



CONSERVATION AGRICULTURE IN RELATION TO RESOURCE CONSERVATION AND SUSTAINABLE AGRICULTURE

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Abstract: Conservation agriculture is a part of sustainable agriculture, aiming at optimizing yields and profits but also at protecting land resources and the environment. Conservation agriculture involves zero or minimum soil disturbance through tillage (no-tillage, reduced tillage, mulch tillage and strip-tillage), a balanced use of fertilizers and herbicides, a permanent soil biomass cover enhancing water and soil conservation, crop rotation and integrated pest management, reduced production costs and increased farming efficiency. Conservation agriculture is an alternative to conventional agriculture and one of the most efficient systems for sustainable agricultural development, stimulating soil biological activity, increasing organic matter and humus content. Conservation agriculture has been identified as one of the practice to sequester soil organic carbon. Organic inputs are necessary to increase soil organic carbon stocks, manure inputs increases soil organic carbon. Continued input is required in order to maintain the higher soil organic carbon level. Once the addition stops, much of the carbon “sequestered” in the soil may be lost due to decomposition. Some residual benefits from manure addition, however, may last for long periods, as improved soil conditions increase productivity and plant residue input into the soil. Conservation agriculture aims to provide and maintain optimal conditions in the root zone (maximum possible depth for crop roots) in order to enable them to grow and function effectively and without hindrance in capturing plant nutrients and water; ensure that water enters the soil so that: (I) plants have sufficient water to express their potential growth; and (ii) excess water passes through soil to groundwater and stream flow, not over the surface as runoff where it can cause erosion. There is greater potential for increased cropping efficiency as more water is held in the soil profile than under conventional systems; increase beneficial biological activity in the soil in order to: (I) maintain and rebuild soil architecture for enhanced water entry and distribution within the soil profile; (ii) compete with potential soil pathogens; (iii) contribute to decomposition of organic materials to soil organic matter and various grades of humus; and (iv) Contribute to the capture, retention and gradual release of plant nutrients; avoid physical or chemical damage to roots and soil organisms that would disrupt their effective functioning.

Keywords: Conservation agriculture, Organic matter, Carbon sequestration.

Introduction: Conservation agriculture is a set of soil management practices that minimize the disruption of the soil's structure, composition and natural biodiversity. Despite high variability in the types of crops grown and specific management regimes, all forms of conservation agriculture share three core principles. These include: maintenance of permanent or semi permanent soil cover (using either a previous crop residue or specifically growing a cover crop for this purpose) minimum soil disturbance through tillage (just enough to get the seed into the ground) regular crop rotations to help combat the various biotic constraints CA also uses or

promotes where possible or needed various management practices listed below: utilization of green manures/cover crops (GMCC's) to produce the residue cover no burning of crop residues Integrated disease and pest management controlled/ limited human and mechanical traffic over agricultural soils. When these CA practices are used by farmers one of the major environmental benefits is reduction in fossil fuel use and greenhouse gas (GHG) emissions. But they also reduce the power/energy needs of farmers who use manual or animal powered systems. Resource Conservation Technology (RCT) has shown to improve, conserve and use

natural resources in a more efficient way through integrated management of available soil, water and biological resources. It is now widely recognised as a viable concept for sustainable agriculture due to its comprehensive benefits in economic, environmental and social terms. Pulses, endowed with unique ability of biological nitrogen fixation, deep root system, low water requirements and capacity to withstand drought, constitute an important component of crop diversification and resource conservation technology. The present bulletin is a compilation of the results of different resource conservation practices like crop diversification, conservation tillage, residue management, raised bed planting and mechanization for resource conservation carried out at IIPR, other research centres and agricultural university.

In South Asia, Bangladesh, India, Nepal, and Pakistan, have devoted nearly half of their total land area of 401.72 million hectare (mha) to feed and provide livelihoods for 1.8 billion people. Rice and wheat are the staple food crops and contribute more than 80% of the total cereal production. Over about 13.5mha of the Indo-Gangetic plains (IGP), spread over the four countries, these two crops are grown in rotation, with other crops such as maize, pigeon pea, sugarcane, and lentil substituting either the rice or wheat crop in some years^[1,2,3,4,5,6,7,8]. The rice–wheat production systems are fundamental to employment, income, and livelihoods for hundreds of millions of rural and urban poor of South Asia^[9]. Despite priority given to rice and wheat research by the national institutions during the 1940s, 1950s and early 1960s, only limited advances were made in productivity. This, combined with unpredictable climatic conditions, meant that South Asia increasingly relied on imported food grains to feed its growing population. The 1960s also witnessed establishment of an international agricultural research system, known as the Consultative Group for International Agricultural Research (CGIAR). The institutions established by the CGIAR included the International Rice Research Institute (IRRI) and Centro Internacional de Mejoramiento de Maize and Trigo (CIMMYT) which gave major boost to international research on rice and wheat, respectively in close partnerships with the national institution, including those in South Asia. The major objective set for this innovative network of national and international working in close collaboration with each other was to develop new

