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Towards Sustainable Agriculture: Challenges and Opportunities

Man, despite his artistic pretensions, his sophistication and many accomplishments, owes the fact of his existence to a six-inch layer of topsoil and the fact that it rains. (Anon.)

Nothing is more important to humanity than sustainable land and reliable food production**.** Agriculture is an essential occupation needed to feed the world's population. It often, however, has negative impacts when practiced without regard for the condition of the soil it depends on.

The environmental impact of agriculture cannot be ignored. In many countries, as much as 70 per cent of the land area is in agricultural use. Over a third of the global agricultural land area is in high-intensity, continuous cropping systems that use high levels of agrochemicals and reshape land and waterways. The rest is under such a farming system that uses far fewer inputs, but requires relatively large expanses of land to compensate for low crop and livestock yields. Both systems have had negative impacts on soil, water, and air quality, global climate, wildlife and biodiversity that, in turn, affect food security and livelihoods of people in the long run.

Conservation agriculture (CA) emphasizes that the soil is a living body, essential to sustain the quality of life on the planet. It recognizes, in particular, the importance of the upper 0-20cm of soil as the most active zone, but also the zone most vulnerable to erosion and degradation. It is the zone where land management activities have the most immediate, and potentially the greatest impact. By protecting this critical soil zone, we ensure the health, vitality, and sustainability of life on this planet. CA seeks to preserve soil composition, structure, natural biodiversity and the sustainability of food production by moving the crop production process closer to that of natural vegetation. In most parts of the world, CA can be expected to use less fossil fuel, be more productive than traditional agriculture, and to contribute to sustainable agriculture and climate change mitigation.

CDM Application in Agriculture

It is well recognized that human emission of various greenhouse gases (GHGs), including carbon gases, have caused a global climate change, altered the atmospheric balance and led to a rise in global temperature. The potential impacts of climate change on human health, sea level rise, agriculture production, have become a public concern and pose serious risks for sustainable development. Human activities related to deforestation and the burning of fossil fuels and biomass has largely contributed to the increased emissions of carbon gases and other GHGs in the atmosphere. The average annual emissions of world carbon were estimated to be 7.1 billion tons per year during the 1980s.(IPCC, 1996) Global carbon emissions from fossil fuels alone are estimated to be 5.5 billion tons per year and are likely to increase by 61% by 2015, compared to the base year of 1990. According to the annual forecast of the Energy Information Administration of the USA, the global emissions of carbon dioxide (CO_2) will reach 43.7 billion tons in 2030, up from 25 billion tons in 2003. In a word, climate change has become one of the most important and complex challenges facing humanity in the twenty-first Century.

Reducing GHG emissions by means of Clean Development Mechanism (CDM) under the Kyoto Protocol is an important example of how market-based approaches can be brought to bear on this challenge. CDM approaches can be practically applied in the agricultural sector of developing countries in achieving sustainable agriculture and rural development, by helping reduce GHG emissions, mitigate climate change, promote sustainable natural resource management, and enhance natural resource resilience. However, the role of sustainable agriculture practices in both reducing GHG emissions and enhancing carbon sequestration has been neglected in the past.

Experiments show that changes in the area under agriculture, land use and land management practices can lead to changes in the biomass stocks and soil organic matter of the upper soil. Improved agriculture practices such as conservation tillage, crop rotations, management of fallow lands, soil conservation and rehabilitation of degraded lands can help significantly reduce CO_2 emissions by increasing carbon sequestration. Batjes and Sombroek (1997) estimated the global stock of organic carbon mass in the upper 1 meter layer of soil is estimated to be 1.22 trillion tons. The historic loss of soil carbon is estimated somewhere between 50 to 100 billion tons. If only 75% of this loss could be captured, it would be about 40 to 70 billion tons in total or 3 billion tons per year, which would be equivalent to 12 to 25 years of atmospheric increase in carbon. The cost of carbon sequestration in the agricultural sector is estimated to be between $10-25 per ton, making it an attractive and cost-effective option. The estimated costs of carbon sequestration in other sectors, such as forestry and industry, vary from $13-26 per ton to $200-250 per ton. This indicates the potential of the agricultural sector to play a significant role in climate change mitigation strategy if implemented under the CDM due to less cost of carbon sequestration in agricultural sector than in other sectors as described above.

