Management of Soil Resources for Sustainable Development under a Changing Climate

M. M. R. Jahangir*, I. Jahan and N. J. Mumu

Department of Soil Science, Bangladesh Agricultural University, Mymensingh-2202

*Corresponding author: mmrjhahangir@bau.edu.bd

Abstract

Development was conventionally driven by one particular need, without fully considering the wider or future impacts. This kind of approach has now been considered to be responsible for the economic and environmental catastrophes that humans are facing: from large scale financial crises caused by irresponsible banking to the changes in global climate resulting from our dependence on fossil fuel based energy sources. Soils provide essential ecosystem services such as primary production, regulation of biogeochemical cycles (with consequences for the climate), water filtration, resistance to diseases and pests, and regulation of above-ground biodiversity. Changing of the climate systems is unequivocal. Adaptation to global climate change through improved soil quality by adoption of improved management practices is key to maintaining sustainable agricultural production. A holistic approach to soil management as the engine for increasing productivity by increasing resource use efficiency and making agriculture environmentally compatible is more important than ever before. Strategies of greenhouse gas emission reduction include those that increase the use efficiency of inputs. Herein, we discussed how management and protection of soil resources can contribute to sustainable development through sustainable agricultural production while maintaining sustenance of soil fertility.

Key words: Carbon sequestration, Crop production, Greenhouse gas, Soil management, Soil quality

Concepts of sustainable development

According to the WCED (World Commission on Environment and Development) sustainable development is the ódevelopment that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987)ô. The concepts of sustainable development thus suggest that meeting the needs of the future depends on how well we balance social, economic and environmental needs when making decisions now. These needs seem to conflict with each other if thinking of the sustainable development is ignored.

Social, economic and environmental objectives should be at the heart of sustainable development and should be complementary and interdependent in the process. In the long term, responsible use of natural resources now will help ensure that there are resources available for the sustained industrial or agricultural growth far into the future. Sustainable development requires that societies meet human needs both by increasing productive potential and by ensuring equitable opportunities for all. This can thus be defined as a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspiration. Hence sustainable development must not endanger the natural systems that support life on earth: the atmosphere, the waters, the soils, and the living beings. Because of the strong impacts of soils on the sustainable development, soil management and protection must be prioritized due to its critical role as a source/sink of atmospheric CO_2, methane and N_2O; the urgency to feed an ever growing world population; the need to minimize risks of water pollution; eutrophication; soil erosion and the importance of enhancing biodiversity.

Although sustainable development is a global challenge, it is more challenging in South- East Asia and Bangladesh, in particular. Every country should promote sustainable development by developing and implementing strategies and by enacting and enforcing laws. Bangladesh has prepared the National Sustainable Development Strategy 2010-21 (NSDS) to address a critical development aspiration which highlighted soil protection from degradation and soil fertility improvement by appropriate management strategies (NSDS, 2013). Sustainable development policy should aim at integrating and harmonizing the three components of sustainable development: social, environment and economic.

Agriculture in sustainable development: insights into food, fibre, fuel and environment

Agriculture plays a vital role in sustainable development and in hunger and poverty elimination. Agriculture is facing great challenges to ensure global food security by increasing yields while reducing environmental cost. By 2050, the world population is expected to increase by 2.4 billion, which will put more pressure on the worldós agricultural systems for food, fuel and fibre and challenge the potential to achieve food security and environmental sustainability (Delgado *et al*., 2011). Food security is a global issue but it is especially severe in developing countries because of population growth and declining availability of land, water and other resources (Ray *et al*., 2015). Similarly, Bangladesh has already been reported to has been affected by the extreme climatic conditions and facing greater challenge for feeding its teeming population against a backdrop of a changing climate and growing competition for land, water, labour and energy. Eliminating poverty and hunger of more than 1 billion malnourished people and meeting the food demand of an additional 2.5 billion by 2050 will necessitate increasing global cereal production by 70% (Lele, 2010). In some developing countries of Africa and Asia we may also need to raise cereal production by 2.5 to 3 times. Yet the estimated global climate change may adversely affect the food supply through alterations in agronomic yields (Lobell *et al*., 2008, Pimentel and Pimentel, 2008). In sustainable agriculture, the seemingly great order is not only essential to advancing food security but also critical to reducing greenhouse gas emissions by agriculture, presently estimated at 30% (IPCC, 2015), and minimizing the problems of non-point source of contamination of surface and ground waters.

Contribution of soil resources to sustainable development

Soils provide essential ecosystem services such as primary production, regulation of biogeochemical cycles (with consequences for the climate), water filtration, resistance to diseases and pests, and regulation of above-ground biodiversity (Brady and Weil, 2002). When evaluating an agricultural management system for sustainability, the central focus should ensure that the system will not exhaust the resource base, will optimize soil conditions and will reduce food production vulnerability, while at the same time maintaining or enhancing productivity. One of the main tools towards sustainable agriculture in the world as well as in Bangladesh is management and protection of soil resources, policy and agrarian reform, participation, income diversification, land conservation and improved management of inputs. Judicious management practices can be advanced through agricultural policies that promote payment for ecosystem services of soils. Examples of payments include those for sequestering carbon in soil to mitigate and adapt to global climate change, enhancing water availability of quality water, strengthening nutrient cycling in soils, controlling floods, combating draughts, decreasing anoxia of coastal ecosystems, increasing biodiversity and providing habitat for plants and animals. Societal benefits of ecosystem services may be local (e.g., water supply) or global (e.g., carbon sequestration in soils to mitigate global climate change (Lal, 2010). Biodiversity conservation, closely related to terrestrial carbon (C) sequestration, is relevant to payment for ecosystem services (Barrios, 2007). Soil erosion, fertility loss, salinity, acidification, compaction and the loss of carbon are natural processes that can be accelerated tremendously by excessive use of soil and inappropriate management practices. Soils are crucial resources for sustainable development and need to be managed wisely and protected timely.

