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Conservation agriculture: synergies of resource-conserving technologies in rice-based systems¹

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BACKGROUND

In 2000, about 850 million people were suffering from hunger, 815 million of which in developing countries. From a global perspective, hunger is a problem not of food production but of accessibility, since to date world food production has kept pace with demand (FAO, 2006). Although recent predictions point to reduced population growth, a considerable increase in overall production is still required – a major challenge, given the already stretched land and water resources. Future yield increases may be limited compared to past trends (FAO, 2006), but by 2030, food production must double to keep pace with demand.

The production of renewable resources is increasingly important, due both to the growing awareness of sustainability and to rising oil prices. Countries producing a food surplus could in future focus more and more on the production of profitable renewable raw material for industrial products and energy rather than simply on the production of food (FAO, 2002).

There are also regional differences to be taken into account. Sub-Saharan Africa remains a hunger hot spot with a stagnating trend in per capita food production, while other regions are seeing a steady increase (FAO, 2005). Countries with a large population like China and India, and which in the past achieved food self-sufficiency, now face the challenge of maintaining and increasing high yield levels in a scenario of increasing climatic variability.

Over the last few decades the growth in agricultural production has come mainly from yield increase and to a lesser extent from area expansion. Now the agricultural

land available per capita is expected to decline (FAO, 2002) while revolutionary technologies for significantly higher production potential do not seem to be in sight. Furthermore, in high intensity agricultural production areas, yield increase seems to have reached a ceiling despite higher input use; in some cases, yields even decline, for example in the grain-producing areas of Punjab in India (Aulakh, 2005).

Water is one of the most precious natural resources for agricultural production and agriculture accounts for 70 percent of water use (FAO, 2002). It is predicted that by 2025 water consumption will exceed “blue water” availability if 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). However, the decline of freshwater resources is due not only to increased consumption, but to careless management. Agriculture contributes to the problem by wasting water and by sealing and compacting the soils so that excess water cannot infiltrate and recharge the aquifer – one of the causes of the growing number of flood catastrophes (DBU, 2002). In regions where water is already the limiting factor for agricultural production, this wasteful practice threatens the sustainability of agriculture. Rising temperatures and evapotranspiration rates combined with more erratic rainfall further aggravate the water problems in rainfed agriculture (Met Office, 2005).

Soil affects not only production, but also the management of other natural resources, such as water. Soil structure is strongly correlated with the organic matter content and the soil life. Organic matter stabilizes soil

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

aggregates, provides feed to soil life and acts as a sponge for soil water. With intensive tillage-based agriculture, the organic matter of soil is steadily decreasing, leading first to a decline in productivity, followed by the visible signs of degradation and finally desertification (Shaxon and Barber, 2003). The lack of yield response to high doses of fertilizer in the Indo-Gangetic Plains can be attributed to poor soil health resulting from over-exploitation (Aulakh, 2005). In the Indian states of Uttaranchal and Haryana, the organic carbon content in soils reaches minimum values of less than 0.1 percent (PDCSR, 2005). While soil degradation is more pronounced in tropical regions, it is also a phenomenon in moderate climatic zones; indeed, the world map of degraded soils indicates that nearly all agricultural lands show some level of soil degradation (FAO, 2000).

RESOURCE-CONSERVING TECHNOLOGIES

Resource-conserving technologies (RCT) have been developed in order to:

- reduce the use of and damage to natural resources through agricultural production; and
- increase the efficiency of resource utilization.

Most of these technologies target the two most crucial natural resources: water and soil, but some also affect the efficiency of other production resources and inputs (e.g. labour, farm power and fertilizer). Some of the more popular RCTs, particularly in irrigated or rice-based cropping systems, are described below.

Laser levelling

For surface irrigated areas it is essential to have a properly levelled surface with the appropriate inclination for the irrigation method adopted. Traditional farmers' methods for levelling by eyesight are not sufficiently accurate (particularly on larger plots), resulting in extended irrigation times, unnecessary water consumption and inefficient water use. The use of laser-guided equipment for the levelling of surface-irrigated fields has become economically feasible and accessible – through hiring services – even to lower-income farmers. Laser levelling reduces the unevenness of the field to about ± 2 cm, resulting in better water application and distribution efficiency, improved water productivity, increased fertilizer efficiency and reduced weed pressure. Savings of up to 50 percent in wheat and 68 percent in rice have been reported (Jat *et al.*, 2006).

