fallow treatment without a crop, weeds covered 52% of the ground area. In contrast to this, the most weed-suppressive cover crop, white mustard (Sinapis alba L.), produced 92% ground cover and reduced ground cover by weeds to just 4%. In addition to light competition, N competition may also have reduced weed growth, as most of the cover crops used were shown to be effective in capturing soil nitrate. Cover crops can provide biological weed control by replacing an unmanageable weed population with a manageable cover crop species (Teasdale 1996). Winter annual cover crops are planted in late summer or early fall, become established before winter, and have the greatest biomass by early spring, before the summer crop is planted. In most cases the cover crop is killed with herbicide or mowed before the summer crop is planted, leaving a mulch residue on the soil surface. Mulched cover crops also may provide favorable microhabitats for beneficial insects (Orr et al. 1997; Reader 1991; Stinner and House, 1990), including entomophagous insects and weed seed predators. Mulched cover crops increase populations of beneficial entomophagous species such as carabids, staphylinids, and spiders (Altieri et al. 1985) which can control pests more effectively. Cover crops can also increase populations of granivores that consume weed seeds. For example, cover crops increased populations of granivorous carabid beetles (House and Alzugaray, 1989; Laub and Luna, 1992; Armstrong and McKinlay, 1997) which are important seed consumers in temperate ecosystems (Brust and House, 1988; Kjellson, 1985; Manley, 1992; Westerman et al. 2003).
3.3 Crop diversification

3.3.1 Intercropping

Intercropping is receiving increasing attention as it offers potential advantages for an increased sustainability in crop production. Intercropping of short duration legume crops with long duration and wide spacing cereals, increased initial ground cover and suppressed emerging weeds. However, intercropping can increase competition between crops and weeds. Maize-legume intercropping led to a higher soil canopy cover (leaf area index) than sole crops. Thus, in maize-legume intercrops the decrease in available light for weeds led to a reduction of weed density and dry matter, compared to sole crops. Intercropping maize and legumes considerably reduced the weed density in the intercrop compared with the maize pure stand. Weed suppression by crops was also greater on a low-productivity site than on a high-productivity site (Bilalis et al. 2010). Intercrops that are particularly effective at suppressing weeds capture a greater share of available resources than sole crops. Abraham and Singh (1984) found, for example, that a grain sorghum (Sorghum bicolor) intercrop intercepted more light, captured greater quantities of macronutrients (N, P and K), produced higher crop yields and contained lower weed densities and less weed dry matter compared with sole-cropped sorghum. Although intercropping is well-suited to labor-intensive farming systems, certain crop mixtures are compatible with farm machinery. Mixtures of cereals, such as barley (Hordeum vulgare L.), wheat or oats (Avena sativa L.), with forage legumes, such as red clover (Trifolium pratense L.) or lucerne, are common in mechanized temperate farming systems and can be useful for suppressing the growth of perennial cool-season weeds, such as Elytrigia repens (L.) Nevski (Dyke and Barnard, 1976). Liebman and Davis (2000) in an experiment of barley and red clover intercropping, after removal of barley grain with a combine harvester, found that red clover grew until the field was plowed the next spring. Red clover reduced weed biomass at barley harvest and suppressed weed growth during the subsequent autumn and spring, when sole-cropped barley plots lay fallow. Residues of red clover and other forage legumes that are initially established in intercrop mixtures can serve as important sources of both N and weed-suppressive chemical compounds.

Saucke and Ackermann (2006) found that in pea + false flax mixed cropping, false flax reduced annual weed (Fallopia convolvulus, Sonchus oleraceus and Matricaria recutita) by 52% to 63% as compared to pea sole crop but was ineffective towards the major perennials (Cirsium arvense and Elytrigia repens).

3.3.2 Crop rotations

Weeds are very competitive, and like to mimic their host crop, for example, Phalaris minor in wheat, and Echinochloa in rice. Crop rotations are also highly effective against parasitic and crop-associated weeds. Parasitic weeds are for example Striga in sorghum and maize, Orobanche in Brassicas, solanaceous crops, tobacco and faba bean, and Cuscuta in alfalfa, linseed, niger (Parker, 1979; Parker and Riches, 1993). Similarly, crop-associated weeds like Avena ludoviciana/fatua and Phalaris minor (in wheat), Cichorium intybus and Coronopus didymus (in Egyptian clover/berseem), Echinochloa colona/crusgalli (in rice) (Gupta, 1998) can be easily managed by a rotation of non-host/non-associated crops. Singh and Singh (2006) reported that P. minor populations in wheat, in rice–wheat systems, were reduced to a great extent through the introduction of mustard, peas, potatoes, and berseem in sequence after rice during the winter season. Switching to a different crop allows a modified management practice, and gives weeds no place to hide. By rotating through a diverse range of crops, weed and disease pressure in cropping systems can be limited.