Management and protection of soil resources for sustainable development

Soil quality can be seen as a conceptual translation of the sustainability concept towards soil. Soil quality is the capacity of a specific kind of soil to function, within natural managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen *et al*., 1997). Intensification of agricultural land use along with increasing use of modern crop varieties has resulted in deterioration of soil quality (Jahir and Satter, 2010). Adaptation to global climate change through improved soil quality by adoption of improved management practices is key to maintaining sustainable soil quality. A holistic and system based approach to soil management as the engine for increasing productivity by increasing efficiency and making agriculture environmentally compatible is more important than ever before (Lal, 2015). Improving the management practices of soil, water and nutrients to improve soil quality, soil fertility, land productivity and ultimately food security and sustainable agriculture while ensure the conservation of natural resources. Improved soil management practices for economic, social and environmental sustainability require better management of soil-crop-nutrient: (i) soil management and conservation for sustainable agriculture and environment. This includes combating desertification, soil erosion assessment, soil fertility enhancement, fertilizer recommendation and soil conservation measures; (ii) technologies and practices for sustainable use and management of water in agriculture. This includes optimizing irrigation systems and enhancing crop water productivity and water use efficiency under rain fed and irrigated agro-ecosystems; and (iii) integrated soil-plant management packages to increase crop productivity in harsh environments (IAEA, 2015).

Conservation agriculture: a holistic approach for sustainable soil management

Long-term sustainability of agro ecosystems requires soil protection from degradation and reduction of greenhouse gas emissions and of environmental pollution. Soil protection needs judicious and prudent use of conservation agriculture to prove its potential as a conservation effective technology, climate resilient agriculture, and a viable option for sustainable intensification of agro ecosystems for advancing food security and for adaptation to/ mitigation of climate change. Conservation agriculture refers to a farming system comprised of crop residue mulch, cover cropping, integrated nutrient management (INM), and no tillage techniques in a rotation cycle for effective soil and water conservation, carbon sequestration, sustainable intensification and climate change adaptation and mitigation (Lal, 2015; Jahangir, 2016). Conservation agriculture (CA) is an approach that aims to sustainably improve farm productivity, profits, and food security by combining three principles which are: minimum mechanical soil disturbance, permanent soil cover, and crop rotation (FAO, 2012b). Conceptually conservation agriculture consists of four basic principles: i) retaining crop residues as surface mulch, ii) including cover crops in the rotation cycle, iii) improving soil fertility by INM for healthy crop growth and biochemical transformation of biomass carbon into soil organic matter or humus (Lal, 2014), and iv) causing minimal or no soil manipulation. CA is reported to improve soil quality, optimize crop yields and reduce input costs. (Hobbs, 2007; Hobbs *et al*., 2008; Wall, 2008). The positive effects of conservation practices are preventing or minimizing soil erosion and soil organic carbon (SOC) loss, improving water capture and use efficiency (Unger, 1990), nutrient cycling and retention and GHG emissions mitigation (Lal, 2003; Kassam et al., 2009; Palm *et al*., 2014). Conservation agriculture practices reduce the required irrigation water compared to CT. This resulted in increased irrigation water productivity (greater than 27%) and total water productivity (greater than 26%) in both the wheat and maize crops (Islam *et al*., 2019). The combination of ZT and residue retention in wheat increases yields, resource-use efficiencies, and soil and water quality, while decreasing production costs, relative to CT (Gathala *et al*., 2013; Haque *et al*., 2016; Hossen *et al*., 2018; Mitra *et al*., 2018; Jat *et al*., 2019; Singh *et al*., 2018).

Positive impacts of conservation agriculture on soil physical fertility (e.g., soil structure and water infiltration rate are specially erosion control in erosion prone erosive climate and erodible soils of the tropics) (Choudhury *et al*., 2014). No tillage increases soil moisture conservation even in the summer draught (Goode *et al*., 2015). Conservation agriculture improves soil physical properties such as bulk density and porosity as well as chemical and biological properties (Verhulst *et al*., 2010). Conservation agriculture caused increase in soil organic carbon content and other chemical properties (Dick, 2008), ameliorate sodic soils (Choudhury *et al*., 2014) and improve agronomic yield. Gómez *et al*., (1999) reported higher crop yields and better crop quality under no-tillage mulching compared to conventional tillage. The CA practices of zero tillage, residue retention and crop rotation or intercropping maintained higher soil organic carbon, and total soil N compared to conventional tillage practices after 4 years (Naab *et al*., 2017). Similarly, it is evident that conservation agriculture can improve soil biological quality: microbial communities (Zhang *et al*., 2012), microbial growth (Franzluebbers *et al*., 1995), soil food web and carbon dynamics (Minoshima *et al*., 2006) earthworms and other macro fauna (Mutema *et al*., 2013).

Management practices to enhance C and other nutrient availability in soil

Tillage practice can influence the concentration and distribution of soil organic carbon (SOC) in the profile with higher SOC content in surface layers with zero tillage than with conventional tillage, but a higher content of SOC in the deeper layers of tilled plots where residue is incorporated through tillage (Jantalia *et al*., 2007). Intensive tillage increases decomposition and mineralization of soil organic matter leading to carbon loss, while the practice of conservation agriculture promotes organic carbon stabilization (Umar *et al*., 2011).

Higher SOC and total N have been documented in CA systems with crop residue retained as surface mulch compared to conventional tilled systems with residue incorporated in long-term experiments in Mexico. (Govaerts *et al*., 2006; Verhulst *et al*., 2011). Govaerts et al. (2009) reported that 40 out of 78 cases, SOC was higher in zero tillage than conventional tillage. The SOCs was significantly higher in no tillage compared to conventional tillage (10% more in Vertisol and 8% more in Cambisol). Average SOCs was 29.35 and 27.36 Mg ha ī 1 under NT and CT, respectively within the 0ï 30 cm depth (Moussadek et al., 2014). SOC concentration was significantly higher in zero tillage relative to both intermediate tillage intensity [1.18 g/kg ± 0.34 (SE)] and high tillage intensity [2.09 g/kg ± 0.34 (SE)] in the upper soil layer (0ï 15 cm) (Haddaway *et al*., 2017).