varieties of rice and wheat to improve productivity. Availability of new varieties, responsive to much higher rates of fertilizer use, and expansion of irrigation systems, led to dramatic increases in productivity and total production of rice and wheat in Asia during late 1960s, which continued through the 1970s, 1980s and early 1990s. Other contributing factors to increased production included: suitable thermal regimes for rice and wheat cultivation; expansion of land under rice–wheat cropping systems; and an increasing demand for staple cereals from the rising population with higher incomes.

Although since the 1960s, the growth rate in the South Asian cereal production (on an average wheat 3.0%, rice 2.3% per annum) has kept pace with population growth^[10], evidence is now emerging that continuous cultivation of rice and wheat is lowering soil fertility and organic matter content^[11], depleting ground water resources in tube-well irrigated areas^[12], exacerbating weed problem, including resistance to herbicide,^[13, 14,15] and pest problems^[16]. In addition, micro-nutrient deficiencies, e.g. zinc, boron, sulfur, have also started appearing as a serious concern^[17]. In view of the increasing threat to sustained incremental food production in the IGP, in 1994, the national and the international partners of the CGIAR established the Rice–Wheat Consortium (RWC) as an eco-regional initiative of the CGIAR. The main mandate of the RWC was address concerns related to sustainability of the rice–wheat production systems and to promote technologies that help farmers to reduce cost of production. This paper reviews the outcome of the work supported by RWC to develop resource conserving technologies (RCTs) and their benefits in terms of improved productivity, farm-gate incomes and potential for mitigation of adverse environmental impacts. The paper also examines the role played by different stakeholders in the rapid dissemination of RCTs.

Key Technologies Developed for Sustainable Management of Natural Resources

1. Tillage and Crop Establishment: The conventional system for establishment of wheat crops includes repeated ploughing (6–8 ploughing), cultivating, planking, and pulverizing of topsoil. This has been substituted with direct drilling of wheat using zero-till seed drills fitted with inverted T-openers to place seed and fertilizers into a narrow slot with only minimal of soil disturbance and without land

preparation. Substitution of conventional tillage with zero or minimum tillage for wheat planting in rice–wheat system, especially in the north-western IGP, is a development of regional significance and contributes to the global application of resource conservation technologies (RCTs) in to a new ecosystem. Rice crop is conventionally established as a puddled transplanted crop. Joint efforts of the public institutions and the small-scale private entrepreneurs are giving promising results for development of ‘double no-till’ system where both rice and wheat crops are drilled with minimum cultivation. This required development of new seed drill fitted with either a double disk openers or mechanical dibbler- ‘punch planter’, shredders-spreader (Happy Seeder) or roto-coulter type disk-drills. Experiments have been undertaken with direct-drilling of rice and wheat crops in both flat and raised bed planting systems [18, 19]. In the IGP, new resource conserving technologies and development of appropriate machinery is being combined with novel land and water management approaches for greater efficiency and sustainability of the rice–wheat systems. At the same time, these technologies are generating alternative sources of productivity growth through diversification and intensification of production systems. For example many farmers are now practicing intercropping in raised bed system. In this system wheat is planted on the raised beds and mint or sugarcane in the furrows. Inter-cropping systems such as maize+ potato/onion/redbeets or sugarcane+ chickpea/Indian-mustard are also becoming popular with farmers in western Uttar Pradesh, India.

