SUSTAINABLE CROP PRODUCTION SYSTEM TO ENHANCE ECOSYSTEM SERVICES

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Global food demand is steadily growing, due to increasing world population (currently ~1.1 percent per year and decreasing towards zero), and changes of food habits due to urbanization and per capita economic growth. With current dominant production systems it is proving difficult to increase agricultural production sustainably to meet demand, and this in a sustainable way.
Additional challenges are posed in some regions with a limited agricultural potential, due to climatic conditions.

Continuous agricultural soil degradation and increasing water scarcity are threatening agricultural productivity (efficiency) and production (output). Major reasons for this development are intensification of production based on mechanical tillage and agrochemicals in the industrialised nations while using extractive production methods and overgrazing in the developing countries. Symptoms of soil degradation are soil erosion by water and wind, and loss of soil organic matter, structure and soil compaction. In addition, soil degradation increases the vulnerability to droughts, thus increasing their frequency. Precious rain water is lost by run-off instead of being infiltrated and stored in the soil and as ground water. Yield levels can be maintained only with ever increasing inputs, fertilizers and irrigation water causing in addition pollution problems. Higher production costs, caused inter alia by increasing prices for fuel and other inputs, cut farm incomes to an extent which threatens the survival of many farms. Further, with tillage agriculture and soil degradation, it is not possible to adequately harness the necessary ecosystem services for the society such as clean water, erosion control, carbon sequestration, nutrient cycling, etc.

The need, therefore, is for farmers to take up more sustainable, productive and profitable ways of production that do not damage the soil, landscape and environment and can deliver both higher productivity and enhanced ecosystem services. However, the land management systems now applied are damaging soils and limiting their capacity to generate rising yields and other ecosystem services on a sustainable basis. At present, the almost world-wide standard practice is to plough before planting a crop in order to loosen the soil and create a weed free seed bed. Mineral fertilizers are applied to replace the soil nutrients taken up by crops. Most agencies that advise farmers on technology choices – and the firms supplying inputs – recommend that increased production should come from more frequent tillage, higher levels of fertilizer and pesticide applications and the use of seed of genetically engineered seeds. This type of farming since the end of World War II has enabled global food production to expand in line with fast rising demand but there is a growing recognition that it is degrading the soil and thus is not sustainable economically and environmentally.

Moreover, it has not succeeded in ensuring that all people have enough food of adequate quality to eat or that levels of poverty are falling significantly amongst rural populations and the yield increases obtained with more inputs are declining, eventually reaching zero or negative values as already observed in India through green revolution.

The problem is that, in many situations the combination of increasingly frequent inversion and non-inversion tillage, a failure to supply nutrients at sufficiently high levels to prevent "mining" and low levels of biomass restitution to the soil results in a progressive degradation of soil health and structure and its fertility and with this of its productive capacity and ability to respond to production inputs. This in turn normally leads to decreased factor productivity, increased production costs and reduced profitability of farming. Such degradation is the consequence of both mechanical damage to the soil (compaction and pulverisation) and an associated decline in its organic matter content and soil biodiversity, especially when crop residues are not retained and soil biota is dysfunctional. The result is a breakdown of soil aggregates and a reduction in the pore spaces within soils that are vital for their drainage and aeration, and their functioning as effective media for plant growth and ecosystem services. Tillage also reduces numbers of soil fauna, most noticeably a reduction in earthworm numbers with their inherent capacity to aerate the soil, incorporate organic matter to lower soil depth and create a porous soil.

These tillage-induced processes lead to physical changes in soil structure with subsequent reduction in a soil's capacity to absorb and hold water, nutrient and air needed for season-long plant growth, particularly in dry and drought-prone situations. Reduced in situ infiltration of rainfall, in turn, causes greater run-off over the land surface, raising the risks of erosion, catchment degradation and more variable stream-flows resulting in downstream flooding and pollution. Loss of organic matter also reduces the soil chemical and biological processes, so important in providing the humic gums which contribute to the stability of soil aggregates and release nutrients for uptake by plants. In short, farming as now widely practised, is not sustainable in the long run, from either environmental or economic viewpoints. It is unfortunate that most governments and the international community continue to promote these tillage-based farming methods with bare and exposed soils throughout much of the intensively farmed areas of the world, contributing to massive, though largely unnoticed, damage to the fragile layer of top-soil on which the future supply of humanity's growing food needs depends.