Crop residues are precursors of the SOC pool and returning more crop residues to the soil is associated with an increase in SOC concentration (Dolan *et al*., 2006). Devêvre and Horwáth (2000) reported that straw decomposition in the field releases carbon dioxide, which can promote soil microbial immobilization or release and mineralize inorganic nitrogen, ultimately forming soil organic matter. Blanco-Canqui and Lal (2007) assessed changes in soil organic carbon from a 10 years impacts of three levels (0, 8, and 16 Mg ha^{-1} on a dry matter basis) of wheat straw applied annually on SOC under zero tillage. The authors found 82.5 Mg ha^{-1} SOC from 0 to 50 cm depth in the unmulched soil, 94.1 Mg ha^{-1} with 8 Mg ha^{-1} mulch, and 104.9 Mg ha^{-1} with 16 Mg ha^{-1} mulch. Crop rotation can influence SOC by changing the quantity and quality of organic matter input (Govaerts *et al*., 2009). Conservation agriculture can increase the possibility for crop intensification due to a faster turnaround time between harvest and planting. Other cropping options may become available since the actual growing period can be increased by the decreased turnaround time (Erenstein and Laxmi 2008). In some situations it may be possible to include an extra crop in the system after the main crop, or by intercropping or relay cropping with the main crop (Jat *et al*., 2006). Replacement of fallow with legume ógreen manuresô such as lentil (*Lens culinaris M.*) and red clover (*Trifolium pratense L.*) appears to be an effective practice where they increase SOC concentrations (Vanden Bygaart *et al*., 2003).

Increased stratification of nutrients is generally observed, with enhanced conservation and availability of nutrients near the soil surface under zero tillage as compared to conventional tillage (e.g. Duiker and Beegle, 2006). The altered nutrient availability under zero tillage compared to conventional tillage may be due to surface placement of crop residues in comparison with incorporation of crop residues with tillage (Ismail *et al*. 1994). The availability of mineral N for plant uptake is dependent on the rate of C mineralization. Zero tillage is generally associated with a lower N availability because of greater immobilization by the residues left on the soil surface (Bradford and Peterson 2000). Govaerts *et al*. (2007) observed a significantly higher total N under both zero tillage and permanent raised beds compared to conventional tillage. Significant increases in total N have been measured with increasing additions of crop residue (Graham *et al*., 2002). Tan *et al*., (2015) reported that the soil organic matter and total nitrogen content increased gradually over 6 years in no tillage (NT), straw mulching (SM), plastic-film mulching (PM), ridging and plastic-film mulching (RPM) and intercropping (In) except traditional tillage (CK). Yang Peipei *et al*. (2011) demonstrated that in conservation tillage, the soil organic matter and the total N, P and K content of soils show the phenomenon of surface accumulation.

Higher extractable P levels have reported in zero tillage than in tilled soil (e.g. Duiker and Beegle 2006, Du Preez *et al*., 2001), largely due to reduced mixing of the fertilizer P with the soil, leading to lower P-fixation. Extractable P in zero tillage system was 42% greater at 0-5 cm, but 8-18% lower at 5-30 cm depth compared with conventional tillage (Ismail *et al*., 1994). Zero tillage conserves and increases availability of nutrients, such as K. Govaerts *et al*. (2007) found that the K concentration increased significantly with increasing residue retention. Higher organic carbon contents at the soil surface, commonly observed under conservation agriculture, can increase the cation exchange capacity (Duiker and Beegle, 2006). The retention of crop residues significantly increase the cation exchange capacity (CEC) compared to soil without residue retention (Govaerts *et al*., 2007). Micronutrient cations (Zn, Fe, Cu and Mn) are higher levels under zero tillage with residue retentions compared to conventional tillage, especially extractable Zn and Mn near the soil surface due to surface placement of crop residues (Franzluebbers and Hons, 1996).

The pH of the topsoil tends to be lower for zero tillage than for conventional tillage (Franzluebbers and Hons, 1996). Sidiras and Pavan (1985) found less acidification under zero tillage than under conventional tillage to a depth of 60 cm in both an Oxisol and an Alfisol. Govaerts *et al*. (2007) found that permanent raised bed planting is a technology that reduces soil sodicity under rain fed conditions. They found the Na concentration to be 2.64 and 1.80 times lower in 0-5 cm and 5-20 cm layer, respectively, in permanent raised beds compared to conventionally till raised beds. They also reported that the Na concentration increased with decreasing amounts of residue retained on the permanent raised beds.

Soil management practices for improving soil biological properties

Soils host a huge biodiversity of microbes and fauna which is not yet well understood: the small size of the soilborne organisms; their immense diversity; the difficulty in isolating them; and the great heterogeneity of their habitats across different scales. The soil biodiversity studies includes microbes (archaea, bacteria, fungi) and fauna (protozoa, microarthropods, nematodes, oligochaeta), and their relation with above-ground biodiversity. We need to extend our capability to explore biological dynamics of soils at the scientific level, increase our knowledge of soil biodiversity and its role in ecosystem services across different soils, climate types and land uses at the technological level, standardize methods and operating procedures for characterizing soil biodiversity and functioning, and develop bioindicators at the economic level, assess the added value brought by cost-effective bioindicators, and cost effectiveness of alternative ecosystem services maintenance policies. For improving soil biological properties we need to deploy our efforts with three approaches: description of soil biodiversity and of the relations between soil biodiversity, soil functions and ecosystem services; long term observatories representative of soil types, climates and land uses, and modeling to elucidate relationships between soil biodiversity and functions.

Alvear *et al*. (2005) found higher soil microbial biomass C and N under zero tillage than under conventional tillage and attributed this to the higher levels of C substrates available for microbial growth, better soil physical conditions and higher water retention under zero tillage. Management practices such as tillage, crop rotation and residue management may have diverse effects on various soil enzymes (Tabatabai, 1994). Enzymatic activities generally decrease with soil depth (Green *et al*., 2007). Zero tillage management increases stratification of enzyme activities in the soil profile, probably because of similar vertical distribution of organic residues and microbial activity (Green *et al*., 2007). Crop rotation and residue management can affect soil enzyme activity. For example, Angers *et al*. (1993) reported 15% larger alkaline phosphatase activity in a barley-red clover rotation than in continuous barley. Retaining crop residues on the surface soil increases microbial abundance, because microbes encounter improved conditions for reproduction in the mulch cover (Salinas-Garcia *et al*., 2002). Yeates and Hughes (1990) found a significantly greater population of nematodes in reduced than in conventional tillage. In general, earthworm abundance, diversity and activity have been found to increase under conservation agriculture when compared to conventional agriculture (Kladivko, 2001). Mulched crop residues are also important since earthworms do not have the ability to maintain constant water content (Edwards and Bohlen, 1996). It has been proposed that ants are as important as earthworms in soil transformation (Gotwald, 1986). Termites and ants are predominant in arid and semi-arid regions where earthworms are normally absent or scarce.