2. Water Management: The total annual irrigation water requirement of the rice–wheat system ranges from 1100 to 1600 mm/yr [20]. Work initiated in Pakistan in close collaboration with the private sector, and later supported by RWC, has successfully adapted the technique of laser land levelling for use in the rice–wheat system. Laser assisted precision land levelling facilitates application of less water more uniformly under flood irrigation, reduces leaching losses and improves crop-stand and yields. In rice–wheat system, precision land levelling saves irrigation water in wheat season by up to 25%; reduces labor requirements by up to 35%; leads to about 2% increase in the area irrigated due to removal and/or reduction in size of bunds made to impound water for rice cultivation; and increases crop yields by up to

20% [21]. Further work is now in progress in all the RWC countries to integrate other land-preparation and crop-establishment methods with laser levelling to reduce water use at the field/farm/basin levels [22].

3. Nutrient Management: In the case of nitrogen, findings from IRRI’s research on matching site-specific capacities of the soil to supply nutrients and to the demand of crop(s) in the system have been reflected in the development of a leaf color chart (LCC) to help farmers select the right dose and time of application for optimum response in rice. Efforts have also been made to extend the LCC technology to wheat crop by synchronising N application with irrigation practices [23,22]. The LCC has been widely distributed to tens of thousand farmers in the consortium countries to assess response. LCC technology has the potential to save about 15–20% of N fertiliser application in rice [24,22]. The work on other nutrients is less advanced at the farm level although a careful examination of long-term experiments undertaken in the consortium countries by the RWC is identifying nutrient mining (such as of K) and imbalances, along with the loss of C in some situations, as contributing factors to reduced yields [25]. These nutrient management strategies are now being adapted to new crop and tillage systems in presence of residues retained on the soil surface.

4. Crop Improvement and Management: The research on the rice–wheat systems is providing useful information to the component commodity programs of the International Agricultural Research Centres (IARCs) and the National Agricultural Research Institutes (NARIs). As a result rice breeders have given greater attention to such traits as early maturity to allow earlier wheat planting to open opportunities for introduction of short-season crops, e.g. pulses, potatoes. More recent commodity research programs in wheat and rice are examining the genotype tillage interactions of cultivars under zero-till, raised-bed and surface seeding situations for their ability to compete with weeds. These developments are also contributing to a broader debate about the need for modification of selection criterion in the breeding programs to accommodate new crop establishment and management practices. As more farmers use the new RCTs, there will be a need to adapt crop, variety, fertilizer, water and pest management practices to new systems in relation to local needs. This is already beginning to happen in the

management of the herbicide resistant weed *Phalaris minor*. In India *P. minor* is an important weed in the wheat crop. Continuous use of isoproturon for the control of this weed has led to development of severe resistance to this herbicide. To overcome this problem integrated approaches involving rotations of crops and other herbicides (e.g. clodinafop, fenoxaprop, sulfosulfuron, tralkoxydim) have been recommended. The use of zero-tillage for wheat planting is emerging as a new tool in integrated weed management. In the short-term it reduces weed population due to elimination of tillage^[26,27] and in conjunction with new herbicides provides effective weed control at lower rates, especially when closer row spacing is adopted^[28].

7. Crop Yield: Researchers from both Pakistan and India are reporting higher wheat yields following adoption of zero-tillage in rice-wheat rotations. In 34 zero-tillage on-farm trials over 3 years in the rice-growing belt of the Pakistan Punjab, higher yields observed with zero-tillage. This is largely due to the time saved in land preparation that enabled a more timely planting of wheat crop. It has been reported from the simulation study that planting time of wheat regulates yield, governed by the climatic parameters, mainly through temperature and delayed planting results in significant losses in yield^[29]. Although a statistical treatment to data from Haryana, India, included in Table 6 was not possible, zero-tillage plots again gave higher yields compared to conventional tillage (based either on farmer survey or crop-cutting experiments in farmers' fields), which over districts and sowing time averaged at around 270 kg/ha (wheat yield of 5380 and 5110 kg/ha for zero till and conventional tillage, respectively).

8. Impact on the Environment: Straw retained on the soil surface reduces weed seed germination and growth, moderates soil temperature and reduces loss of water through evaporation. In addition, crop residue is also an important source of fodder for animals in the IGP countries. Despite these potential benefits, however, large quantities of straw (left over after rice and wheat harvesting) are burnt each year by farmers to facilitate land preparation for crop planting. It is estimated that the burning of one ton of straw releases 3 kg particulate matter, 60 kg CO, 1460 kg CO₂, 199 kg ash and 2kg SO₂. With the development of new drills, which are able to cut through crop residue, for zero-tillage crop planting, burning of straw can be avoided, which amounts to as much as 10 tons per hectare,

