Synergies of resource-conserving technologies in rice-based systems[1]

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Resource-conserving technologies (RCTs) have become popular in many cropping systems as a response to increasingly limited agricultural production resources and in view of the projected demand for agricultural products. Worldwide experiences have shown synergies between RCTs when they are applied in combination as, for example, in conservation agriculture.
Conservation agriculture (CA) is a concept for resource-saving agricultural crop production characterized by three principles that are linked to each other: zero tillage, soil cover, and crop rotations. As such, CA is being applied worldwide in different agro-climatic zones and farming situations, providing socioeconomic benefits for farmers and environmental services. Traditional paddy rice cultivation practices involve intensive soil tillage during puddling operations not compatible with the concept of CA. Adapting rice growing to CA principles is possible and is being progressively implemented. Besides offering the known benefits of CA, adoption in rice would bring further benefits for saving water as an increasingly scarce resource and providing scope to address greenhouse gas emissions from rice paddies without sacrificing production potential.

The traditional paddy production system involving puddling results in destruction of soil structure and has come under increasing pressure from conservationists. Water consumption of traditionally puddled rice is restricted in some areas, which has forced people to look for alternatives. The cultivation of summer rice, grown prior to the monsoon season, is not allowed in parts of northern India. In Karakalpakstan, adjacent to the Aral Sea in Uzbekistan, rice cultivation is restricted in view of the scarce water resources and high evaporation losses. In China, the paddy rice areas around the city of Beijing have been replaced by other crops due to the alarmingly falling groundwater table. Also, the traditional approach faces criticism because of the release of greenhouse gases such as methane (Gao 2006).

In view of this scenario, a number of resource-conserving technologies (RCTs) have been developed with the objective of reducing the use and damage of natural resources through agricultural production and increasing the efficiency of their use. The next section discusses in detail some of the main RCTs.

Resource-conserving technologies

Most RCTs have been aiming at the two most crucial natural resources, water and soil. However, some of them would also affect the efficiency of other production resources and inputs such as labor and farm power or fertilizer.

[1] The views expressed in this paper are the personal opinion of the authors and do not necessarily reflect the official policy of FAO.

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Agriculture accounts for 70% of the actual water use (FAO 2002). Predictions are that by 2025 water consumption will exceed the available "blue water" if the current trends continue (Ragab and Prudhomme 2002). In the Indian state of Punjab, characterized by intensive irrigated agriculture, the groundwater table is falling at a rate of 0.7 m per year (Aulakh 2005). Rising temperatures and evapotranspiration rates combined with more erratic rainfall aggravate water problems in rainfed agriculture (Met Office 2005).

Soil affects both production and other natural resources, specifically water. Soil structure is strongly correlated to organic matter content and soil life. Organic matter stabilizes soil aggregates, provides feed to soil life, and acts as a sponge for soil water. With intensive tillage-based agriculture, soil organic matter is steadily decreasing, leading first to a decline in productivity, later to visible signs of degradation, and finally to desertification (Shaxson and Barber 2003). The lack of yield response to a high fertilizer dose in the Indo-Gangetic Plains can be attributed to deteriorated soil health as a result of overexploitation (Aulakh 2005). In the Indian states of Uttaranchal and Haryana, the organic carbon content in soil reaches minimum values below 0.1% (PDCSR 2005). Agricultural production worldwide has led to soil degradation, more pronounced in tropical regions, but also in moderate climatic zones. The world map of degraded soils indicates that nearly all agricultural lands show some level of soil degradation (FAO 2000).