Bed planting

Bed planting refers to a cropping system where the crop is grown on beds and the irrigation water is applied in furrows between the beds. This is common practice for row crops, but not for small grain crops such as wheat and rice. The technique offers a number of advantages, such as improved fertilizer efficiency, better weed control and reduced seed rate. It also saves irrigation water compared to a flat inundated field: the evaporation surface is reduced and water application and distribution efficiency are increased. In addition, the rooting environment is changed and the aeration of the bed zone is better than in flat planting. Reported water savings (compared to flat surfaces) reach 26 percent for wheat and 42 percent for transplanted rice, and yield increases 6.4 percent for wheat and 6.2 percent for rice (RWC-CIMMYT, 2003).

Direct seeding

Direct seeding of rice – compared with transplanting – may be considered an RCT:

- It saves labour and fuel.
- Seeding into dry soil saves water as there is no puddling.
- The total growing period from seed to seed is reduced by about 10 days.
- Yields and water efficiency of the subsequent rotation crops are increased (PDCSR, 2005).

On the other hand, weed management is more difficult in dry direct-seeded rice than in puddled and transplanted rice (RWC-CIMMYT, 2003).

Reduced tillage, zero tillage

Intensive soil tillage is the main cause of reduced soil organic matter and hence of soil degradation. Tillage accelerates the mineralization of organic matter and destroys the habitat of the soil life. On the contrary, when soil tillage is reduced or eliminated, soil life returns and the mineralization of soil organic matter slows down, resulting in better soil structure. 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 (Reicosky, 2001). Zero tillage also results in water saving and improved water-use efficiency: since the soil is not exposed through tillage, the unproductive evaporation of water is reduced while water infiltration is facilitated (DBU, 2002). The potential water saving through zero tillage varies according to the cropping

system and the climatic conditions. On average, water savings of 15 to 20 percent can be expected (PDCSR, 2005). Used in isolation, however, zero tillage can lead to problems with weed control, compaction or surface crusting, depending on the soil type.

Mulching and green manure

The supply of organic matter to the soil through mulching and green manure is important for maintaining and enhancing soil fertility. Mulching material can come from crop residues or green manure crops; it provides feed for the soil life and mineral nutrients for the plants. If legume crops are used as green manure they can supply up to 200 kg/ha of nitrogen to the soil; in the case of rice, this can result in mineral fertilizer savings of 50 to 75 percent (RWC-CIMMYT, 2003). The spreading of mulch on the soil surface reduces evaporation, saves water, protects from wind and water erosion, and suppresses weed growth.

Controlled traffic farming

Controlled traffic farming restricts any traffic in the field to the same tracks. While these tracks become heavily compacted, the rooting zone does not at all, resulting in better soil structure and higher yields. 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). Controlled traffic farming is the ideal complement to zero tillage or to bed planting systems, but it also provides advantages in conventional agriculture through time and fuel savings, since resistance to soil tillage in the compaction-free rooting zones is significantly lower and traction is more efficient when tyres work on compacted tracks (RWC-CIMMYT, 2003). In the latter case, either GPS (global positioning system) guidance or visible bed and furrow systems must be used to limit the tillage operation to the rooting zones and to not disturb the tracks.

SYNERGIES BETWEEN RESOURCE-CONSERVING TECHNOLOGIES

Resource-conserving technologies provide scope for synergy, for example, between bed planting and controlled traffic or mulching and zero tillage. Used in isolation, any of these technologies may face specific problems (e.g. surface crusting or weeds in direct seeding rice) or have limitations (e.g. zero tillage under irrigated conditions).

The combination of resource-conserving technologies working in synergy is commonly referred to as “conservation agriculture” (CA).

Conservation agriculture

Conservation agriculture (CA) is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits 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 external inputs – e.g. agrochemicals and nutrients of mineral or organic origin – are applied at an optimum level taking care to not interfere with or disrupt the biological processes. CA is characterized by three interlinked principles:

- minimum mechanical soil disturbance throughout the entire crop rotation;
- permanent organic soil cover; and
- diversified crop rotations in the case of annual crops or plant associations in the case of perennial crops.

During the last decade, CA has been gaining in popularity throughout the world and 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. CA adapts 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.

Zero tillage

When the soil is not tilled, the soil structure changes. A system of continuous macropores is established, facilitating water infiltration and soil aeration as well as root penetration into deeper zones. Soil organic matter content increases, with higher values near the surface, gradually decreasing with depth. Soil macro- and microfauna and flora is re-established resulting in better soil fertility.