Soil management for improving soil physical properties

Soil structure is the key physical properties in soil functioning and is an important factor in the evaluation of the sustainability of crop production systems because it is directly connected to the size, shape and arrangement of solids and voids, continuity of pores and voids, their capacity to retain and transmit fluids and organic and inorganic substances, and the ability to support vigorous root growth and development, to which we would add their ability to permit the diffusion of gases (Jahangir *et al*., 2011), especially oxygen and carbon dioxide. Physical disturbance of soil structure through tillage results in a direct breakdown of soil aggregates and an increased turnover of aggregates (Six et al., 2000) and fragments of roots and mycorrhizal hyphae, which are major binding agents for macro aggregates (Bronick and Lal, 2005). Zero tillage with residue retention improves dry aggregate size distribution compared to conventional tillage (Govaerts *et al*., 2009). The aggregate formation process in conventional tillage is interrupted each time the soil is tilled with the corresponding destruction of aggregates. Choudhary *et al*. (2018) reported higher maize and wheat yields under ZT which could be attributed to improvements in soil structure, better soil thermal dynamics and moisture and increased soil permeability (Jat *et al*., 2018) which may contribute to further benefits through higher soil micro- and macro- fauna biological activities facilitating better root and soil relationships.

The residues lying on the soil surface in conservation agriculture protect the soil from raindrop impact. No protection occurs in conventional tillage, which increases susceptibility to further disruption (Six *et al*., 2000). The return of crop residue to the soil surface increases the aggregate formation and decreases the breakdown of aggregates by reducing erosion and protecting the aggregates against raindrop impact. Crops can affect soil aggregation by their rooting system because plant roots are important binding agents at the scale of macro aggregates (Six *et al*., 2004). Altering crop rotation can influence the potential to alter soil aggregation indirectly. Soil porosity can change in both space and time following a change in tillage practices. These changes primarily reflect changes in the form, magnitude and frequency of stresses imposed on the soil, the placement of crop residues and the population of microorganisms and fauna in the soil (Kay and VandenBygaart, 2002). A plough pan may be formed by tillage immediately underneath the tilled soil, causing higher bulk density in this horizon in tilled situations (Dolan *et al*., 2006). Introduction of zero tillage can result in the loss of total pore space as indicated by an increase in bulk density. Hydraulic conductivity is expected to be higher in zero tillage with residue retention compared to conventional tillage due to the larger macropore conductivity as a result of the increased number of biopores (Eynard *et al*., 2004). Zero tillage almost doubled saturated hydraulic conductivity compared to conventional tillage (Sharratt *et al*., 2006). Soil management practices that increase the organic matter content of the soil could have a positive impact on the soil water holding capacity (Hatfield *et al*., 2001). The water content at saturation was found higher for reduced compared to conventional tillage (DóHaene *et al*., 2008). Residue retention and reduced tillage increased soil water content and crop yields in Kenya, Zambia, and Zimbabwe (Gicheru *et al*., 2006; Thierfelder and Wall, 2009, 2010; Theirfelder *et al*., 2012).

Straw mulching increased the soilôs capacity to retain water (Blanco-Canqui and Lal, 2007). Soil erosion is affected by crop residues that break the raindrop impact and slow down runoff, reducing erosion. Aggregate breakdown is a good measure for soil erodibility, as breakdown to finer, more transportable particles and microaggregates increases erosion risk (Le Bissonais, 2003). Conservation tillage has been frequently practiced in recent years to reduce water and wind erosion, increase water storage and alleviate ecological pressure (Hobbs *et al*., 2008). In the United States, reduced tillage systems have been reported to reduce soil erosion (Dabney *et al.*, 2004; Wilson *et al*., 2004), reduce nutrient losses (Kimmell *et al*., 2001), sequester carbon as a result of increasing organic matter (West and Post, 2002), and increase crop yields (Wilhelm and Wortmann, 2004).

Erosion rates from conventionally tilled agricultural fields average 1-2 orders of magnitude greater than erosion under native vegetation, and long-term geological erosion exceeds soil production (Montgomery, 2007). Hevia *et al*. (2007) reported that erodible fraction is 20% of the total sample weight in zero tillage and 49% in conventional tillage, showing that the conventional tillage soil was more susceptible to wind erosion. Vegetation and crop residue cover also play an important role in decreasing wind erosion by reducing the exposure of soil to wind at the surface and intercepting saltating material. Surface residue reflects solar radiation and insulates the soil surface (Shinners *et al*., 1994). The heat flux in soils depends on the heat capacity and thermal conductivity of soils, which vary with soil composition, bulk density, and water content (Hillel, 1998). Because soil particles have a lower heat capacity and greater heat conductivity than water, dry soils potentially warm and cool faster than wet soils.

Global and national priorities for sustainable soil management

Carbon sequestration: an exemplar indicator of soil security

Soil organic carbon has been considered as a primary indicator of soil quality. Through mineralization, soil organic matter releases substantial quantities of N, P, S and smaller amount of micronutrients. Soil organic matter is a key factor in maintaining long-term soil fertility since it is the reservoir of metabolic energy, which drives soil biological processes involved in nutrient availability (Jahir and Satter, 2010). Soil organic matter degradation with its severe consequences on the use efficiency of inputs and agronomic production must be reversed through restoration of the soil organic carbon pool above the threshold level of about 1.1% in the root zone (Lal, 2010). Management of soil organic matter has now become a major issue in dealing with the sustainable soil fertility and productivity in Bangladesh agroecosystems. Improvement in soil quality through carbon sequestration can increase agronomic productivity and advance food security in Bangladesh. An increase in the soil organic carbon pool by 1×10^{-9} Pg C ha^{-1} can increase crop yield by 20 to 70 kg ha^{-1} for wheat (*Triticum aestivum*), 10 to 50 kg ha^{-1} for rice (*Oryza sativa*), 30 to 300 kg ha^{-1} for corn, and 10 to 20 kg ha^{-1} for beans (*Phaseolus vulgaris*) (Lal, 2010).