Rotating crops with different life cycles favors the natural loss of weed seeds across time because producers can prevent new seeds being added to the soil. With less seeds in the soil, fewer seedlings emerge in following crops (Sagar and Mortimer, 1976; Roberts, 1981). However, long-term rotation studies using conventional herbicide programs show a striking trend; weed density increases if rotations consist of one cool-season crop followed by one warm-season crop, such as winter wheat-proso millet (Anderson, 2005). In contrast, if rotations are arranged in a cycle of four, with two cool-season crops followed by two warm-season crops, weed density declines with time. Comparing trends across three rotation studies, weed seedling density was eightfold higher in two-crop rotations compared with four-crop rotations comprised of cool- and warm-season crops.

Another trend noted with long-term rotation studies is that with four-crop rotations, weed density increases if the same crop is grown two years in a row (Anderson, 2003). When winter wheat is grown two years in a row, density of the winter annual grasses, downy brome and jointed goat grass, escalate rapidly. Seed decay of weeds in the
soil is minimal during the three-month interval between winter wheat harvests and planting, thus seedling emergence is high in the second winter wheat crop. In contrast, replacing one crop of winter wheat with another cool-season crop, such as dry pea, provides an opportunity to reduce seedlings of winter annual weeds that emerged over winter because dry pea is planted in late March or early April. A similar benefit occurs when a warm-season sequence of corn and sunflower is used rather than two years of corn; corn is planted in early May whereas sunflower is planted three to four weeks later. Diversifying crops with different planting dates within a life-cycle category, i.e., warm-season crops, accentuates the benefit gained with rotations comprised of two year intervals of cool- and warm-season crops. Examples of four-year rotations used in the region are winter wheat-corn-sunflower-fallow or dry pea-winter wheat-corn-proso millet; like sunflower, proso millet is planted three to four weeks later than corn. The impact of rotations on the weed community density is related to seed survival in soil. With downy brome and green foxtail, approximately 20% of the seeds are alive one year after seed shed, whereas less than 5% of their seeds are alive after two years (Anderson, 2003).

3.4 Integration of conservation agriculture principles

The individual conservation agriculture (CA) components can affect weed dynamics. The integration of two or more components can prove to be even more effective in handling weed issues. Zero tillage keeps soil undisturbed so that no mixing of weed seeds in soil occurs. If other components (i.e., residue retention or cover crops or intercrops or crop rotation imposed on ZT) are implemented together with ZT, weed emergence and seed multiplication can be further reduced. Wicks et al. (1994) observed that the benefit of zero tillage with crop residues lying on the soil surface is the reduction of the establishment of weed seedlings; in the semiarid steppe, each 1000 kg/ha of winter wheat residues on the soil surface reduces weed seedling establishment by 14%. To enhance crop residue suppression of weed emergence, producers grow taller cultivars of winter wheat at seeding rates 50% higher than normal, with low rates of N and P banded with the seed at planting. These tactics increase residue production from 2000 to 2500 kg/ha (Anderson, 2003). Similar suppression of weed establishment occurs with residues of other crops. Long-term experiments carried out by Malik et al. (2000a) showed that ZT combined with alternative herbicides decreased P. minor populations over a period of five years. ZT techniques in combination with timely sowing of wheat had shown promising results in reducing P. minor infestations on research farms and farmers’ fields at different locations in Punjab (Brar, 2002). The weed problem is more pronounced under DSR than PTR. Integration of CA techniques with herbicides can be an effective tool for weed management. Stale seed bed techniques, crop residue retention, and cover crops like, mungbean or cowpea, helped in reducing broadleaf and sedge weeds in DSR (Singh et al. 2009). Further, brown manuring (broadcasting of Sesbania along with rice seeding and killing Sesbania by spraying 2, 4-D around 30 days after seeding) or mulching reduced the weed density by 37-42% compared to the rice crop without brown manuring and mulching (Singh et al. 2009). Rice yield was greater when Sesbania was seeded 0 and 5 days after rice seeding compared to 10 days after rice seeding and sole rice crop. Some herbicides found effective in DSR are pendimethalin, cyhalofop-butyl, fenoxaprop-propyl, propanil, bipyridil, penoxsulam, triclopyr, carfentrazone, halosulfuron, bensulfuron, ethoxsulfuron, azimsulfuron, quinclorac, clomazone, 2,4-D, chlorimuron+metsulfuron, and molinate. Integration of herbicides with one hand weeding around 45 days after seeding (DAS) was found effective in reducing weeds and improving yields. For season long and broad-spectrum sustainable weed management, the integration of different herbicides and weed control measures are needed as part of an integrated weed management strategy. Continuous monitoring of weed flora is needed to identify shifts in weed flora due to shifting from conventional puddled transplanted rice to DSR and to focus on the emerging problematic new weed species that are even more difficult to control and competitive in nature, such as weedy rice. Hence, cropping systems based on weed management strategies, like better water management, laser leveling, timely planting, and competitive rice cultivars were found helpful in managing weeds in DSR. Moreover, weed surveillance may also prove beneficial in selecting suitable herbicides and weed management strategies for shifting weed flora (Singh et al. 2009).