Soil cover

The permanent soil cover through crops, mulch or green manure cover crops complements the effects of zero tillage by supplying substrate for soil organic matter build-up and for the soil life which is facilitated by not disturbing the soil. By protecting the soil surface, the mulch reduces evaporation, avoids crusting and

suppresses weed growth. Problems experienced in direct seeding or zero tillage (applied in isolation) are thus reduced. It should also be noted that the application of zero tillage and direct seeding facilitates the management of residues which in conventional systems are often considered a problem.

Crop rotation

In addition to the phytosanitary and weed management benefits, crop rotation serves to open different soil horizons with different rooting types. While conventional agriculture “cultivates the land”, using science and technology to dominate nature, conservation agriculture tries to “least interfere” with natural processes. Similar thoughts have been developed over the past 50 years in the Far East by Masanobu Fukuoka (1975) and applied in rice-based farming.

Permanent beds

In systems where surface irrigation is applied, bed planting results in water saving. Under CA, the beds are converted into permanent beds and soil tillage is limited to a periodic cleaning and reshaping of the furrows. The same permanent bed system is applicable under conservation agriculture also for crop rotations, which include crops grown on beds (e.g. for drainage purposes). The furrow distances and bed width must be harmonized for all crops in the rotation and for all mechanized traffic operations. In this way a permanent bed system leads also to controlled traffic, another RCT.

Direct seeding

Direct seeding is another complement to CA. Although transplanting of crops, including paddy rice, is possible under zero tillage, direct seeding is preferable for the reasons mentioned above. Direct seeding results in less soil movement than transplanting, which often involves some sort of strip tillage. CA facilitates direct seeding by reducing a number of problems encountered when direct seeding is applied in isolation (e.g. surface crusting or weed control).

Laser levelling

The benefits of laser levelling in conservation agriculture are as for conventional agriculture under surface irrigation conditions. To begin with, significant soil movement is required, and so laser levelling is considered an initial investment before converting to a permanent zero tillage

cropping system (i.e. conservation agriculture). The investment in laser levelling lasts much longer than in conventional systems, since under CA no further soil tillage (which could upset the levelling of the field) is applied.

Effects of CA

Under CA the levels of soil erosion are inferior to the build-up of new soil. The soil under CA “grows” at an average rate of 1 mm per year due to 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 percent per year due to the residues left on the soil surface, the remaining root biomass and the reduced mineralization. Within a crop rotation, different root systems structure different soil horizons and improve the efficiency of the soil nutrient use. In general the soil structure becomes more stable (Bot and Benites, 2005).

Soils under conservation agriculture also improve water efficiency. The increased amount of continuous vertical macropores facilitate the infiltration of rainwater into the ground and help recharge the aquifer. The increased soil organic matter levels improve the level of water accessibility to plants: 1 percent of organic matter in the soil profile can store water at a rate of 150 m³/ha. The permanent soil cover and the avoidance of mechanical soil tillage reduce the unproductive evaporation of water, water-use efficiency is increased and a crop’s water requirements can be reduced by about 30 percent under both irrigation and rainfed conditions (Bot and Benites, 2005). In addition to the quantitative benefits, reduced leaching of soil nutrients and farm chemicals together with reduced soil erosion lead to a significant improvement in the water quality in watersheds where CA is applied (Bassi, 2000; Saturnino and Landers, 2002).

CA can reduce the overall requirement for farm power and energy for field production by up to 60 percent compared to conventional farming (Doets, Best and Friedrich, 2000). This is due to the fact that the most power-intensive operations, such as tillage, are eliminated and equipment investment, particularly the number and size of tractors, is significantly reduced (Bistayev, 2002). CA produces a decline in the use of agrochemicals due to enhanced natural control processes: natural control of pests and diseases improves over time and experience in weed management through crop rotations also facilitates

this long-term decline in agrochemical use (Saturnino and Landers, 2002). The same is true for mineral fertilizer: less fertilizer is lost through leaching and erosion and the different rooting systems recycle more soil nutrients from a larger soil volume, resulting in improved overall efficiency of fertilizer use in the long term with a significant reduction in the fertilizer requirements to maintain the production and soil nutrient levels over the crop rotation (Saturnino and Landers, 2002).

Climate and climate change

Recent decades have seen an increase in the frequency and strength of harsh climatic events, including very high precipitations as well as extended drought periods and extreme temperatures (Met Office, 2005). Agricultural production systems are highly vulnerable to these changes.