potentially reducing release of some 13–14 tons of carbon dioxide^[30]. Elimination of burning on just 5 million hectares would reduce the huge flux of yearly CO₂ emissions by 43.3 million tons (including 0.8 million ton CO₂ produced upon burning of fossil fuel in tillage). Zero-tillage on an average saves about 60 l of fuel per hectare thus reducing emission of CO₂ by 156 kg per hectare per year^[31, 30]. Adoption of RCTs which allow alterations in water, tillage and surface residue management practices can have a direct effect on emissions of greenhouse gases (GHGs) and enhance the carbon stocks of the soil. Soil submergence in rice cultivation leads to unique processes that influence ecosystem sustainability and environmental services such as carbon storage, nutrient cycling and water quality. For example the submergence of soils promotes the production of methane by anaerobic decomposition of organic matter. However, worries that such rice systems are a major contributor to global warming were allayed through a wide-scale study in the region^[31]. It has been noticed that methane emissions from rice fields range from 16.2 to 45.4 kg/ha during the entire season, whereas nitrous oxide emission under rice and wheat crops amounts to 0.8 and 0.7 kg/ha, respectively^[32]. Incorporation of straw increases methane emissions under flooded conditions, but surface management of the straw under aerated conditions and temporary aeration of the soils can mitigate these effects. Thus, adoption of aerobic mulch management with reduced tillage is likely to reduce methane emissions from the system. The water regime can strongly affect the emission of nitrous oxide, another GHG, which increases under submergence, and is negligible under aeration. Any agronomic activity that increased nitrous oxide emission by 1 kg/ha needs to be offset by sequestering 275 kg/ha of carbon, or reducing methane production by 62 kg/ha. Adoption of RCTs would favour the decrease of this GHG. In order to minimize nitrate pollution of ground water, volatilization losses of fertilizer N in rice/wheat, and address issues of crop residue burning, receding water table and emission of GHG, measures such as introduction of a legume crop (Mung bean) between wheat and rice, deep placement of nitrogenous fertilisers and raised bed planting and laser land levelling have been developed. With further refinement of double disk planters, punch planter and rotodisk- drill it has become easier to plant crops with through retained residues. These implements are now

being evaluated in farmer participatory trials along with modified fertilizer and irrigation practices^[22, 33]. Given the potential of RCTs to influence all the major GHGs, and underground water reserves and its quality, in planning future research it is important that due consideration is given to potential positive and negative impacts of agronomic and crop management practices on the environmental quality.

Conclusion: RCTs, which encompass practices that enhance resource- or input-use efficiency; provide immediate, identifiable, and demonstrable economic benefits such as reductions in production costs, and savings in water, fuel, and labor requirements; and ensure timely crop establishment and uniform crop stands, resulting in higher crop yields. Indirect benefits of RCTs include effective control of *Phalaris* minor weed in wheat by zero-tillage; replacement of residue burning by retention of crop residues in the RW system, resulting in short-term soil carbon sequestration; reduction in methane emission from nonpuddled and nonflooded rice fields; buildup of soil fertility over the long term, leading to sustainability of intensive rice-wheat cultivation; and generation of rural employment by training and empowering local farm machine manufacturers, custom-hire service providers, retailers and traders, and seed producers. While tillage and crop establishment options have been more successful in wheat, the next frontier will be to make similar headway in rice. In addition, integrated crop management (good agronomy) will continue to be a key to improving productivity and production and eventually attaining national food security. What we need now is to develop an effective program for wider dissemination of proven RCTs and ICMR to deprived farming communities outside project areas to realize their great impact on food security and farmers' livelihood in South Asia. For this to happen, we need to sensitize agricultural policymakers and encourage them to allocate more resources for wider dissemination of successful RCTs in the region. In addition, there are needs to (a) foster new models of public-private partnerships, especially for faster, scalable, and sustainable delivery of improved crop and resource management technologies along with associated knowledge; and (b) create a highly qualified professional workforce for private- and public-sector extension by establishing a Certified Crop Advisor (CCA) program. The changes in the RWSs have the

potential to change the balance in global warming gases. Reduced tillage increases carbon accumulation in the soil and reduces fuel-based emissions. Soil submergence is the dominant feature of present rice cultivation in the IGP and leads to unique biogeochemical processes that influence methane and nitrogen gas emissions and nutrient availability. Changes in rice culture to a more aerated system could change the balance of these gases for the better.

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