4. Conclusion

In this paper, the effect of tillage crop establishment, residue management, cover cropping, intercropping, and crop rotation on weed flora was reviewed to determine the general concepts of sustainable weed management under CA systems. In long-term studies it is concluded that ZT reduced weed emergence after the first year, and weed emergence continues to decline in succeeding years, if further weed seed
production is controlled. The weed seed bank of upper soil layer declined over the years, since the newly produced weed seed may lose viability by remaining on the soil surface (no soil disturbance) due to extreme environment and seeds in lower soil layer may be unable to germinate. Stale seed bed techniques with non-selective herbicides and post-emergence application of selective herbicide during the initial two to three years of permanent ZT, reduced the soil seed bank and can be the sustainable solution for the long-tem. Crop rotations are the panacea for parasitic and crop-associated weeds. Crop rotation of legume crops in cereal based cropping systems increased the possibilities to use more herbicides to control grassy weeds. Minimum soil disturbance and stale seed beds, in combination with soil covering (with dead crop residue or live mulching or brown manuring), will be the holistic approach for sustainable weed management. The management factors like laser land leveling, competitive cultivars, sowing time, optimum seed rate/plant populations/spacing, nutrient management, chemical weed control, and irrigation management support the CA principles for better and more sustainable weed management. Changes in weed flora in response to altered crop establishment methods require keen surveillance for selecting suitable herbicides and weed management strategies in a region.

Future research needs
Continuous monitoring/surveillance of weed flora is needed to identify the shifts in weed flora due to switching from conventional PTR to DSR and to focus on the emerging problematic new weed species that are even more difficult to control and competitive in nature, such as weedy rice. Herbicides, method of application and time of application need to be evaluated for different residue conditions. The allelopathic effects of rotational crop or intercropping on weeds also can be studied for additional methods of weed management.

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References


Chapter 9. Conservation agriculture in northwestern Bangladesh: A review of soil tillage, crop establishment methods, and cropping systems

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Abstract

Bangladesh covers a geographical area of 0.144M km^2 between 20° 34’ and 26° 38’ North latitude and 88° 01’ and 92° 41’ East longitude. Bangladesh has a sub-tropical monsoonal climate and average rainfall between 2000 and 2009 was 2,237 mm. Rangpur is located in the northwestern hub area of the Cereal Systems Initiative for South Asia (CSISA). Monsoon rice (aman) is the main crop (80% of the area has rice, which is grown during June-November), and the annual rainfall varies between 1,340-3,147 mm. Rice based cropping systems with wheat/maize are important for the food security and livelihood of people who live in the hub domain. Conservation agriculture is a resource-saving agricultural crop production system that strives to increase production and enhance the quality of the natural resource base.

Keywords: Conservation agriculture, conservation tillage, residue management, crop rotation, direct-seeded rice, brown manuring, new molecules for weed control in DSR and cereal based cropping systems

Introduction

Bangladesh is an agricultural country. Rice, wheat, and maize are the main cereals grown in the country, and jute, sugarcane, potato, pulses, and tobacco are the principal crops. Rice is the staple food of about 150 million people of Bangladesh. Maize is the third most important cereal crop in Bangladesh, after rice and wheat. It can be cultivated year-round. Rice provides nearly 48.1% of rural employment, about two-thirds of the total calorie supply, and about one-half of the total protein intake of an average person in the country. The rice sector contributes half of the agricultural GDP, and a sixth of the national income in Bangladesh. Almost all of the 13 million families involved in farming within the country grow rice. Rice is grown on about 10.5 million hectares, a figure which has remained relatively stable over the past three decades. About 75% of the total cropped area and over 80% of the total irrigated area is planted with rice. Thus, rice plays a vital role in the livelihood of the people of Bangladesh.