Some of the more popular RCTs, particularly in irrigated or rice-based cropping systems, are the following: (1) *laser leveling:* for surface-irrigated areas, a properly leveled surface with the required inclination according to the irrigation method is absolutely essential. Traditional farmers' methods for leveling by eyesight, particularly on larger plots, are not accurate enough and lead to extended irrigation times, unnecessary water consumption, and inefficient water use. The use of laser-guided equipment for the leveling of surface-irrigated fields has become economically feasible and, through hiring services, become accessible even to lower-income farmers. With laser leveling, the unevenness of the field is reduced to about ±2 cm, resulting in better water application and distribution efficiency, improved water productivity, better fertilizer efficiency, and reduced weed pressure. Water savings of up to 50% have been reported in wheat and 68% in rice (Jat et al 2006). (2) *Bed planting:* Bed planting refers to a cropping system where the crop is grown on beds and irrigation water is applied in furrows between the beds. This is a common practice for row crops, but not for small grain crops such as wheat and rice. The advantages are improved fertilizer efficiency, better weed control, and a reduced seed rate. The most important one as an RCT is the saving of irrigation water because of reduced evaporation surface and efficiency in distribution. In addition, the rooting environment is changed and aeration of the bed zone is better than with flat planting. Water savings compared to flat surfaces of 26% for wheat and 42% for transplanted rice have been reported, with yield increases at the same time of 6.4% for wheat and 6.2% for rice (RWC-CIMMYT 2003). (3) *Direct seeding:* Direct seeding of rice compared with transplanted rice saves water as there is no puddling. There are huge savings of labor and fuel. Further, the total growing period from seed to seed is reduced by about 10 days and yields and water efficiency of the following rotation crops other than rice are increased (PDCSR 2005). However, weed management is more difficult in dry direct-seeded rice (RWC-CIMMYT 2003). (4) *Reduced tillage, zero-tillage:* Intensive soil tillage is the main cause for the reduction in soil organic matter and hence degradation of soils. Tillage accelerates the mineralization of organic matter and destroys the habitat of soil life. To the extent that soil tillage is reduced or eliminated, soil life returns and the mineralization of soil organic matter decreases. This results in better structuring of the soil. Under zero-tillage, the mineralization of soil organic matter can be reduced to levels inferior to the input converting the soil into a carbon sink. In addition to this, zero-tillage results in water savings and improved water-use efficiency. Since the soil is not exposed through tillage, the unproductive evaporation of water decreases. At the same time, water infiltration is facilitated (DBU 2002). The possible water savings through zero-tillage vary depending on the cropping system and climatic conditions. On average, water savings of about 15–20% can be expected (PDCSR 2005). However, used in isolation, zero-tillage might face problems with weed control, compaction, or surface crusting depending on the soil type. (5) *Mulching and green manure:* The supply of organic matter to the soil through mulching and green manure is an important factor for maintaining and enhancing soil fertility. The mulching material can result from crop residues or green manure crops. This provides feed for the soil life and mineral nutrients for plants. If legume crops are used as green manure, they can supply up to 200 kg ha^{-1} nitrogen to the soil. This can result for rice in savings of mineral fertilizer of 50–75% (RWC-CIMMYT 2003). Left on the soil surface, the mulch reduces evaporation, saves water, protects from wind and water erosion, and suppresses weed growth. (6) *Controlled traffic farming:* Controlled traffic farming restricts any traffic in the field to always the same tracks. Although these tracks are heavily compacted, the rooting zone never receives any compaction, resulting in better soil structure and higher yields. Through border effects, the area lost in the traffic zones is easily compensated for by better growth of plants adjacent to the tracks so that overall yields are usually higher than in conventional systems with random traffic (Kerr 2001). Obviously, controlled traffic farming is the ideal complement to zero-tillage or bed-planting systems. Also in conventional agriculture, controlled traffic provides advantages through time and fuel savings since the resistance to soil tillage in the compaction-free rooting zones is significantly lower and traction is more efficient when tires work on compacted tracks (RWC-CIMMYT 2003). However, in this case, provision must be made either by GPS guidance or visible bed and furrow systems to limit tillage operations to the rooting zones and not to disturb the tracks.

Synergies between resource-conserving technologies: the concept of conservation agriculture

The examples of RCTs have already indicated a certain scope for synergies, for example, between bed planting and controlled traffic or mulching and zero-tillage. At the same time, any of these technologies used in isolation faces limitations or specific problems, such as surface crusting or weed problems in direct-seeded rice or zero-tillage under irrigated conditions. The combination of RCTs taking advantage exactly of those synergetic effects has become popular under the term conservation agriculture.