Need for a change of production systems and agricultural policies

The above described situation calls for a drastic change in agricultural production systems at the paradigm level. What is required are production systems which are no longer extractive and disruptive of ecosystem functions, *i.e*. which protect field from water run-off and soils from erosion, and which maintain soil fertility by restitution of organic matter and plant nutrients exported from the field.

The "key" to a sustainable future is to move towards environmentally friendly farming systems that are effective in harnessing nature to sustain higher levels of productivity. Critical to this is an increase in the quantities of organic matter on and in the soil, to provide the surface-protection, energy and nutrients required by soil-inhabiting flora and fauna that constitute the "life" of a soil, playing a vital role in maintaining its porosity, enhancing its moisture holding capacity and extending the availability of nutrients to crops.

Water use-efficiency, may it be rain water or irrigation water, has to be increased in many parts of the world. This is pertinent in face of increased probability of drought and dry spells during the cropping season due to climate change and increasing competition for water between the agricultural sector and other consumers. Shrinking net returns of farms due to increased input prices and reduced production because of progressing soil degradation threaten the survival of many farm households, if no measures for reducing production costs and degradation are taken. It is also questionable if governments can continue subsidising agricultural production to the same extent. Recent cuts of subsidies of fuel and fertilizers are signs of the continuous liberalisation of agricultural markets.

All of the above calls for on-farm changes but also for changes in agricultural and environmental policies.There is an urgent need for a change to sustainable intensified crop production systems. Technical solutions are available, but supportive policies and institutional support are required for their adoption, especially by smallholder farmers.

Sustainable Intensification of Agricultural Production and Ecosystem Services

Rising global food demand against the background of rising cost of energy and production inputs, land degradation and climate change calls for an increase in agricultural production. This is best achieved by intensification of production systems, but in a sustainable way, referred to by FAO as "Sustainable Intensification of Crop Production" (SCPI). SCPI has been defined as producing more from the same area of land while reducing negative environmental impacts and increasing contributions to natural capital and the flow of environmental services, also referred to as ecosystem services. For this farmers have to adopt what is generally called "Good agricultural practices". Good agricultural practices are environmentally friendly. They rely less on external inputs and more on biological processes and synergistic interactions between system components. Nutrient recycling and build up of soil organic matter are key processes. This is very much in line with ecosystems approaches to production, as **agricultural landscape is an altered and managed ecosystem, an agro-ecosystem**. Nutrient recycling and build up of soil organic matter are key processes. This is very much in line with ecosystems approaches, as **agricultural landscape is a managed ecosystem, an agro-ecosystem**.

GOOD AGRICULTURAL PRACTICES
1. No Mechanical Soil Disturbance and Maintenance of Soil Cover with Residues:
Soil is not tilled and all the necessary actions are carried out to achieve and maintain a proper soil surface residue cover for the production system. This minimizes soil erosion and degradation, and it promotes soil health and an efficient use of water and nutrients.
2. Crop Rotations/Associations/Sequences:
It promotes the most diverse and intensified cropping system (involving rotations, sequences and associations) possible according to the economic and agro-ecological conditions (soil and climate).

3. Integrated Pest Management (IPM):
Damaging and beneficial species are monitored to determine a management measure, if necessary, based on the economic damage threshold. Approved and registered phytosanitary products are used, and selective active principles, with minimum impact on environment and human health, are prioritized.
4. Efficient and Responsible Phytosanitary Products Use:
It considers the conditions under which the products used are applied, stored, transported, etc., and the residues they may produce are properly disposed. The personnel are properly trained and have all the necessary safety equipment.
5. Balanced Nutrition:
It promotes the proper use and the balanced replacement of soil nutrients, based on soil testing and plant analysis, and also nutrient cycling, whenever the system allows it, avoiding transfer, concentration and/or contamination due to excesses. It avoids soil degradation and aims to increase productivity.
6. Stockbreeding Information Management:
It complies with the required sanitary documentation and other traceability evidences according to national regulations.

Ecosystem services

Societies everywhere benefit from the many resources and processes supplied by nature. Collectively these are known as ecosystem services, and include clean drinking water; edible and non-edible biological products; processes that decompose and transform organic matter; and regulatory processes that maintain air quality. Many of the key ecosystem services are considered to be important environmental services of a public goods nature. These ecosystem services operate at various levels from field scale to agro-ecological or watershed scale and beyond. Ecosystems services can be classified in different categories such as:

- ✓ **Provisioning services** – food; water; pharmaceuticals, biochemicals, and industrial products; energy; genetic resources etc.;
- ✓ **Regulating services** – carbon sequestration and climate regulation; waste decomposition and detoxification; purification of water and air; crop pollination; pest and disease control; mitigation of floods and droughts, etc.;
- ✓ **Cultural services** – cultural, intellectual and spiritual inspiration, recreational experiences, scientific discovery, etc.
- ✓ **Supporting services** – soil formation; nutrient dispersal and cycling; seed dispersal; primary production, etc.; Healthy ecosystems contribute directly or indirectly to human well-being. However most of them are currently in decline, and making their value clear to those who benefit from them, but are not direct land users, can encourage investment in their protection and enhancement.