Conservation Agriculture: A Form of Sustainable Agriculture

Conventional Agriculture

Conventional agriculture is mainly characterised by intensive tillage, straw burning and external inputs. The mechanization and intensification of the traditional, tillage-based system of agriculture has often been accompanied by numerous adverse impacts on soil systems. Tillage left the soil bare, and when it is pulverized excessively and exposed to wind and rain, most of the rainwater then runs off the land, carrying precious topsoil with it and results in significant soil erosion and degradation. Crop yields in these soils are lower than those in protected soils. In some locations, crop yields on severely degraded soils were lower than those on slightly degraded soil. Excessive usage of fertilizers, pesticides and irrigation help to offset the deleterious effects of low crop yields, but lead to soil pollution and health problems, destroy natural habitats, and contribute to high energy consumption and unsustainable agricultural systems. The negative effect on soil degradation is estimated to increase agricultural production costs by about 25% each year. Due to soil degradation processes, about 10 million hectares of agricultural land are lost per year. The GLASOD study in 1990 estimated that about 1.9 billion hectares of cultivated land are affected by soil degradation worldwide. The Asian and Pacific regions had the highest area (850 million ha) of soil degradation. The global agro-ecological zone analysis by FAO/IIASA in 1998 estimated about 26.11% of land worldwide to be under severe to very severe human-induced degradation. Although it would be difficult to estimate additional cultivated land under moderate to severe degradation by 2015 and 2030, existing scenarios suggest that the global community needs to give serious attention to preventing further land degradation and invest more on rehabilitation of already degraded land.

In addition to land degradation, conventional agriculture produces extra CO_2 emissions to the atmosphere and reduces the potential CO_2 sink effect of the soil. According to a study, the burning of crop straws in fields after harvests is a significant contributor to China's CO_2 emissions and other pollutants. (Chinese Science Bulletin) Burning has been widely adopted by the Chinese farmers as an easy and cheap way to remove the straw from lands after harvests, despite the practice being banned by the government. Some farmers believe that burning straws increase the fertility of the field, though previous research has shown no significant effects. It is estimated that straw burning produced 2.1 billion tons of CO_2 in 2000, or 6.1% of China's total emissions that year. The study also revealed that other pollutants from straw burning account for a significant proportion of total pollution discharges. For example, straw burning in 2000 accounted for 10.8% of volatile organic compounds and 7.7% of carbon monoxide. If low-cost ways for collecting straw and making it into biomass briquettes, biofuel, or construction material could be developed, the benefits would be three-fold: reduced pollutant emissions, reduced consumption of other energy resources and increased farmer incomes from selling straw.

Besides subsurface degradation, tillage and traffic on the soil reduce biological activity in the soil and promote root zone waterlogging, causing the conversion of crop nutrients into damaging GHG such as nitrous oxide and methane. Waterlogged, anaerobic conditions of the soil reduce fertilizer efficiency, promote denitrification and produce nitrous oxide. This is a potent GHG with 310 times more global warming potential than CO_2 (Tullberg, J.N. 2006).

Conservation Agriculture (CA)

CA aims to pursue more sustainable agriculture and rural development through the application of three major principles: minimal or no soil disturbance, permanent soil cover and crop rotations.

Three Major Principles of CA:

(i) Minimum/No Soil Disturbance. In contrast to plowing, CA advocates little or no soil disturbance through minimum or zero tillage (direct seeding). Zero tillage aims to enhance and sustain farm production by maintaining a permanent or semi-permanent organic soil cover that protects the soil from sun, rain and wind and allows soil micro-organisms and fauna to take on the task of "tilling" and soil nutrient balancing - natural processes disturbed by mechanical tillage.

Furthermore, by not tilling the soil, farmers can save their labor time and fuel costs as compared with the conventional method of farming. This implies more opportunity for women farmers at a time when farmers (mostly men) leave their farms for cities in search of better employment opportunities. The migration of the men to the urban areas implies that more and more women in the villages are required to take on farming responsibilities. In this context, CA can facilitate effective farming for women to take on multi-faceted tasks. As a more effective, resource-efficient form of agriculture, CA holds tremendous potential for all sizes of farms and agro-ecological systems; but its adoption is perhaps most urgently required by smallholder farmers, especially those facing acute labor shortages in the Asian and Pacific region.

(ii) Permanent Soil Cover. Permanent soil cover needs to be integrated into farming systems to obtain additional benefits. Crop residues will not be burnt since they are made part of the permanent soil cover, and air pollution will thus be reduced where burning is stopped. Residues from previously planted crops, other cover crops, and green manure cover crops are utilized for permanent or semi- permanent organic soil cover. The dead-residue biomass of the cover crops functions as mulch, protecting the soil physically from sun, rain and wind. Soil mulch reduces water evaporation, conserves moisture, and helps moderate soil temperature, making conditions more hospitable for below-ground biota. Mineralization and nutrient losses are reduced, and more satisfactory levels of organic soil matter are built up and maintained.