The population of Bangladesh is still growing by two million every year, and may increase by another 30 million over the next 20 years. During this time, the total rice area will shrink to 10.28 million hectares. Rice yields, therefore, need to increase from the present 2.74 t/ha to 3.74 t/ha (BRKB, 2010). Yet, to meet the food requirements of the population estimated for 2015, an additional 5 million tons of grain needs to be produced from the continuously decreasing agricultural lands (BRKB, 2010).

Bangladesh experiences four distinct seasons, namely winter (Jan-Feb), summer (March-May); the southwestern summer monsoon (June-September) and the post-monsoon season, due to northeastern monsoons. Summer monsoons significantly affect the use of natural resources in the area. Monsoons start in mid April/May (mostly during June-Sept) and stay up until October. This period accounts for 80% of the total rainfall. The average annual rainfall varies from 1,429 to 4,388 mm. But in the Rangpur CSISA-Dinajpur hub (northwestern Bangladesh), the domain had a rainfall average of 2,237 mm (1,340-3,147mm) from 2000 to 2009, where monsoon rice (aman/kharif-II) is the main crop grown (80% rice area, about 5.44 Mha) during June-November. There are 4.2 Mha highlands (HL), and 5.04 Mha medium highlands (MHL); these areas have the potential for growing winter wheat, maize, potato, pulses, vegetable, oil seeds; also, there are about 3.07 Mha medium lowlands (MLL), lowlands (LL) and very lowlands (VLL), where irrigated Boro (winter rice) and rainfed deep water rice (DWR) are generally cultivated in Bangladesh (BRKB, 2010; BBS, 2009) (Table 1).
The physiography of Bangladesh has been divided into 24 sub-regions and 54 units where major soils in the CSISA-Dinajpur hub domains are as follows: Tista-Karatoya floodplain (light textured silt loam soil, low pH), Barind and Madhupur tracts (red soils with finer textured soils, low pH) and the high Ganges floodplain (light textured, calcareous soils with alkaline pH) (Banglapedia, 2010). Except for the hilly regions in the northeast and southeast, soils in the highlands found in the northern parts of the country are generally fertile lands. A network of rivers exists in the country of which the Padma, the Jamuna, the Teesta, the Brahmaputra, the Surma, the Meghna, and the Karnaphuli are important. The alluvial soil is thus continuously being enriched by fresh silt deposited by river systems during the rainy season. NASA studies have shown that fast, large-scale land-use changes due to urban growth are causing heat and pollution, increasing rainfall in towns, and reducing cropped lands (Purdue University, 2009). In order to improve food security and create higher returns for smallholder farmers, nine hubs were established in CSISA to pursue project goals following conservation agriculture (CA) principles (Gupta, 2009). A landmark United Nations study from 1991, estimated that soil from 552 million hectares of land, equal to 38% of today’s globally cultivated area, had been degraded to some degree by agricultural mismanagement since World War II (Gardner, 1997). Since then, the concept of sustainability in cropping systems has received considerable attention. New technologies are needed in order to improve efficiency of land and labor, reduce production costs, increase sustainability of the cereal systems, and reduce yield gaps. Such technologies can facilitate reduction in “rice fallows,” enhance fertilizer use, and promote inclusive deployment of new cultivars in cropping systems (Gupta, 2009). Despite the availability of improved varieties with increased yield potential, the potential increase in production is generally not attained because of poor crop management (Reynolds and Tuberosa, 2008). Another direct consequence of farmers’ persistent use of traditional production practices is the rapidly increasing production costs associated with the inefficient use of inputs, the cost of which continues to rise. In addition, any new, more sustainable management strategy must be compatible with emerging crop diversification policies that may evolve to meet new consumer or industrial requirements. All of this must be accomplished with decreasing area available for crop production because of urbanization and industrial expansion, and the recent dramatic increases in the use of land for biofuels and industrial crop production, instead of food (Verhulst et al. 2010).