Ecosystem approach to sustainable intensification

To promote sustainable crop intensification and to protect ecosystem functions and services at the same time, an ecosystem approach has to be applied. The ecosystem approach uses inputs, such as land, water, seed and fertilizer, to complement the natural processes that support plant growth, including that allows plants to access nutrients. The ecosystem approach can provide the "win-win" outcomes required to meet the dual challenges of feeding the world's population and saving the planet. SCPI will allow countries to plan, develop and manage agricultural production in a manner that addresses society's needs and aspirations, without jeopardizing the right of future generations to enjoy the full range of environmental goods and services. One example of a win-win situation – that benefits farmers as well as the environment – would be the elimination of mechanical soil tillage as a practice that is highly disruptive to soil life and structure, together with a reduction in the overuse of inputs such as mineral fertilizers and pesticides. Reduced spending on agricultural inputs can free resources for investment in farms and on farm families' food, health and education.

Core ecological elements of sustainable production systems

The ecosystem approach needs to be applied throughout the input supply production-output value chain in order in order to increase efficiencies and strengthen the global and local food and agricultural systems. At the scale of cropping systems, management should be based on biological processes and integration of a range of plant species, as well as avoidance of soil tillage, adopting integrated approaches to crop, nutrient, water and pest management, and the judicious use of external inputs such as fertilizers and pesticides. SCPI is based on agricultural production systems and management practices that are described in the following chapters. They include:

- ✓ maintaining healthy soil to enhance crop nutrition and ecosystem services;
- ✓ cultivating a wider range of species and varieties in associations, rotations and sequences;
- ✓ using well adapted cultivars and good quality seeds as well as appropriate sowing time, seedling age (in the case of rice), spacing and seed rate;
- ✓ integrated management of insect pests, diseases and weeds;
- ✓ efficient water management; and
- ✓ effective farm power and efficient energy use.

For optimal impact on productivity and sustainability, SCPI will need to be applicable to a wide variety of farming systems, and adaptable to specific agro-ecological and socio-economic contexts. It is recognized that appropriate management practices are critical to realizing the benefits of ecosystem services while reducing negative consequences and externalities from agricultural activities.

Farming systems for sustainable crop production intensification can offer a range of productivity, socio-economic and environmental benefits to producers and to society at large, including high and stable production and profitability; adaptation and reduced vulnerability to climate change; enhanced ecosystem functioning and services; and reductions in agriculture's greenhouse gas emissions and "carbon footprint".

These farming systems need to be based on three technical objectives:

- ✓ Simultaneous achievement of increased agricultural productivity and enhancement of natural capital and ecosystem services;
- ✓ Higher rates of efficiency in the use of key production inputs, including water, nutrients, pesticides, energy, land and labour;
- ✓ Use of managed and natural biodiversity to build system resilience to abiotic, biotic and economic stresses.

The farming practices required to implement these objectives will differ according to local biophysical and socio-economic conditions and needs (FAO, 2011). However, in all cases and in all production systems they will need to:

- ✓ *minimize soil disturbance by avoiding mechanical tillage* in order to maintain soil organic matter, soil structure and overall soil health;
- ✓ *enhance and maintain a protective organic cover* on the soil surface, using cover crops and crop residues, in order to protect the soil surface, conserve water and nutrients, promote soil biological activity and contribute to building soil health and to integrated weed and pest management;
- ✓ *cultivate a wider range of plant species* – both annuals and perennials – in associations, sequences and rotations that can include trees, shrubs, pastures and crops, in order to enhance crop nutrition and improve system resilience as well contribute to integrated weed and pest management.

