

Conservation Agriculture: Principles, Sustainable Land Management and Ecosystem Services

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Introduction

At present, the predominant form of agriculture is based on the '*interventionist approach*', in which most aspects of the production system are controlled by human technological interventions, such as soil tilling, curative pest and weed control with agrochemicals, and the application of synthetic mineral fertilizers for plant nutrition. Most of these crop production systems are both economically and environmentally vulnerable and unsustainable (MEA, 2005; WDR, 2008; McIntyre *et al.*, 2008; Foresight, 2011). However, there are now a growing number of production systems with a predominantly '*ecosystem approach*', underpinned by healthy soils, and characterised as Conservation Agriculture (CA) that are not only effective in producing food and other raw materials economically, but also more sustainable in terms of land management and environmental services and impacts. Their further development and spread merit deeper support with the development of suitable policies, funding, research, technologies, knowledge-diffusion, and institutional arrangements.

Principles of CA in relation to Sustainability

The production systems which follow a predominantly *ecosystem approach* offer a range of productivity, socio-economic and environmental benefits to producers and to society at large on a sustainable basis. They are based on five overall objectives: (i) simultaneous achievement of increased agricultural productivity and enhanced ecosystem services; (ii) enhanced input-use efficiency, including water, nutrients, pesticides, energy, land and labour; (iii) judicious use of external inputs derived from fossil fuels (such as mineral fertilizers and pesticides) and preference for alternatives (such as recycled organic matter, biological nitrogen fixation and integrated pest management); (iv) protection of soil, water and biodiversity through use of 'minimum soil disturbance' and maintaining organic matter cover on the soil surface to protect the soil and enhance soil organic matter and soil biodiversity; and (v) use of managed and natural biodiversity of species to build systems' resilience to abiotic, biotic and economic stresses, with an underlying emphasis on improving soils' content of organic matter as a substrate essential for the activity of the soil biota.

The farming practices required to implement these objectives will differ according to local conditions and needs, but will have the following necessary characteristics: (i) *minimizing soil disturbance by mechanical tillage* (once physical soil problems such as compactions have been rectified), and, whenever possible, seeding or planting directly into untilled soil, in order to maintain soil organic matter, soil structure and overall soil health; (ii) *enhancing and maintaining organic matter cover on the soil surface*, using crops, cover crops or crop residues. This protects the soil surface, conserves water and nutrients, promotes soil biological activity and contributes to integrated weed and pest management; and (iii) *diversification of species* – both annuals and perennials - in associations, sequences and rotations that can include trees, shrubs, pastures and crops, all contributing to enhanced crop nutrition and improved system resilience.

The practices described above are those generally associated with CA, now widely used in all continents over 117 million hectares (Kassam *et al.*, 2010). However, for production intensification, these CA practices need to be strengthened by additional best management practices: (i) use of well adapted, high yielding varieties and good quality seeds; (ii) enhanced crop nutrition, based on healthy soils; (iii) integrated management of pests, diseases and weeds; and (iv) efficient water management.

Sustainable crop production intensification is the combination of all seven of these improved practices applied in a timely and efficient manner. Such sustainable production systems are knowledge and management-intensive and relatively complex to learn and implement. They offer farmers many possible combinations of practices to choose from and adapt, according to their local production conditions and constraints (Pretty, 2008; Kassam *et al.*, 2009; FAO, 2010, 2011; Pretty *et al.*, 2011).

Relevance of CA for Sustainable Land Management

Sustainable agricultural land management and production intensification is facilitated with CA because biological optimisation of soil conditions is continuous, and repeated 'soil-recuperative' breaks (essential in tillage-based systems) are unnecessary. A main criterion for ecologically sustainable production systems or sustainable land management is the maintenance of an environment in the root-zone to optimise soil biota, including healthy root functions, to the maximum possible depth. Roots are thus able to function effectively and without restrictions to capture plant nutrients and water as well as interact with a range of soil microorganisms beneficial for soil health and crop performance (Shaxson, 2006; Uphoff *et al.*, 2006; Shaxson *et al.*, 2008; Kassam *et al.*, 2009). Maintenance or improvement of soil organic matter content and biotic activity, soil structure, and associated porosity, are critical indicators for sustainable production and other ecosystem services.

A key factor for maintaining soil structure and organic matter is to limit mechanical soil disturbance in the process of crop-management. This is because it provokes accelerated oxidation of organic matter and loss of the resulting CO₂ back into the atmosphere. In so doing, it depletes soil organic matter, the energy-rich substrate for the life processes of the soil biota which are essential for developing and maintaining any soil in a healthy and productive condition. Nevertheless, for any agricultural system to be sustainable in the long term, the rate of soil formation – from the surface downwards – must exceed the rate of any degradation due to loss of organic matter (living and/or non-living), and of soil porosity, evidenced by consequent soil erosion. In the majority of agroecosystems this is not possible if the soil is mechanically disturbed (Montgomery, 2007). For this reason the avoidance of unwarranted mechanical soil disturbance is a starting point for sustainable production. Not tilling the soil is therefore a necessary condition for sustainability, but not a sufficient condition: other complementary techniques including mulch cover, crop rotations and legume crops are also required.