### Table 1. Land type, area, and proportion of Bangladesh's total area based on flooding depth.

<table>
<thead>
<tr>
<th>Land type with water depth (cm)</th>
<th>Area (Mha)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (H) (above normal)</td>
<td>4.19</td>
<td>29</td>
</tr>
<tr>
<td>MH-1 (&lt;30cm deep)</td>
<td>5.04</td>
<td>35</td>
</tr>
<tr>
<td>MH-2 (Depth of 30-90cm)</td>
<td>1.77</td>
<td>12</td>
</tr>
<tr>
<td>ML (Depth of 90-180cm)</td>
<td>1.10</td>
<td>8</td>
</tr>
<tr>
<td>LL (Depth of 180-300cm)</td>
<td>0.19</td>
<td>1</td>
</tr>
<tr>
<td>VLL (Depth &gt;300cm)</td>
<td>2.17</td>
<td>15</td>
</tr>
<tr>
<td>Total soil area</td>
<td>12.30</td>
<td>85</td>
</tr>
<tr>
<td>River, Urban, Homestead, etc</td>
<td>2.17</td>
<td>15</td>
</tr>
<tr>
<td>Grand Total</td>
<td><strong>14.48</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Highlands=h, medium highlands=MHL, medium lowlands=MLL, lowlands=LL, very lowlands=VLL.

The physiography of Bangladesh has been divided into 24 sub-regions and 54 units where major soils in the CSISA-Dinajpur hub domains are as follows: Tista-Karatoya floodplain (light textured silt loam soil, low pH), Barind and Madhupur tracts (red soils with finer textured soils, low pH) and the high Ganges floodplain (light textured, calcareous soils with alkaline pH) (Banglapedia, 2010). Except for the hilly regions in the northeast and southeast, soils in the highlands found in the northern parts of the country are generally fertile lands. A network of rivers exists in the country of which the Padma, the Jamuna, the Teesta, the Brahmaputra, the Surma, the Meghna, and the Karnaphuli are important. The alluvial soil is thus continuously being enriched by fresh silt deposited by river systems during the rainy season. NASA studies have shown that fast, large-scale land-use changes due to urban growth are causing heat and pollution, increasing rainfall in towns, and reducing cropped lands (Purdue University, 2009). In order to improve food security and create higher returns for smallholder farmers, nine hubs were established in CSISA to pursue project goals following conservation agriculture (CA) principles (Gupta, 2009). A landmark United Nations study from 1991, estimated that soil from 552 million hectares of land, equal to 38% of today’s globally cultivated area, had been degraded to some degree by agricultural mismanagement since World War II (Gardner, 1997). Since then, the concept of sustainability in cropping systems has received considerable attention. New technologies are needed in order to improve efficiency of land and labor, reduce production costs, increase sustainability of the cereal systems, and reduce yield gaps. Such technologies can facilitate reduction in “rice fallows,” enhance fertilizer use, and promote inclusive deployment of new cultivars in cropping systems (Gupta, 2009). Despite the availability of improved varieties with increased yield potential, the potential increase in production is generally not attained because of poor crop management (Reynolds and Tuberosa, 2008). Another direct consequence of farmers’ persistent use of traditional production practices is the rapidly increasing production costs associated with the inefficient use of inputs, the cost of which continues to rise. In addition, any new, more sustainable management strategy must be compatible with emerging crop diversification policies that may evolve to meet new consumer or industrial requirements. All of this must be accomplished with decreasing area available for crop production because of urbanization and industrial expansion, and the recent dramatic increases in the use of land for biofuels and industrial crop production, instead of food (Verhulst et al. 2010).

#### 2. What is conservation agriculture?

Conservation agriculture (CA) is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment (FAO, 2009). Conservation agriculture has been proposed as a widely adapted set of management principles that can assure more sustainable agricultural production. The name conservation agriculture has been used to distinguish this more sustainable agriculture from the narrowly defined “conservation tillage” (Wall, 2007). Conservation tillage is a widely used term that denotes soil management systems that result in at least 30% of the soil surface being covered with crop residues after seeding of the subsequent crop (Jarecki and Lal, 2003). To achieve this level of ground cover, conservation tillage normally involves some degree of tillage reduction and the use of non-inversion tillage methods. Conservation agriculture aims to achieve sustainable and profitable agriculture and subsequently aims at improving the livelihoods of farmers. Conservation agriculture removes the emphasis from the tillage component alone and addresses a more enhanced concept of the complete agricultural system (FAO, 2009).
Principles of conservation agriculture

Conservation agriculture combines the following basic principles:

- **Reduction in tillage**: The objective is to achieve zero tillage, but the system may involve controlled tillage seeding systems that normally do not disturb more than 20-25% of the soil surface. It should be noted that the following are being promoted in Dinajpur: minimum tillage; two-wheel tractor operated seeders; two-wheel tractor operated strip till drills; two wheel tractor operated bed planters; and four-wheel tractors.