Conservation agriculture (CA) is defined as a concept for resource-saving agricultural crop production that strives to achieve acceptable profits and high and sustained production levels while concurrently 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 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 do not interfere with or disrupt biological processes. CA is characterized by three principles that are linked to each other:

1. Minimum mechanical soil disturbance throughout the crop rotation.
2. Permanent organic soil cover.
3. Diversified crop rotations for annual crops or plant associations for perennial crops.

During the last decade, conservation agriculture has been gaining popularity worldwide. It is now applied on about 95 million ha (Derpsch 2005). Together with other organizations and stakeholders, FAO has been promoting and introducing CA in several countries in Latin America, Africa, and Asia. By applying these three principles, CA has been adapted to different climatic conditions from the equatorial tropics to the vicinity of the polar circle and to different crops and cropping systems, including vegetables, root crops, and paddy rice.

Since the soil is never tilled, the soil structure changes. A system of continuous macro pores is established, facilitating water infiltration and aeration of the soil as well as root penetration into deeper zones. Soil organic matter contents increase, with higher values near the surface, gradually declining at increased depth. Soil macro- and microfauna and -flora are re-established, resulting in better soil fertility.

The permanent soil cover through crops, mulch, or green manure cover crops complements zero-tillage effects by supplying substrate for soil organic matter buildup and for soil life, which is facilitated by not disturbing the soil. Through protection of the soil surface, the mulch is reducing evaporation and avoiding crusting. It also suppresses weed growth. Problems experienced in direct seeding or zero-tillage when applied in isolation are reduced in this way. On the other hand, the application of zero-tillage and direct-seeding technology facilitates the management of residues, which in conventional systems are often considered a problem.

The same applies for crop rotations. Besides phytosanitary and weed management objectives, crop rotations serve to open different soil horizons with different rooting types.

In systems where surface irrigation is applied, bed planting would provide the benefits of water savings. Under CA, the beds would be converted into permanent beds, whereas any soil tillage would be limited to a periodic cleaning and reshaping of furrows. The same permanent bed system would be applicable under CA also for crop rotations, which include crops grown on beds, for example, for drainage purposes. However, the precondition for such a permanent bed system is the harmonization of furrow distances and bed width for all crops in the rotation and for all mechanized traffic operations. In this way, a permanent bed system leads also to controlled traffic taking additional advantage of that RCT.

Direct seeding is another complement to conservation agriculture. Although transplanting of crops, including paddy rice, is possible under zero-tillage, direct seeding is preferable for the reasons mentioned above. In addition, direct seeding results in less soil movement than transplanting, which often involves some sort of strip tillage. At the same time, CA facilitates direct seeding by reducing several problems, such as surface crusting or weed control, encountered when direct seeding is applied in isolation.

Laser leveling provides the same benefits to conservation agriculture as to conventional agriculture under surface irrigation conditions. However, it involves significant soil movement in the beginning and would be considered as an initial investment before converting to a permanent zero-tillage cropping system as CA. The benefits are long term as no further soil tillage would accrue.

Impact of conservation agriculture

Under CA, the levels of soil erosion are inferior to the buildup of new soil. On average, the soil under CA "grows" at a rate of 1 mm per year because of the accumulation of soil organic matter. This growth continues until a new point of saturation is reached in the soil, which takes 30 to 50 years (Crovetto 1999). The organic matter levels rise by 0.1–0.2% per year due to the residues left on the soil surface, the remaining root biomass, and reduced mineralization. Within a crop rotation, different root systems structure different soil horizons and improve the efficiency of soil nutrient use. In general, the soil structure becomes more stable (Bot and Benites 2005).

Soils under CA improve water efficiency. The increased amount of continuous vertical macro pores facilitates the infiltration of rainwater into the ground and hence a recharge of the aquifer. The increased soil organic matter levels improve the availability of water accessible to plants. Some 1% of organic matter in the soil profile can store water at 150 $m^3\ ha^{-1}$. The permanent soil cover and the avoidance of mechanical soil tillage reduce the unproductive evaporation of water. Also, the water requirements for a crop can be reduced by about 30%, under either irrigation or rainfed conditions (Bot and Benites 2005).