Sustainable agricultural land management can be harnessed through sustainable crop production principles of CA described above (e.g., for Canada, see Lindwall and Sonntag, 2011; Baig and Gamache, 2009; for Brazil, see ITAIPU, 2011; Laurent, 2011), and these principles can be readily integrated into other ecosystem-based approaches to generate greater benefits, for example:

System for Rice Intensification (SRI) has proven to be successful as a basis for sustainable intensification in all continents under a wide range of circumstances. Trained farmers have shown SRI embodies CA principles to offer higher factor productivities and income, and requires less seeds, water, energy, fertilizer and labour compared with conventional irrigated or rainfed flooded rice production systems (Kassam *et al.*, 2011). *Organic agriculture*, when integrating CA, can lead to greater soil health and productivity, increased efficiency of use of organic matter, and reduction in use of energy. Organic CA farming is already practiced in the USA, Brazil and Germany, as well as by subsistence CA farmers in Africa. *Agroforestry systems* involve the cultivation of woody perennials and annual crops together in a sustainable manner and, with perennial legumes, are increasingly practised in degraded areas. CA with trees has now become an important option for many farming situations, particularly in the tropics. These CA systems have become the basis for major scaling-up programmes with thousands of farmers in Zambia, Malawi, Niger, and Burkina Faso (Garrity *et al.*, 2010). The incorporation of the indigenous acacia species *Faidherbia albida* into maize-based CA system in Zambia on a large scale is a noteworthy example. *Shifting agriculture*, (also referred to as 'swidden' or 'slash and burn'), entails the clearing of land to prepare a cultivation plot and subsequently returning this to re-growth and eventual natural reforestation, during which damaged

soil structure and depleted 'indigenous' plant nutrients are restored. For sustainable intensification, such systems can be adapted to follow CA principles, changing from slash and burn systems to *slash and mulch* systems with a no-till diversified cropping with intercropping and crop rotations that include legumes and organic matter management to maintain soil fertility and to reduce the need for extra land clearing as in Peru's Colca Valley (Montgomery, 2007). *Integrated crop-livestock systems* including trees have long been a foundation of agriculture. In recent decades, there have been practical innovations that harness synergies between the production sectors of crops, livestock and agroforestry in CA systems. Integration can be on-farm as well as on an area-wide basis. The integration of production sectors can enhance livelihood diversification and efficiency through optimization of production inputs including labour, offer resilience to economic stresses, and reduce risks (FAO, 2010).

Ecosystem Services and CA

Societies everywhere benefit from the many resources and processes supplied by nature. Collectively these are known as ecosystem services, and include the *provisioning* services of clean drinking water, edible and non-edible biological products, processes that decompose and transform organic matter, carbon sequestration, biologically fixed nitrogen; *regulatory* services that control air quality, soil erosion, pest and diseases, natural hazards; and *supporting* services of soil formation, nutrient cycling, water cycling, pollination (MEA, 2005). These ecosystem services operate at various nested levels from field scale to agro-ecological or watershed scale and beyond. CA facilitates ecosystem services on agricultural land, particularly those services related to provisioning, regulating and supporting and derived as a result of improved conditions in the soil volume used by plant roots (Kassam *et al.*, 2009). The improvement in the porosity of the soil is effected by the actions of the soil biota, which are present in greater abundance in the soil under CA. The mulch on the soil surface in CA systems, protects against the compacting and erosive effects of heavy rain, buffers temperature fluctuations, and provides energy and nutrients to the organisms below the soil surface. When the effects are reproduced across farms in a contiguous micro-catchment within a landscape, the ecosystem services provided – such as clean water, sequestration of carbon, avoidance of erosion and runoff or of dust clouds – become more apparent. The co-benefits of more water infiltrating into the ground beyond the depth of plant roots is perceptible in terms of more regular stream flow from groundwater through the year, and/or more reliable yields of water from wells and boreholes. The benefits of carbon capture become apparent in terms of the darkening colour and more crumbly 'feel' of the soil, accompanied by improvements in crop growth, plus less erosion and hence less deposition of sediment in adjacent waterways.

Legumes in CA rotations provide increased *in situ* availability of nitrogen, thus diminishing the need for large amounts of applied nitrogenous fertilizers. Society gains from CA on regardless of farm size by diminished erosion and runoff, less downstream sedimentation and flood damage to infrastructure, better recharge of groundwater, more regular stream flow throughout the year, resulting in a more assured community water supply and quality. Cleaner civic water supplies also reduce costs of treatment for urban/domestic use. CA also contributes to increased stability of food supplies due to greater resilience of crops in the face of drought. The rural community ultimately benefits from better nutrition, overall health and less pressure on curative health services. In CA systems, the sequences and rotations of crops also encourage agrobiodiversity as each crop will attract different overlapping spectra of microorganisms. The optimization of populations, range of species and effects of the soil-inhabiting biota is encouraged by the recycling of crop residues and other organic matter that provides the substrate for their metabolism. Rotations of crops inhibit the build-up of weeds, insect pests and pathogens by interrupting their life cycles, making them more vulnerable to natural predator species, and contributing development-inhibiting allelochemicals. The same crop mixtures, sequences and rotations provide above-ground mixed habitats for insects, mammals and birds. Under CA systems, it is possible to harness many of the above ecosystem services mainly because the ecosystem functions that generate these services are enhanced and protected, so that agriculture is not in competition with nature but works in harmony with it.

CA-based recognition schemes for ecosystem services operate in different parts of the world. Two good examples are: (1) the agricultural carbon offset scheme in Alberta, Canada, that allows regulated companies to offset their emissions by purchasing verified tonnes from a range of approved sources including agriculture projects (Haugen-Kozyra and Goddard, 2009); (2) the hydrological services from Paraná III Basin in Brazil located in the western part of Paraná State on the Paraguay's border in which the Itaipú Dam *Programa Cultivando Água Boa* (cultivating good water) has established a partnership with farmers to achieve the sustainable use of soil and water in the watershed for efficient electricity generation (ITAIPU, 2011; Laurent *et al.*, 2011).

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