- **Retention of adequate levels of crop residues and soil surface cover**: The objective is the retention of sufficient residue on the soil to protect the soil from water and wind erosion; to reduce water run-off and evaporation; to improve water productivity, and to enhance soil physical, chemical, and biological properties associated with long term sustainable productivity. The amount of residues necessary to achieve these ends will vary depending on the biophysical conditions and the cropping system. In Bangladesh, farmers often do not have the required machinery to plant crops in loose crop residues. Efforts are being made to promote the design of such tools.

- **Use of crop rotations**: The objective is to employ diversified crop rotations to help moderate/mitigate possible weed, disease, and pest problems; to utilize the beneficial effects of some crops on soil conditions and on the productivity of subsequent crops; and to provide farmers with economically viable cropping options that minimize risk. Conservation agriculture is based on enhancing natural biological processes above and below the ground (Verhulst et al. 2010). To achieve this, it is crucial to improve carbon substrate levels in the soils to promote biological activity to replace mechanical energy of the tractors.

- **The CA principles are applicable to a wide range of crop production systems from low-yielding, dry, rainfed conditions to high-yielding, irrigated conditions. However, the techniques to apply CA principles will be very different in different situations, and will vary with biophysical and system management conditions and farmer circumstances. The principles of marked tillage reductions are initially applied in combination with the retention of sufficient amounts of crop residues on the soil surface, with the assumption that appropriate crop rotations can be maintained or incorporated into the system later to achieve an integrated, sustainable production system.**

3. Advantages of conservation agriculture

Conservation agriculture provides a number of advantages on a global, regional, local and farm level. It provides a truly sustainable production system that not only conserves but also enhances natural resources and increases the variety of soil biota, fauna, and flora (including wildlife). This agricultural production system achieves this without sacrificing yields or high production levels. As CA depends on biological processes to work, it enhances the biodiversity in an agricultural production system on a micro- as well as macro level. Zero tillage (ZT) fields act as a sink for CO₂, and conservation farming applied on a global scale could provide a major contribution to control air pollution in general and global warming in particular. Farmers applying this practice could eventually be rewarded with carbon credits and have very high water infiltration capacities reducing surface runoff and thus soil erosion significantly (Verhulst et al. 2010; FAO 2009). Retaining only 30-50% of the organic residues improved the soil structure considerably compared to plots where it was removed completely (Licher et al. 2008).

Moreover, FAO (2009) states the following as benefits of CA: (1) Economic benefits that improve production efficiency (2) Agronomic benefits that improve soil productivity and (3) Environmental and social benefits that protect the soil and make agriculture more sustainable.

3.1. Economic benefits

Three major economic benefits resulting from CA adoption are time saving and thus reduction in labor requirements as well as reduction of costs, e.g., fuel, machinery-operating costs and maintenance, as well as a reduced labor costs (FAO, 2009). Their avoidance increases the margin between profits and costs, which formerly, under tillage agriculture, were accepted as “normal” expenses to be anticipated. Conservation agriculture systems are less vulnerable to insect pests, diseases, and drought effects because better soil and plant conditions also include greater biotic diversity of potential predators on pests and diseases (Ortega et al. 2006), while crop rotations break insect pest buildups, especially root rot and cereal nematodes (Govaerts et al. 2006). Here, much of the cost of avoiding or controlling significant pest attacks is diminished because of it being undertaken by healthier plants, breaks in pest life cycles, and
natural predators. Research conducted in Paraguay and in Brazil has shown that crop rotation and short-term green manure cover crops can reduce the cost of herbicides drastically, due to reduction in weed infestations over time (Blackshaw et al. 2007). While many still think that green manure cover crops are economically not viable, farmers in Brazil and Paraguay have learned that the economic benefits of CA can be substantially increased with their use (Derpsch, 2008). As a result, the financial benefits for farmers in Latin America who have adopted CA have been striking. However, these take time to fully materialize. The positive impact of CA on the distribution of labor during the production cycle and, even more important, the reduction in labor requirement are the main reasons that farmers in Latin America have adopted CA, especially those farmers who rely fully on family labor. Govaerts et al. (2005) reported high and stable yields and incomes from CA under rainfed drylands. As an effect of CA, the productive potential of soil rises because of improved interactions between the four factors of productivity: (a) physical: better characteristics of porosity for root growth, movement of water, and root-respiration gases; (b) chemical: raised cation exchange capacity gives better capture, release of inherent and applied nutrients: greater control/release of nutrients; (c) biological: more organisms, organic matter, and its transformation products; (d) hydrological: more water available (Verhulst et al. 2010; Govaerts et al. 2006, 2007).