Climate change adaptation and mitigation

World cropland soils cover about 1.5 b ha and have a large capacity to sink carbon (Lal, 2010). Management of soil organic carbon pool is an important aim to achieve adaptation to and mitigation of global climate change (Hansen *et al*., 2008), while advancing global food security (Lal *et al*., 2004). As an important sink of carbon, crop land soils can be used to mitigate and adapt to global climate change. The rate and total magnitude of soil organic carbon sequestration (an average of about 0.55×10^{-9} Pg C ha^{-1} y^{-1}; West and Post, 2002) depend on residue management and recycling of organics, climate regime, N application and soil properties. Similar to crop land soils, forest and grassland soils can also be important for carbon sequestration. Many factors are involved in carbon sequestration in forest soils, including carbon input by litter and roots into different soil horizons, soil age, N application, moisture regime, site management, frequency and intensity of burning and the addition of charcoal and residue management (Lal, 2005a, 2005b). McKinsey and Company (2009) estimated that by 2030, afforestation can mitigate 0.27 Pg C yr^{-1}; reforestation, 0.38 Pg C yr^{-1} and improved management, 0.08 Pg C yr^{-1}. Grassland soils cover 2.9 b ha globally, including 2.0 b ha under tropical grasslands or savannas and 0.9 b ha under temperate grasslands (Lal, 2010). Possible management practices for C sequestration in grassland can be fertilization, controlled grazing, conversion of degraded cropland and native vegetation to pasture, sowing of leguminous and grass pasture species, fire management and water conservation (Conant *et al*., 2001). Mean rate of soil C sequestration in grassland is 5.4×10^{-10} Pg C ha^{-1} yr^{-1} (Conant *et al*., 2001).

Conclusions

Sustainable agriculture needs to protect the natural resource base, prevent the degradation of soil and water; conserve biodiversity; contribute to the economic and social well-being of all; ensure a safe and high-quality supply of agricultural products; and safeguard the livelihood and well-being of the nation. The world now faces modern soil crisis that eclipses those of the past. The challenges that agriculture is facing in sustainable development are working out ways of bringing about a society that is materially sufficient, socially equitable and ecologically sustainable and one that is not obsessed by growth only, but motivated by satisfying human needs and equity in resource allocation and use. Soils are crucial resources for sustainable development and need to be managed and protected. Sustainable agriculture must nurture healthy ecosystems and support the sustainable management of soil resources while ensuring global food security and environmental safety. In order to adequately address the utterly important role of soils for sustainable development a holistic approach is needed. Sustainable development can be possible by an integrated approach of soil management to address the social, economic and environmental dimensions. Soil carbon should be linked with soil function not only as a potential mechanism for climate change mitigation but also with fundamental provision of food, fibre, water and biodiversity provides insights into a far broader set of environmental, economic and social outcomes for the planet. Adaptation to climate change can be enhanced through mulch farming, agroforestry systems, INM, and soil water conservation. Improved soil management practices for economic, social and environmental sustainability require combating desertification, soil erosion assessment, soil fertility enhancement, fertilizer evaluation and soil conservation measures and adopting integrated soil-crop-water management package to increase crop productivity in harsh environments. Agricultural package comprising of reduced tillage, cover crop, crop rotation, INM and application of organics can be best soil management and protection tool.

References

Alvear, M., Rosas, A., Rouanet, J.L., and Borie, F. 2005. Effects of three soil tillage systems on some biological activities in an Ultisol from southern Chile. Soil Till. Res. 82:195-202.

Angers, D.A., Bissonnette, N., Legere, A., and Samson, N. 1993. Microbial and Biochemical-Changes Induced by Rotation and Tillage in A Soil Under Barley Production. Can. J. Soil Sci. 73:39-50.

Barrios E. 2007. Soil biota, ecosystem services and land productivity. Environ. Econ. 64: 269–285.

Blanco-Canqui, H. and Lal, R. 2007. Impacts of long-term wheat straw management on soil hydraulic properties under no-tillage. Soil Sci. Soc. Amer. J. 71:1166-1173.

Bradford, J.M. and Peterson, G.A. 2000. Conservation tillage. In Handbook of soil science, ed. M. E.

Sumner, G247-G269. Boca Raton, FL, USA: CRC Press.

Brady, N.C. and Weil, R.R. 2007. The nature and properties of soils. 14th Edition. Prentice Hall.

Bronick, C.J. and Lal, R. 2005. Soil structure and management: a review. Geoderma 124:3-22.

Choudhary, M., Jat, H.S., Datta, A., Yadav, A.K., Sapkota, T.B., Mondal, S., Meena, R.P., Sharma, P.C., Jat, M.L., 2018. Sustainable intensification influences soil quality, biota, and productivity in cereal-based agroecosystems. Appl. Soil Ecol. 186: 189ï 194.

Choudhury, S.G., S. Srivastava, R. Singh, S.K. Chaudhari, D.K. Sharma, S.K. Singh, and Sarkar, D. 2014. Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice-wheat cropping system under reclaimed sodic soil. Soil Till. Res. 136:76-83.

Conant R.T., Paustian K., and Elliott E.T. 2001. Grassland management and conversion into grassland: Effects on soil carbon. Ecol. Appl. 11: 343ï 355.

Dabney, S. M., Wilson, G. V., McGregor, K. C., and Foster, G. R. (2004). History, residue and tillage effects on erosion of loessial soil. *Trans. ASAE* 47, 767ï 775. doi: 10.13031/2013.16108

Delgado, J.A., Groffman, P.M. Nearing, M.A., Goddard, T., Reicosky, D., Lal, R., Kitchen, N.R., Rice, C.W., Towery, D., and Salon, P. 2011. Conservation practices to mitigate and adapt to climate change. J. Soil Water Conserv. 66(4): 118-129.