(iii) Crop Rotations. The use of crop rotation will help control pests, diseases, weeds and other biotic factors. Well-balanced crop rotations can neutralize many of the possibly negative aspects of minimum/no-tillage, such as pest build-up, as they increase the diversity of favorable insects and organisms that can help maintain checks on the spread and impact of pests and diseases.

Recent practice shows permanent bed controlled traffic minimum tillage system, known as Controlled Traffic Farming (CTF) or Permanent Raised Beds (PRB), can overcome the direct costs, subsurface degradation and system impacts of wheel ruts from random wheel traffic.

Benefits offered by CA:

CA can bring socio-economic benefits to farmers and ecological/environmental benefits to climate change mitigation. Conventional tillage is a fossil-energy intensive process. On most farms where CA is practiced, fewer field operations are needed, meaning farmers need less equipment and the costs of both labor and fuel are reduced. In addition, the number of implements can be reduced since plows and harrows are no longer required. In the case of tractor-powered farming, the size of the tractor can be reduced, and in animal draught systems, fewer animals are needed. Generally, CA reduces the energy consumption of farming operations and increases energy productivity –this is the yield output per energy input- in the range of 15%-50% and 25%-100%, respectively. In no-till olive crops, for example, a savings of about 60 to 80 liters of fuel and 3 to 5 hours of labor per hectare annually is estimated as compared to conventional tillage.

Europe offers another example. Direct seeding (minimum/no-tillage) requires as little as one pass for planting, compared to two or more tillage operations plus planting for conventional tillage. Besides fuel savings, fewer passes also save an estimated 97 EUR per hectare on machinery depreciation and maintenance costs. That is, about 1,950 EUR savings on a 200 hectare farm. These savings normally compensate for or exceed the extra costs of conservation tillage (application of herbicides and direct seeding machinery). The annual cost reduction in direct seeding of annual crops compared to conventional tillage ranges between 40 and 60 EUR per hectare in Southern Europe. Therefore, in some areas, farmers who adopt conservation techniques are strongly motivated by cost-saving.

Table. Benefits for the Application of CA

Benefits	Increased profit with decreasing inputs of labour, time, farm power and fuel consumption
	Improved long-term productivity and more stable yields
	Reduced soil erosion
	Increased organic matter and improved soil fertility/health
	Recharge of the aquifers through improved water infiltration
	Decreased soil compaction
	Better traffic ability in the field through CTF or PRB
	Reduced air pollution through reduced release of carbon gases and nitrous oxides
	Increased carbon sequestration
	More micro biota and improved biodiversity

Drawbacks and problems which can be observed in some cases of introducing CA are not necessarily inherent characteristics of CA but often the outcomes of some missing elements in the cropping system or simply a result of inexperience during the learning phase.

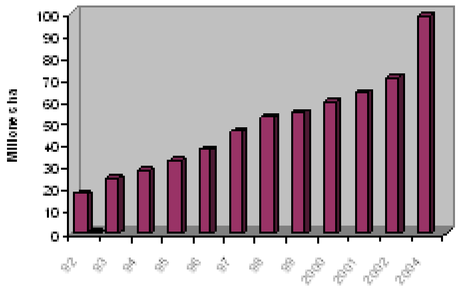
Background and Current Situation

The initial research on CA was triggered by a

"Black Storm" (a strong sand storm) that swept the United States in May 1935, followed up with more intensive research in the late 1950's, and in Europe from the 1960's to 1970's. After several decades of experiments, CA has proved adaptable to different climate and soil conditions, from the tropics to the Arctic Circle, as well as different agrarian systems from grain crops to pulses, including sugar cane, vegetables, potatoes, beets, cassava and a wide range of fruits.

The adoption of CA techniques has seen a steady increase worldwide since the 1990s (see Figure 1).