In addition to the quantitative benefits, the reduced leaching of soil nutrients and farm chemicals together with reduced soil erosion leads to a significant improvement in water quality in watersheds where CA is applied (Bassi 2000, 2002). Conservation agriculture can reduce the overall requirement for farm power and energy for field production by up to 60% compared with conventional farming (Doets et al 2000) because of a decrease in tillage. Finally, long-term experiences with CA show a decline in the use of agrochemicals due to enhanced natural control processes.

FAO has been working on rice-based CA systems in China and DPR Korea, while in the Indo-Gangetic Plains the Rice-Wheat Consortium has been introducing RCTs into rice-based cropping systems with good success. Not puddling or even zero-tillage in rice resulted in higher yields of other nonrice crops in the crop rotations. The reported water savings through RCTs in paddy rice was usually higher than in other rotation crops (PDCSR 2005). Cropping systems involving residue retention and zero-tillage were best performing in terms of profitability, yield, and resource conservation, whereas conventional systems and zero-tillage systems without residue retention were inferior.

In addition to resource-conserving effects, the cropping systems involving permanent zero-tillage, so called "double zero-tillage"[2] and residue retention, resulted in significantly increased water infiltration rates (PDCSR 2005). In this way, the experiences and results obtained in CA in other cropping systems could be confirmed also for rice-based cropping systems. The Rice-Wheat Consortium has developed technologies that allow the application of CA in rice-based cropping systems (RWC-

[2] This term is used in rice-wheat cropping in South Asia to describe a system where both rice and wheat are cropped under zero-tillage.

CIMMYT 2003). Those include laser leveling, permanent bed planting, and the retention of residues, including rice straw. The introduction of sesbania as a cover crop to bridge the gap between the wheat harvest and rice seeding in the rice-wheat system is well accepted by the farming community. This helps with weed control and adds additional nitrogen and organic matter to the system. Direct-seeding equipment has been developed and introduced to the market to seed different crops into residues and under zero-tillage either on flat fields or raised beds (PAU 2006). With the latest model of the Turbo Happy Seeder, a machine has become available that can even cope with seeding into fresh rice straw (Dasmesh 2006).

Over the past decades, extreme climatic events—extreme precipitation as well as extended drought periods or extreme temperatures—have become more frequent and stronger (Met Office 2005). Agricultural production systems are highly vulnerable to those changes.

Conservation agriculture can assist in the adaptation to climate change by improving the resilience of agricultural cropping systems and hence making them less vulnerable to abnormal climatic situations. Better soil structure and higher water infiltration rates reduce the danger of flooding and erosion catastrophes after high-intensity rainstorms. Yield variations under CA in extreme years, under either dry or wet conditions, are less pronounced than under conventional agriculture (Shaxon and Barber 2003, Bot and Benites 2005).

Conservation agriculture can also help to mitigate climate change, at least as far as the release of greenhouse gases is concerned. With increasing soil organic matter, soils under CA can retain carbon from carbon dioxide and store it safely for long periods of time.

Conclusions

Resource-conserving technologies applied in isolation have advantages and disadvantages. For this reason, they are not universally applicable since in some cases the problems outweigh the benefits. However, by combining different RCTs, synergies can be achieved where the disadvantages of single technologies are eliminated while the benefits of the technologies can be accumulated. Different RCTs are successfully applied under the concept of conservation agriculture in different cropping systems around the world, allowing stable agricultural production without the known negative environmental impact.

The Rice-Wheat Consortium of the Indo-Gangetic Plains has been instrumental in adapting the concept of CA to rice-based cropping systems, resulting in higher yield and better profitability of the entire cropping system, enhanced soil fertility, and better water-use efficiency. Thus, a way toward sustainable agricultural production in rice-based systems could be shown. Of particular concern is high water consumption. In regions where cropping mainly depends on groundwater for irrigation purposes and where groundwater tables are falling dramatically, such as in the Punjab of India, water-saving technologies might not be sufficient to assure sustainability of the cropping systems. The combination of different RCTs, such as mulching, direct seeding, and "double zero-tillage," results not only in water savings but also in increased infiltration rates and hence recharge of the aquifer during the monsoon season. In view of the benefits of combined RCTs as conservation agriculture for the farming sector, the environment, and the general public, a more concerted effort for their promotion and adoption is needed. FAO, together with regional partners in the Rice-Wheat Consortium, could play an important role in this process.

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Notes

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