Conservation agriculture can assist in the adaptation to climate change, by improving the resilience of agricultural cropping systems and making them less vulnerable to abnormal climatic situations. Better soil structure and higher water infiltration rates reduce the danger of flooding and erosion following high intensity rainstorms (Saturnino and Landers, 2002). Increased soil organic matter levels improve the water-holding capacity and hence the ability to cope with extended drought periods. Yield variations under CA in extreme years (dry or wet) are less pronounced than under conventional agriculture (Shaxon and Barber, 2003; Bot and Benites, 2005).

But CA also helps mitigate the effects of climate change, at least with regard to the emission of greenhouse gases. With the increasing soil organic matter, soils under CA can retain carbon from carbon dioxide and store it safely for long periods of time. This carbon sequestration continues for 25 to 50 years before reaching a new plateau of saturation (Reicosky, 2001). The consumption of fossil fuel for agricultural production is significantly reduced under CA and burning of crop residues is completely eliminated, which also contributes to a reduction in greenhouse gas release. Soils under zero tillage – depending on the type of management – might also emit less nitrous oxide (Izaurrealde *et al.*, 2004). With paddy rice in particular, the change to zero tillage systems combined with adequate water management can positively influence the release of other greenhouse gases, such as methane and nitrous oxides (Belder 2005; Gao 2006).

CONSERVATION AGRICULTURE IN RICE-BASED CROPPING SYSTEMS

Irrigated paddy rice has for a long time been considered a stable and sustainable cropping system, although it is far from being conservation agriculture (the puddling results in the destruction of the soil structure). However, irrigated rice is increasingly subject to pressures:

- The high fuel costs of puddling and the reduced availability of labour mean that there is pressure to change from transplanted to direct-seeded rice.
- The water consumption of traditionally puddled rice is too high in many regions – alternatives must be found and rice growing is already restricted in some areas: 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 because of the scarce water resources and the high evaporation losses; in China, the paddy rice areas around the city of Beijing have been replaced by other crops due to the alarming fall in the ground-water table.
- The release of greenhouse gases such as methane is high in traditionally flooded rice (Gao, 2006).

Rice cultivation has therefore been adapted to conservation agriculture in several countries. Rice can be cultivated without puddling or permanent flooding by adopting resource-conserving technologies. FAO has been working on rice-based CA systems in China and the Democratic People's Republic of Korea, while in the Indo-Gangetic Plains the Rice-Wheat Consortium has been successfully introducing RCTs into rice-based cropping systems. Neither puddling nor zero tillage in rice result in higher yields of the non-rice crops in the crop rotations. The reported water saving through RCTs is usually higher in paddy rice than in other rotation crops (PDCSR, 2005). Cropping systems involving residue retention and zero tillage perform better in terms of profitability, yields and resource conservation, while conventional systems and zero tillage systems without residue retention are inferior. In addition to the resource-conserving effects, the cropping systems involving permanent zero tillage, so-called “double zero tillage”²

² Term used in rice-wheat cropping in South Asia to describe a system where both, rice and wheat, are cropped under zero tillage.

and residue retention result in significantly increased water infiltration rates (PDCSR, 2005).

The experiences and results obtained in CA in other cropping systems can be confirmed for rice-based cropping systems. This includes options for mitigating climate change by sequestering carbon in the soil and reducing the emission of other greenhouse gases (Gao, 2006). The Rice-Wheat Consortium has developed technologies which allow the application of conservation agriculture in rice-based cropping systems (RWC-CIMMYT, 2003): laser levelling, permanent bed planting and the retention of residues (including rice straw). In rice-wheat systems, the introduction of sesbania as a cover crop to bridge the gap between the wheat harvest and rice seeding is well accepted by the farming community. It 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). The latest model of the “Turbo Happy Seeder” can even cope with seeding into fresh rice straw (Dasmesh, 2006).

CONCLUSIONS

Resource-conserving technologies applied in isolation have advantages and disadvantages; they are not universally applicable as the problems can sometimes outweigh the benefits. However, by combining different resource-conserving technologies, synergies can be created to eliminate the disadvantages of single technologies and accumulate the benefits.