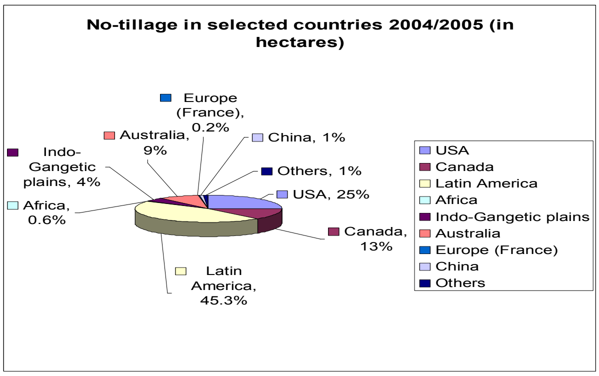
Figure1. Development Trend of Minimum/no-tillage (Direct Seeding) in the World



Source: FAO Agriculture 21/Spotlight 2006

According to the biannual statistics of FAO for 2004/2005, the total area under CA practices was 98.8 million ha. The leading countries included the USA with 25 million ha, followed by Brazil with 24m ha, Argentina with 18m ha, Canada with 13m ha, Australia with 9m ha, and Paraguay with 1.7m ha.(See Figure 2)

Figure2. No-tillage in selected countries 2004/2005



Source: FAO Agriculture 21/Spotlight 2006

Although the biggest area under minimum/no-tillage is found in the USA, the techniques are applied only on 16.3% of the total cultivated area in this country, against 21% in Brazil, 32% in Argentina and 52% in Paraguay. In relation to the total cultivated area, Paraguay has the highest adoption rate of minimum/no-tillage in the world. Approximately 83.3% of the techniques are practiced in the Americas (North and South), about 9% in Australia and only about 7.7% in the rest of the world. Asian countries only share a tiny portion of the big "pie". (see Figure 2).

There is a great potential to bring the soil conserving techniques to the developing countries in Asia and the Pacific. The detailed limitation of CA will be explained Part V of this paper.

The Successful Practice of CA in Latin America

It was not until 1971 that research on CA started in Brazil and Latin America. At first, minimum/no-tillage was conceived as an efficient technology for soil conservation since the arable farming had brought about the widespread occurrence of erosion in the southern states of Brazil. With time, the technology evolved to a truly sustainable production system with positive economic, environmental and social consequences.

In Latin America (mainly Brazil, Argentina, Paraguay and Uruguay), the technology experienced a twenty-fold expansion between 1987 and 1997 against a 4.6 fold increase of the area in the USA during the same period. The production and availability of a greater variety of more efficient herbicides, together with a greater diversity of more efficient minimum/no-tillage seeding equipment in Brazil and Argentina, has led to an unprecedented growth of minimum/no-tillage farming in South America.

The main factors that induced such a rapid change include: 1) Successful erosion control under conditions with high erosion and soil degradation potential. 2) Appropriate knowledge available in the region through research and development as well as farmers' experiences. 3) Widespread use of cover crops for weed suppression (reduction in the use of herbicides), organic matter build up, biological pest control, etc. 4) The same consistent, positive message, about minimum/no-tillage has generally been voiced by all sectors involved (private and public) without contradictions. 5) Minimum/no-tillage has been the only conservation tillage technology recommended to farmers. 6) There has been an aggressive farmer to farmer extension through farmers associations. 7) Publications of adequate, practical and useful information were made available to farmers and extension specialists. 8) Economic evaluations with a system approach showed high economic returns for the conservation system. 9) Latin American farmers have to be very competitive in the global market since there are no subsidies in general.

Among the above factors, raising awareness amongst farmers, technicians, extension specialists and researchers away from soil degrading tillage operations towards sustainable production systems of minimum/no-tillage was critical for changing the attitudes of farmers. Practice tells that if the farmer does not make a radical change in his mental approach, he will never bring the technology to work adequately. This is not only true for farmers but also for technicians, extension specialists and scientists. Minimum/no-tillage is so different from conventional tillage and puts everything upside down so that anybody who wants to have success with the technology has to forget almost everything they learned about conventional tillage systems and be prepared to learn all the new aspects of this new production system. That is, the farmer first has to change his mind before changing his planter.

The Adoption of Zero-Tillage in Indo-Gangetic Plains

The Indo-Gangetic Plains in South Asia - a 120,000 km^2 area stretching from Pakistan, through Nepal and India to Bangladesh - were the cradle of the Green Revolution in 1960s. Using improved wheat and rice varieties, irrigation and higher doses of fertilizer, farmers were able to double rice production and boost wheat output by almost five times in just three decades.