The combination of the above features to raise productive potential makes the soil a better environment for the development and functioning of crop plants’ roots. Improvements in the soil’s porosity have two effects: a greater proportion of the incident rainfall enters into the soil and the better distribution of pore-spaces of optimum sizes results in a greater proportion of the received water being held at plant-available tensions. Either or both together mean that, after the onset of a rainless period, the plants can continue growth towards harvest — for longer than would previously have been the case — before the plant-available soil water is exhausted. In addition, increased quantities of soil organic matter result in improved availability, and duration of their release into the soil water, of needed plant nutrients — both those within the organic matter and those from off-farm. Thus the availability of both water and plant nutrients is extended together. Under these conditions, plants have a better environment in which to express their genetic potentials, whether they have been genetically engineered or not. Yield differences have been reported in the range of 20–120% between CA systems and tillage systems in Latin America, Africa, and Asia (Pretty et al. 2006; Govaerts et al. 2006, 2007; FAO, 2008). In Paraguay, small farmers have been able to successfully grow crops that initially were thought not to be appropriate for zero tillage systems, such as cassava. Planting cassava under CA in combination with cover crops has resulted in substantial yield increases, sometimes double the yields compared to conventional farming systems (Derpsch and Friedrich, 2009).

3.2. Agronomic benefits

Adopting CA leads to the improvement of soil productivity through organic matter increase, in-soil water conservation and improvement of soil structure, and thus rooting zone. The constant addition of crop residues leads to an increase in the organic matter content of the soil. In the beginning this is limited to the top layer of the soil, but with time this will extend to deeper soil layers. Organic matter plays an important role in the soil: fertilizer-use efficiency, water-holding capacity, soil aggregation, rooting environment, and nutrient retention, all depend on organic matter (Govaerts et al. 2006, 2007).

Conservation agriculture is a fundamental change in the agricultural production system. Conservation agriculture is a means of assuring that production of plants occurs sustainably and that water resources are conserved. It does this by favoring improvements in the condition of soils as rooting environments. Conservation agriculture is not a single technology, but a range based on one or more of the three main CA components described previously. Conservation agriculture functions best when all three key features are blended in a manner such as to produce the desired results. It is significantly different from conventional tillage agriculture (Hobbs, 2007). Conservation agriculture can retain and mimic the soil’s original desirable characteristics (i.e., forest floor conditions) on land being first opened for agricultural use. Throughout the transformation to agricultural production CA can sustain the health of long-opened land that is already in good condition, and it can regenerate that in poor condition (Doran and Zeiss, 2000). CA is a powerful tool for promoting soil and thus agricultural sustainability. It is important to recognize that the improvements seen at macro-scale (e.g., yields, erosion avoidance, water supplies, and farm profitability) are underlain and driven by essential features and processes happening at micro-scale in the soil itself. FAO
(2008) indicate that widespread adoption of CA has been demonstrated to be capable of producing large and demonstrable savings in machinery, energy use, and in carbon emissions; a rise in soil organic matter content and biotic activity; less erosion; increased crop-water availability and thus resilience to drought; improved recharge of aquifers; and reduced impact of the apparently increasing volatility in weather associated with climate change. It will cut production costs, lead to more reliable harvests, and reduce risks, especially for small landholders.

3.3. Environmental benefits
Conservation agriculture reduces soil erosion. It also fosters carbon sequestration and results in the improvement of water quality, air quality, and biodiversity. Residues on the soil surface reduce the splash-effect of the raindrops, and once the energy of the raindrops has dissipated the drops proceed to the soil without any harmful effect. This results in higher infiltration and reduced runoff, leading to less erosion (Verhulst et al. 2010). The residues also form a physical barrier that reduces the speed of water and wind over the surface. Reduction of wind speed reduces evaporation of soil moisture.

Soil erosion is reduced close to the regeneration rate of the soil or even adds to the system due to the accumulation of organic matter. Soil erosion fills surface water reservoirs with sediment, thus reducing water-storage capacity. Sediment in surface water increases wear and tear in hydroelectric installations and pumping devices, which results in higher maintenance costs and necessitates earlier replacement. More water infiltrates into the soil with CA rather than running off the soil surface. Streams are then fed more by subsurface flow than by surface runoff. Thus, surface water is cleaner and more closely resembles groundwater in CA than in areas where intensive tillage and accompanying erosion and runoff predominate. Greater infiltration should reduce flooding, by causing more water storage in soil and slow release to streams. Infiltration also recharges groundwater, and thus increases well supplies and revitalizes dried up springs (Verhulst et al. 2010; FAO, 2009).