Devêvre, O. C., & Horwáth, W. R. 2000. Decomposition of rice straw and microbial carbon use efficiency under different soil temperatures and moistures. Soil Biol. Biochem. 32: 1773ï 1785

D'Haene, K., Vermang, J., Cornelis, W.M., Leroy, B.L.M., Schiettecatte, W., De Neve, S., Gabriels, D., and Hofman, G. 2008. Reduced tillage effects on physical properties of silt loam soils growing root crops. Soil Till. Res. 99:279-290.

Dick, W.A. 2008. Organic-Carbon, Nitrogen, and Phosphorus Concentrations and Ph in Soil Profiles As Affected by Tillage Intensity. Soil Sci. Soc. Am. J. 47:102-107.

Dolan, M.S., Clapp, C.E., Allmaras, R.R., Baker, J.M., and Molina, J.A.E. 2006. Soil organic carbon and nitrogen in a Minnesota soil as related to tillage, residue and nitrogen management. Soil Till. Res. 89:221-231.

Du Preez, C.C., Steyn, J.T., and Kotze, E. 2001. Long-term effects of wheat residue management on some fertility indicators of a semi-arid Plinthosol. Soil Till. Res. 63:25-33.

Duiker, S.W. and Beegle, D.B. 2006. Soil fertility distributions in long-term no-till, chisel/disk and moldboard plow/disk systems. Soil Till. Res. 88:30-41.

Edwards, C.A., Bohlen, P.J. 1996. Biology and ecology of earthworms. London, UK: Chapman and Hall.

Erenstein, O. and Laxmi, V. 2008. Zero tillage impacts in India's rice-wheat systems: A review. Soil Till. Res. 100:1-14.

Eynard, A., Schumacher, T.E., Lindstrom, M.J., and Maio, D.D. 2004. Porosity and pore-size distribution in cultivated ustolls and usterts. Soil Sci. Soc. Am. J. 68:1927-1934.

FAO 2012. What is CAò? ñPrinciples of CAò, ñBenefits of CA. Available at: http://www.fao.org/ag/ca/index.html.

Franzluebbers, A.J., Hons, F.M. 1996. Soil-profile distribution of primary and secondary plantavailable nutrients under conventional and no tillage. Soil Till. Res. 39:229-239.

Franzluebbers, A.J., Hons, F.M. and Zuberer, D.A. 1995. Soil organic-carbon, microbial biomass, and mineralizable carbon and nitrogen in sorghum. Soil Sci. Soc. Amer. J. 59:460-466.

Gathala, M.K., Kumar, V., Sharma, P.C., Saharawat, Y.S., Jat, H.S., Singh, M., Kumar, A., Jat, M.L., Humphreys, E., Sharma, D.K., Sharma, S., Ladha, J.K., 2013. Optimizing intensive cereal-based cropping systems addressing current and future drivers of agricultural change in the north-western Indo-Gangetic Plains of India. Agric. Ecosyst. Environ. 177: 85ï 97.

Gómez J., Giráldez J., Pastor M. and Fereres E. 1999. Effects of tillage method on soil physical properties, infiltration and yield in an olive orchard. Soil till. Res. 52: 167ï 175.

Goode, E. 2015. Farmers put down the plow for more productive soils. The New York Times, Science Section, 10 March. http://nyti.ms/1A9ok7B.

Gotwald, W.H. 1986. The Beneficial Economic Role of Ants. In Economic Impact and Control of Social insects, ed. S. B. Vinson, 290-313. New York: Praeger Special Studies.

Govaerts, B., Sayre, K. D., Goudedeune, B., De Corte, P., Lichter, K., Dendooven, L., et al. 2006. Conservation agriculture as a sustainable option for the central Mexican highlands. Soil Till. Res. 103: 222ï 230.

Govaerts, B., Sayre, K.D., Goudeseune, B., De Corte, P., Lichter, K., Dendooven, L., and Deckers, J. 2009. Conservation agriculture as a sustainable option for the central Mexican highlands. Soil Till. Res. 103:222-230.

Govaerts, B., Sayre, K.D., Lichter, K., Dendooven, L., and Deckers, J. 2007. Influence of permanent raised bed planting and residue management on physical and chemical soil quality in rain fed maize/wheat systems. Plant Soil 291:39-54.

Graham, M.H., Haynes, R.J., and Meyer, J.H. 2002. Soil organic matter content and quality: effects of fertilizer applications, burning and trash retention on a long-term sugarcane experiment in South Africa. Soil Biol. Biochem. 34:93-102.

Green, V.S., Stott, D.E., Cruz, J.C., and Curi, N. 2007. Tillage impacts on soil biological activity and aggregation in a Brazilian Cerrado Oxisol. Soil Till. Res. 92:114-121.

Haddaway, N.R., Hedlund, K., Jackson, L.E., Kätterer, T., Lugato, E., Thomsen, I.K., Jørgensen, H.B., Isberg, P. 2017. How does tillage intensity affect soil organic carbon? A systematic review. Environ. Envi. https://doi.org/10.1186/s13750-017-0108-9

Hansen J., Sato M., Kharecha P., Beerling D., Berner R, Masson-Delmotte V., Pagani M., Raymo M., Royer D.L., Zachos J.C. 2008. Target atmospheric CO_2: Where should humanity aim? Open Atmosp. Sci. J. 2: 217ï 231.

Haque, M.E., Bell, R.W., Islam, M.A., Rahman, M.A. 2016. Minimum tillage unpuddled transplanting: an alternative crop establishment strategy for rice in conservation agriculture cropping systems. Field Crops Res. 185: 31ï 39.

Hatfield, J.L., Sauer, T.J., and Prueger, J.H. 2001. Managing soils to achieve greater water use efficiency: A review. Agr. J. 93:271-280.

Hevia, G.G., Mendez, M., and Buschiazzo, D.E. 2007. Tillage affects soil aggregation parameters linked with wind erosion. Geoderma 140:90-96.

Hillel, D. 1998. Environmental Soil Physics. San Diego, CA, USA: Academic Press.

Hobbs P.R., Sayre K., Gupta R. 2008. The role of conservation agriculture in sustainable agriculture. Philosophical Transactions of the Royal Society B: Biol. Sci. 363: 543ï 555.