Those three key practices are generally associated with **Conservation Agriculture (CA),** which has been widely adopted in both developed and developing regions in all continents and agro-ecologies. However, in order to achieve the sustainable crop production intensification (SCPI) necessary for increased food production, they need to be supported by five additional management practices:

- ✓ *the use of well adapted varieties* with resistance to biotic and abiotic stresses and improved nutritional quality planted at an appropriate time, seedling age and spacing;
- ✓ *enhanced crop nutrition based on healthy soils*, through crop rotations and judicious use of organic and inorganic fertilizer;
- ✓ *integrated management of pests, diseases and weeds* using appropriate practices, biodiversity and selective, low risk pesticides when needed;
- ✓ *efficient water management*, by obtaining "more crops from fewer drops" while maintaining soil health and minimizing off-farm externalities;
- ✓ *careful management of machines and field traffic* to avoid soil compaction.

Ideally, SCPI is the combination of all of the above practices applied simultaneously in a timely and efficient manner. However, the very nature of sustainable production systems is dynamic: they should offer farmers many combinations of practices to choose from and adapt, according to their local production conditions and constraints.

A management consideration relevant to SCPI is the role of farm power and mechanization. In many countries, the lack of farm power is a major constraint to intensification of production. Using manual labour only, a farmer can grow enough food to feed, on average, three other people. With animal traction, the number doubles, and with a tractor increases to 50 or more. Appropriate mechanization can lead to improved energy efficiency in crop production, which enhances sustainability and productive capacity and reduces harmful effects on the environment (carbon emissions).

At the same time, uncertainty about the price and availability of energy in the future suggests the need for measures to reduce overall requirements for farm power and energy while maximizing energy use efficiency. Conservation Agriculture can lower energy requirements by up to 60 percent or more, compared to conventional farming. The saving is due to the fact that most power intensive field operations, such as tillage, are eliminated, which eases labour and power bottlenecks particularly during land preparation. Investment in equipment, notably the number and size of tractors, is significantly reduced (although CA requires investment in new and appropriate farm implements such as direct seeders). The savings also apply to small-scale farmers using hand labour or animal traction. Studies in the United Republic of Tanzania indicate that in the fourth year of implementing zero-tillage maize with cover crops, labour requirements fell by more than half.

The role of multi-functional agriculture

Agriculture is an altered and managed ecosystem, and to be ecologically sustainable, it must deliver specific ecosystem services to society in addition to food and other biological products.

Major agro-ecosystem services

- ✓ ***Climate change mitigation:*** The role of agriculture in mitigating climate change consists of reducing its own emissions and enhancing the absorption or “sinks” of greenhouse gases (GHG). It is important to further unlock the agricultural sector’s potential to mitigate, adapt and make a positive contribution through GHG emission reduction, production efficiency measures including improvements in energy efficiency, biomass and renewable energy production, carbon sequestration and protection of carbon in soils based on innovation.
- ✓ ***Watershed protection***: Agriculture accounts for more than half of all water use in the world and can contribute to pollution of water resources, thus influences both the quantity and quality of water available for other human uses. Changing agricultural practices could contribute to water quantity available by improving from agricultural production.
- ✓ ***Biodiversity conservation***: Biodiversity is an environmental good and its conservation has assumed great importance in the effort to improve environmental management and ecosystem health. Agricultural producers can contribute to biodiversity conservation.

Farmers play an important role as ecosystem managers in that they balance their decisions regarding land and other agricultural inputs for production. Maximum biomass production increases the production of ecological services and benefits to the whole of society and modify their practices to adjust the positive and negative impacts to the environment. However, so far the main guiding principle is short term economic profit attributed mainly to the agricultural production. Yet, by their choices of production inputs and management practices, farmers shape their impacts on the environment. Despite their importance, the current economic system does not account for these functions and the result is that they essentially are not ‘valued’ in the market. Environment costs are just externalized.

Some agronomic practices, especially those in Conservation Agriculture (i.e. the practice of no tillage and direct seed drilling through mulch cover) are capable of providing ecosystem services such as the provisioning, regulating and cultural services. These ecosystem services all rely on the “supporting services”, such as soil formation, nutrient and water cycles and the production of plant biomass. It is the farmer who manages, for better or for worse, the formation and preservation of soils, the nutrient cycle and the total production of plants by the yields. The objective is good management and intensive production but with more from less.

Maximum biomass production increases the production of ecological services and benefits to the whole of society!