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 conservation agriculture to rice-based cropping systems, resulting in higher yields, greater profitability, enhanced soil fertility and better water-use efficiency – it represents a possible route towards sustainable agricultural production in rice-based systems. High water consumption is a particular concern. In regions where cropping mainly depends on groundwater for irrigation purposes and where the groundwater tables are falling dramatically, such as in the Punjab of India, water-saving technologies might not be sufficient to guarantee sustainability of the cropping systems. The combination of different RCTs –

such as mulching, direct seeding and double zero tillage – results not only in water saving but also in increased infiltration rates (and hence the recharge of the aquifer during the monsoon season).

Combined resource-conserving technologies applied in conservation agriculture produce benefits for the farming sector, the environment and the general public, and it is therefore important to promote and adopt them. FAO and regional partners, such as the Rice-Wheat Consortium, can play an important role in this process.

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Agriculture de conservation: synergies entre technologies de conservation des ressources dans les systèmes de production à base de riz

L'Agriculture de conservation (AC) se définit comme un concept visant à un type de production agricole économe en ressources de base, tout en gardant une rentabilité acceptable et un niveau de production à la fois élevé et durable, le tout dans le respect de l'environnement. L'AC a pour principe de base l'intensification des processus biologiques, tant au dessus de la surface du sol qu'en dessous. Les interventions telles que le labour physique du sol sont maintenues à un minimum absolu, et le recours aux

intrants extérieurs tels que produits agrochimiques et nutriments d'origine minérale ou biologique est optimisé, de façon à respecter les processus biologiques sans leur opposer d'obstacle ou de contrainte. L'AC se caractérise par trois principes liés entre eux:

1. Un minimum de bouleversement mécanique du sol tout au long du cycle cultural.
2. La permanence d'un couvert organique du sol.
3. Rotations de cultures diversifiées dans le cas des cultures annuelles, et

associations de cultures diversifiées en cas de cultures pérennes.

Les façons culturales traditionnelles en riziculture font appel à un travail du sol intensif à l'occasion de la mise en boue – ce qui n'est pas compatible avec le concept de l'AC. Cependant, la riziculture peut s'adapter aux principes de l'AC tels qu'ils sont mis en œuvre de façon de plus en plus courante. Outre les avantages qu'on lui connaît déjà, l'application de l'AC à la riziculture conduirait également à une économie d'eau (une ressource

de plus en plus rare) et contribuerait à la solution du problème des émissions de gaz d'effet de serre à partir des rizières – sans pour autant compromettre le potentiel de

production. Le document explique le concept et les principes de l'AC et examine l'étendue de son expansion actuelle à travers le monde. On y trouvera des exemples factuels

d'introduction de l'AC dans des systèmes de production agricole basés sur le riz, et une vue générale de ses avantages, tant déjà démontrés qu'attendus à l'avenir.

Agricultura de conservación: sinergias de las tecnologías de conservación de los recursos en los sistemas basados en el arroz

La agricultura de conservación se define como un concepto de producción agrícola con ahorro de recursos que procura obtener ganancias aceptables y niveles de producción elevados y constantes y asegurar, al mismo tiempo, la conservación del medio ambiente. Este enfoque se basa en la potenciación de los procesos biológicos naturales, tanto por encima como por debajo del suelo. En la agricultura de conservación se reducen lo más posible intervenciones como la labranza mecánica del suelo, mientras que insumos externos tales como agroquímicos y nutrientes de origen mineral u orgánico se aplican en la cantidad óptima para no interferir con

los procesos biológicos ni perturbarlos. Tres principios relacionados entre sí caracterizan la agricultura de conservación:

1. Perturbación mecánica del suelo reducida al mínimo en todo el ámbito de la rotación de cultivos.
2. Cubierta orgánica permanente del suelo.
3. Rotación diversificada de cultivos en el caso de los cultivos anuales, o asociación de plantas en el de los perennes.

Las prácticas tradicionales empleadas en los arrozales se basan en la labranza intensiva del suelo durante el enfangado, lo cual no es compatible con los principios de la agricultura de conservación. Sin

embargo, es posible adaptar el cultivo de arroz a estos principios, cuya aplicación está cada vez más difundida. Además de sus reconocidas ventajas, en el caso del arroz la agricultura de conservación también permitiría ahorrar agua (un recurso que escasea cada vez más) y ayudaría a hacer frente al problema de las emisiones de gases de invernadero procedentes de los arrozales sin sacrificar su potencial productivo. El documento explica el concepto y los principios de la agricultura de conservación y el alcance de su aplicación actual en todo el mundo, proporciona ejemplos de su introducción en sistemas de cultivo basados en el arroz, y traza un cuadro de sus ventajas probadas y previstas.