Hobbs, P.R. 2007. Conservation agriculture: what is it and why is it important for future sustainable food production? J. Agric. Sci. 145: 127ï 137.

Hobbs, P. R., Sayre, K. D., and Gupta, R. 2008. The role of conservation agriculture in sustainable agriculture. Philos. Trans. R. Soc. B. 363: 543ï 555.

Hossen, M.A., Hossain, M.M., Haque, M.E., Bell, R.W., 2018. Transplanting into non- puddled soils with a small-scale mechanical transplanter reduced fuel, labour and irrigation water requirements for rice (*Oryza sativa L.*) establishment and increased yield. Field Crops Res. 225: 141ï 151.

International Atomic Energy Association (IAEA), 2015. Soil and Water Management and Crop Nutrition Subprogramme of the Joint FAO/IAEA Programme of Nuclear Techniques in Food and Agriculture (http://www-tc.iaea.org/tcweb/tcprogramme/default.asp).

IPCC. 2015. Climate Change 2014: Synthesis Report. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

Ismail, I., Blevins, R.L., and Frye, W.W. 1994. Long-Term No-Tillage Effects on Soil Properties and Continuous Corn Yields. Soil Sci. Soc. Amer. J. 58:193-198.

Jahangir, M.M.R., Roobroeck, D., Van Cleemput, O., Boeckx, P. 2011. Spatial variability and biophysicochemical controls on N_2O emissions from differently tilled arable soils. Biol. Fertil. Soils, 47(7): 753-766.

Jahangir, M.M.R. 2016. Soil: A weapon for food security and climate change adaptation and mitigation. J. Adv. plant Agric. Res., 3(3): 00095. DOI: 10.15406/apar.2016.03.00095.

Jahir, M., Satter, M.A. 2010. Agricultural Research Priority : Vision- 2030 and beyond-land and soil resource management. Final Report, March 2010. Bangladesh Agricultural Research Council, Farmgate, Dhaka.

Jantalia, C.P., Resck, D.V.S., Alves, B.J.R., Zotarelli, L., Urquiaga, S., and Boddey, R.M. 2007. Tillage effect on C stocks of a clayey Oxisol under a soybean-based crop rotation in the Brazilian Cerrado region. Soil Till. Res. 95:97-109.

Jat, M.L., Gupta, R.K., Erenstein, O., and Ortiz, R. 2006. Diversifying the Intensive Cereal Cropping Systems of the Indo-Ganges through Horticulture. Chronica Hort. 46:16-20.

Jat, R.K., Singh, R.G., Kumar, M., Jat, M.L., Parihar, C.M., Bijarniya, D., Sutaliya, J.M., Jat, M.K., Parihar, M.D., Kakraliya, S.K., Gupta, R.K., 2019. Ten years of conservation agriculture in a rice-maize rotation of Eastern Gangetic Plains of India: yield trends, water productivity and economic profitability. Field Crops Res. 232: 1ï 10.

Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.G., Harris, R.F., and Schuman, G.E. 1997. Soil quality: A concept, definition, and framework for evaluation. Soil Sci. Soc. Am. J. 61:4-10.

Kassam, A., Friedrich, T., Shaxson, F., and Pretty, J. 2009. The spread of conservation agriculture: justification, sustainability and uptake. Int. J. Agric. Sustain. 7: 292ï 320.

Kay, B.D. and VandenBygaart, A.J. 2002. Conservation tillage and depth stratification of porosity and soil organic matter. Soil Till. Res. 66:107-118.

Kimmell, R.J., Pierzynski, G.M., Janssen, K.A., and Barnes, P.L. 2001. Effects of tillage and phosphorus placement on phosphorus losses in a grain sorghum-soybean rotation. J. Environ. Qual. 30: 1324ï 1330.

Kladivko, E.J. 2001. Tillage systems and soil ecology. Soil Till. Res. 61:61-76.

Lal, R. 2003. Global potential of soil C sequestration to mitigate the greenhouse effect. *Crit. Rev.* Plant Sci. 22: 151ï 184.

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. Sci. 304: 1623ï 1627.

Lal, R. 2005a. Forest soils and carbon sequestration. Forest Ecol. Manage. 220: 242ï 258.

Lal, R. 2005b. Soil carbon sequestration in natural and managed tropical ecosystems. J. Sust. Forestry, 2: 1ï 30.

Lal, R. 2010. Managing Soils and Ecosystems for Mitigating Anthropogenic Carbon Emissions and Advancing Global Food Security. BioSci. 60:701-721.

Lal, R. 2014. Societal value of soil carbon. J. Soil Water Conserv. 69:186A-192A

Lal, R. 2015. Sequestering carbon and increasing productivity by conservation agriculture. J. Soil Water Conserv. 70: 56A-62A.

Le Bissonnais, Y. 2003. Aggregate Brealkdown Mechanisms and Erodibility. In Encyclopedia of Soil Science, ed. R. Lal, Marcel Dekker, Inc.

Lele, U. 2010. Food security for a billion poor. Sci. 326: 1554.

Lobell, D.B., Burke, M.B., Tebaldi, C, Mastrandea, M.D., Falcon, W.P., Naylor, R.L. 2008. Prioritizing climate change adaptation needs for food security in 2030. Sci. 319: 607ï 610.

McKinsey and Company. 2009. Pathways to a Low Carbon Economy. Version 2 of the Global Greenhouse Gas Abatement Cost Curve. McKinsey and Company. (21 July 2010; https://solutions.mckinsey.com/ ClimateDesk/default/en-us/requestfullreport.aspx).

Minoshima, H., Jackson, L.E., Cavagnaro, T.R., Sanchez-Moreno, S., Ferris, H., S.R. Temple, S. Goyal, and Mitchell, J.P. 2007. Soil food webs and carbon dynamics in response to conserva-tion tillage in California. Soil Sci. Soc. Amer. J. 71:952-963.

Mitra, B., Patra, K., Bhattacharya, P.M., Chowdhury, A.K., 2018. Unpuddled trans- planting: a productive, profitable and energy-efficient establishment technique in rice under Eastern sub-Himalayan plains. Oryza 55 (3): 459ï 466.