During the 1990s, however, those same farmers,and South Asia's population who were growing by some 56 million a year, faced uncertainty. Green Revolution technologies which spurred increases in annual rice output of more than 3% - and probably saved millions of people from the threat of famine - were considered "almost exhausted" of any further productivity gains. Annual production increases had slipped to around 1.25% since 1990. Evidence suggested that growth in cereal yields began to slow in many high-potential agricultural areas, possibly owing to soil nutrient mining, declining levels of organic matter, increasing salinity, falling water tables (the underground water level) and the build-up of weed, pathogen and pest populations. The challenge facing the region, therefore, was to further increase productivity while making agriculture more efficient and ecologically sound and sustainable.

The answer was not more irrigation and chemical fertilizer. FAO research indicated that farmers could produce more and help conserve their natural resource base by abandoning current land plowing and harrowing practices in favor of zero tillage. The conventional cropping system is now being replaced by new practices focused on more ecologically-sound management of plants, soil, water and nutrients, and soil biological processes. The whole concept and practice of CA has not been adopted by all farmers, but the main elements of zero tillage and maintaining residue cover on the soil are gaining wide acceptance, including crop rotations, pest and weed control, and the mindset change of the farmers.

Opportunities and Policy Recommendations

The rapidly increasing population and decreasing arable land, particularly in the Asian and Pacific region, require more intensive farming activities for food security. The more intensified farming activities, in turn, degrade the limited land and the environment. To break such a vicious cycle and move toward healthier and sustainable agriculture development, CA is a viable option for more efficient method of agricultural production with the minimal adverse impact on the farming environment.

However, CA was adopted relatively slowly so far in the large farming areas in Asia. It took 15 years for Pakistan and 10 years for India to reach significant adoption of the zero tillage component of CA with wheat. Other areas have adopted some aspects of this technology, usually zero-tillage, but permanent soil cover needs to be integrated into farming systems to obtain additional benefits. This is the case in the rice-wheat areas of South Asia where farmers are obtaining higher wheat yields at less cost by adopting zero tillage. It also took some 15 years to conduct experiments on conservation tillage in China. There is a great potential for expanding conservation tillage in this big agricultural country.

There are several constraints and limitations to the adoption due to lack of CA, availability of direct seeding machines, inadequate knowledge, and institutional support, as well as the farmer’s attitudes toward CA.

Lack of direct seeding implements for planting into the permanent soil cover is one of the main limitations. In order to implement CA, the minimum a farmer needs is a zero-tillage planter. Buying one without knowing the system or even having seen it first is a risk that few farmers take. Machinery dealers might not wish to promote CA as long as it is not supported by extension. This is partly due to the cost of the equipment but, more importantly, because the widespread adoption of CA will reduce machinery sales, particularly of large tractors. The cost-effective and efficient direct seeding machines suitable in Asian countries, especially the lower horsepower tractors, are in urgent need. Farmers in this region are primarily characterized as “small holders” and possess a very limited or no risk-bearing capacity towards ready acceptance of any newly-proposed technological shift.

Lack of knowledge and information is another constraint to minimum/no-tillage adoption in most Asian countries. Information has to be relevant, factual, locally appropriate, and useful in order to generate mindset change among farmers. For instance, the biggest challenge a farmer has to face when moving from conventional to minimum/no-tillage is weed and disease control. To be able to manage this new situation, a farmer has to have sound, site specific knowledge on herbicides, weeds and application technology.

Another impediment to accelerated adoption is the farmer's mindset that favors the status quo ontillage and the fear of failure. CA contravened the conventional wisdom built up over thousands of years about the benefits of tillage. Farmers had to experiment with minimum/no-tillage to convince themselves that it works but many are still hesitant to take any risk. Past successful experiences show the first years might be very difficult for farmers, meaning they might need moral support from other farmers or from extension services and perhaps even financial support (to invest in zero tillage planters).

Based on the above, the following policy recommendations might be worthy of consideration:

- An institutional framework of government services to mainstream sustainable agriculture development and GHG mitigation into national policies, laws, investment strategies, education and extension programmes;
- Raise public awareness to facilitate the extension of CA techniques by full involvement of all concerned stakeholders, including farmers, researchers, technicians, extension specialists and agronomists;
- Enhanced research and manufacturing of suitable direct seeding implements supported by both public and private sectors;
- Sharing of knowledge about all aspects of minimum/no-tillage system by farmers, researchers, technicians and extension specialists;
- Demonstration of good practices to promote farmers' mindset change toward minimum/no-tillage CA;
- Subsidies for buying new implements and phasing out of the old ones;
- Policy on financing the application of CDM in agricultural sector;
- Promote the public-private partnership in financing of the CDM application to the agricultural sector.

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