4. How CA can solve some of Bangladesh’s agricultural problems
4.1. Conservation agriculture based tillage, crop establishment methods, and crop rotation
The concept of CA was introduced in Bangladesh by the Rice Wheat Consortium through the International Maize and Wheat Improvement Center (CIMMYT) and by the Food and Agriculture Organization of the United Nations (FAO) through the project TCP/BDG/2902, which targeted rice-wheat growing systems. More recently, CIMMYT has been trying to introduce new CA machines and new herbicide molecules for effective weed management and to do away with the age-old practice of puddled transplanted rice. This was done through projects funded by CSISA and the Australian Center for International Agricultural Research (ACIAR). Puddling is achieved by intensive tillage under ponded water conditions, which serves to break down soil aggregates, reduce micro-porosity, disperse the clay fraction, and form a dense zone of compaction (i.e., “plow pan”) at depth. Although the soil physical changes from puddling can be favorable for rice cultivation, they can be very detrimental to the growth of subsequent non-rice crops by causing temporary water logging, poor crop emergence, and restricted root development. Fortunately, alternative establishment practices for rice such as direct seeding into dry, unpuddled soil (henceforth referred to as direct-seeded rice or DSR) are suitable for different production environments in South Asia and may alleviate many of the problems associated with transplanted rice (TPR) in rice-wheat-mungbean and rice-chickpea systems (Gopal et al. 2010; Mazid et al. 2006). Direct-seeded rice combined with residue retention from the preceding crop, follows the principles of CA and may offer economic, energy, labor, and water saving advantages in rice-wheat-legume cropping systems (Gopal et al. 2010).

Sesbania co-culture (brown manuring) and soil cover management in rice based systems: Crop residues when retained on the soil surface, serve as physical barrier to the emergence of weeds, moderate soil temperature, conserve soil moisture, and build soil organic matter. The practice of brown manuring involves dry seeding of rice and Sesbania crop 25-30 days after sowing with 2,4-D ester at 0.40-0.50 kg per ha. Sesbania grows rapidly
and suppresses weeds. Co-culture technology can reduce the weed population by nearly half without any adverse effect on rice yield and supplies 10-15 kg N/ha on decomposition. In areas where soil crusting is a problem, germinating Sebania helps break it and facilitates the emergence of rice seedlings. Rice and Sebania can be planted with the same drill. In the DSR-wheat/maize rotation, the possibility of fitting summer legumes is through relay cropping of these crops coinciding with the last irrigation water application in winter crops so that the DSR can be planted in time after knocking down of the relay legumes using 2, 4-D herbicide. This will also help in meeting early N requirement of the DSR crop and in avoiding early nitrogen and moisture stresses in DSR (Gopal et al. 2010).

Weed control options and herbicide molecules in direct-seeded rice: The problem of weeds in the same crop varies with cropping systems and production environments. Therefore, the weed spectrum in relation to cropping systems, season, and production environment is a must for effective and economical weed management.

Chemical weed control: The right herbicide for use in DSR depends on the weed flora present in a given field; individual herbicides have strengths and weaknesses, e.g., Oxadiazol is good for pre-emergence and Pyrozulphurphuran is a good early- or post-emergence herbicide used in dry DSR. The control efficacy of herbicides is also contingent on the use of proper spray techniques. For example, it is better to use flat fan nozzles in combination with multiple nozzle booms to achieve spray uniformity across the field (Gopal et al. 2010).

5. Bottlenecks to using CA on rice crops in rainfed/irrigated systems

Lack of machinery and local services
- Non availability of the right machines/seeding devices
- Cost and quality of seeding devices
- Poor quality of the drills and non-availability of spare parts
- Lack of skilled mechanics for repairing the machines
- Mindset of the national scientists about CA practices, often due to lack of exposure to CA practices

6. Equipment for conservation agriculture

Before going on to describe a couple of case studies from Asia and Mexico, there is a need to discuss the critical importance of equipment that leads to success with CA; zero tillage and CA is bound to fail if suitable equipment is not available to drill seed into residues at the proper depth for good germination. It is urgent that CA equipment is perfected, easily available, and adopted for this new farming system. There are some excellent reviews of the equipment needs for zero tillage systems. Equipment in a CA system must be capable of the following: handling loose straw (cutting or moving aside), seed and fertilizer placement, furrow closing, and seed/soil compaction. There is also a need for small-scale farmers to adapt direct drill seeding equipment to animal or small tractor power sources (reduced weight and draft requirements) and costs must be reduced so farmers can afford the equipment, although the use of rental equipment and service providers allow small scale farmers to use this system even if they do not own a tractor or seeder.
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References


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