A natural order exists in biomass management:

- ✓ **Soil cover**: The soil must be covered all year round for this cover to protect and nourish the biological activity. The farmer must recycle a significant part of crop residues into the soil to build and preserve it.
- ✓ **Carbon storage in the soil**: The higher the yields are, the greater the amount of plant residues are that can remain on the ground, the greater the biological activity and the greater carbon storage.
- ✓ **Human food and animal feed:** Production of food and animal feed is the prime objective of agriculture. And food safety is not secure in many parts of the world. Depending on the climate zone and food and feed requirements, it is always a debate which part (percentage) of the total yield has to be used for society, and which part of yields (biomass) remains on the ground to accommodate carbon sinks and biodiversity.
- ✓ **Biomaterial**s: plant fibres are more often used in the industry to replace synthetic materials (because of light weight) and also in house construction (heat insulation).
- ✓ **Renewable energy**: A fact often forgotten is the high energy dependence of agriculture on fossil energies (fuel for field work and transport, fertilizers, pesticides). Food sovereignty relies on secure energy. The production of bioenergies secures food for society regardless of the energy crisis context. Biogas and biofuel production must supply the autonomy of agricultural production and distribution systems in priority - just in case.

Achieving high yields and permanent recycling is the cornerstone of sustainability. With good agronomic management techniques, achieving high yields is fundamental, to render all possible ecological services to society..

Even though (good) farmers are increasingly expected to be ecosystem managers in addition to producing agriculture produce, they are not paid for the environmental services they provide to the society. If society realizes the value of these services, it should be willing to pay farmers for these services, including supporting the cost of transformation from tillage-based systems to no-till CA systems.

Contribution of sustainable intensification farming system practices to important ecosystem services

Objective	System component			
	Minimize soil disturbance/ no tillage	**nutrients Soil cover**	**Legumes to supply plant**	**Crop rotation**
Simulate optimum "forest-floor" conditions	✓	✓		
Reduce evaporative loss of moisture from soil surface		✓		
Reduce evaporative loss from upper soil layers	✓	✓		
Minimize oxidation of soil organic matter and loss of CO2	✓			
Minimize soil compaction	✓	✓		
Minimize temperature fluctuations at soil Surface Provide regular supply of organic matter as substrate for soil organism activity	✓	✓		
Increase, maintain nitrogen levels in root zone	✓	✓		
Increase cation exchange capacity of root zone	✓		✓	✓
Maximize rain infiltration, minimize runoff	✓	✓	✓	✓
Minimize soil loss in runoff and wind	✓			
Permit, maintain natural layering of soil horizons through action of soil	✓	✓		

biota				
Minimize weeds	✓	✓		
Increase rate of biomass production		✓		✓
Speed recuperation of soil porosity by soil biota	✓	✓	✓	✓
Reduce labour input	✓	✓		
Reduce fuel/energy inputs	✓	✓	✓	✓
Recycle nutrients	✓	✓	✓	✓
Reduce pest-pressure of pathogens	✓ -	✓		✓
Rebuild damaged soil conditions and dynamics	✓	✓	✓	✓
Pollination services	✓	✓	✓	✓

Sources of Benefits from Conservation Agriculture
The adoption of CA practices will normally bring direct, though not always immediate, financial rewards to farmers. It will also generate other important economic, social and environmental benefits. To the extent that these are subject to market failures, the creation of incentives, policies and legislation to encourage adoption would be justified
Financial benefits for farmers
✓ *Greater stability in yields;*
✓ *Higher ratios of outputs to inputs;*
✓ *Reduced demands for labour and much lower costs of farm power, through reduced*
✓ *Tillage and weeding; though not true initially in manually weeded systems.*
✓ *Greater resilience to drought – through better water capture and soil moisture retention;*
✓ *Release of labour at key times in the year, permitting diversification into new on-farm and off-farm enterprises.*
Benefits to communities and society
✓ *Greater supply of environmental services from landscapes;*
✓ *More reliable and cleaner water supplies: lower treatment costs;*
✓ *Less flooding – through better water retention and slower run-off: less damage to infrastructure – e.g. roads and bridges.*
✓ *Better food and water security.*
Environmental benefits
✓ *Conserves soil and water and hence better hydrology and flows in rivers;*
✓ *Reduced incidence and intensity of desertification;*
✓ *Increased biodiversity both in the soil and the above-ground agricultural environment;*

✓	*Lower levels of soil sediments in rivers, dams and irrigation systems;*
✓	*Greater carbon sequestration and retention in soils; reduced emissions of greenhouse gases including those of carbon and nitrogen origin;*
✓	*Reduced need for deforestation – through land use intensification, and more reliable and higher crop yields;*
✓	*Less water pollution from pesticides and applied nutrients;*
✓	*Less soil compaction through reduced use of heavy farm machinery.*

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