Montgomery, D.R. 2007. Soil erosion and agricultural sustainability. P. Natl. Acad. Sci. USA 104:13268-13272.

Moussadek, R., Mrabet, R., Dahan, R., Zouahri, A. 2014. Tillage System Affects Soil Organic Carbon Storage and Quality in Central Morocco. Applied and Environ. Soil Sci. Doi: 10.1155/2014/654796.

Mutema, M., Mafongoya, P.L. Nyagumbo, I. and Chikukura, L. 2013. Effects of crop residues and reduced tillage on macrofauna abundance. J. Organic Systs. 8:5-16.

Naab, J.B., Mahama, G.Y., Yahaya, I., Prasad, P.V.V. 2017. Conservation Agriculture Improves Soil Quality, Crop Yield, and Incomes of Smallholder Farmers in North Western Ghana. Front. Plant Sci. https://doi.or g/10.3389/fplVs.2017.00996

National Sustainable Development Strategy (NSDS), 2013. General Economics Division, Ministry of Planning, Government of the Peopleôs Republic of Bangladesh, May 2013. (http://www.plancomm.gov.bd/national-sustainable-development-strategy/).

Palm, C., Blanco-Canqui, H., DeClerck, F., Gatere, L., and Grace, P. 2014. Conservation agriculture and ecosystem services: an overview. Agric. Ecosyst. Environ. 187: 87ï 105.

Pimentel D, Pimentel MH. 2008. Food, Energy and Society. CRC Press, Taylor and Francis.

Ray, D.K., Gerber, J.S., MacDonald, G.K., and West, P.C., 2015. Climate variation explain a third of global crop yield variability, Nature Commun. 6:1-9.

Salinas-García, J.R., Velázquez-García, J.D., Gallardo-Valdez, A., Díaz-Mederos, P., Caballero-Schoenau, J.J. and Campbell, C.A. 1996. Impact of crop residues on nutrient availability in conservation tillage systems. Can. J. Plant Sci. 76:621-626.

Sharratt, B., Zhang, M.C., and Sparrow, S. 2006. Twenty years of conservation tillage research in subarctic Alaska - II. Impact on soil hydraulic properties. Soil Till. Res. 91:82-88.

Shinners, K.J., Nelson, W.S., and Wang, R. 1994. Effects of Residue-Free Band-Width on Soil-Temperature and Water-Content. T. ASAE 37:39-49.

Sidiras, N. and Pavan, M.A. 1985. Influencia do sistema de manejo do solo no seu nivel de fertilidade. Rev. Bras. Cienc. Solo 9:244-254.

Singh, V.K., Dwivedi, B.S., Yadvinder-Singh, Singh, S.K., Mishra, R.P., Shukla, A.K., Rathore, S.S., Shekhawat, K., Majumdar, K., Jat, M.L., 2018. Effect of tillage and crop establishment, residue management and K fertilization on yield, K use efficiency and apparent K balance under rice-maize system in North-Western India. Field Crops Res. 224: 1ï 12.

Singh, V.K., Yadvinder-Singh, Dwivedi, B.S., Singh, Majumdar, K., Jat, M.L., Mishra, R.P., Rani, M., 2016. Soil physical properties, yield trends and economics after five years of conservation agriculture-based rice-maize system in north-western India. Soil Tillage Res. 155: 133ï 148.

Six, J., Bossuyt, H., Degryze, S., and Denef, K. 2004. A history of research on the link between (micro)aggregates, soil biota, and soil organic matter dynamics. Soil Till. Res. 79:7-31.

Six, J., Elliott, E.T., and Paustian, K. 2000. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Biol. Biochem. 32:2099-2103.

Tabatabai, M.A. 1994. Soil enzymes. In Methods of soil analysis: Microbiological and biochemical properties, (ed.) R.W. Weaver, J.S. Angle, P. Bottomley, D. Bezdicek, S. Smith, A. Tabatabai, and A.G. Wollum, 775-827. Madison, WI: Soil Science Society of America.

Tan, C., Cao, X., Yuan, S., Wang, W., Feng, Y., Qiao, B. 2015. Effects of Long-term Conservation Tillage on Soil Nutrients in Sloping Fields in Regions Characterized by Water and Wind Erosion. Sci. reports 5: 17592.

Thierfelder, C., and Wall, P. C. 2010. Rotation in conservation agriculture systems of Zambia: effects on soil quality and water relations. *Exp. Agric.* 46, 309ï 325. doi: 10.1017/S001447971000030X

Thierfelder, C., and Wall, P. C., 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil Tillage Res. 105: 217ï 227. doi: 10.1016/j.still.2009.07.007

Thierfelder, C., Chisui, J. L., Gama, M., Cheesman, S., Jere, Z. D., Bunderson, W. T., et al. 2012. Maize-based conservation agriculture systems in Malawi: long-term trends in productivity. Field Crops Res. 142: 47ï 57. doi: 10.1016/j.fcr.2012.11.010

Umar, B. B., Aune, J B., Johnsen, E.H., and Lungu, O.I. 2011. Options for improving smallholder conservation agriculture in Zambia. J. Agric. Sci. 3: 50ï 62.

Unger, P.W. 1990. Conservation tillage systems. Adv. Soil Sci. 13: 27ï 67. doi: 10.1007/978-1-4613-8982-8_3

VandenBygaart, A.J., Gregorich, E.G., and Angers, D.A. 2003. Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. Can. J. Soil Sci. 83:363-380.

Verhulst, N., Govaerts, B., Verachterbt, E., Castellanos, A. N., Mezzalamaa, M., Walla, P. C., et al. 2010. ñConservation agriculture, improving soil quality for sustainable production systems?,ò in Advances in Soil Science: Food Security and Soil Quality, (eds.) R. Lal and B. A. Stewart (Boca Raton, FL: CRC Press), 137ï 208.

Verhulst, N., Nelissen, V., Jespers, N., Haven, H., Sayre, K. D., Raes, D., et al. 2011. Soil water content, maize yield and its stability as affected by tillage and crop residue management in rainfed semiarid highlands. Plant Soil 344: 73ï 85. doi: 10.1007/s11104-011-0728-8

Wall, P. C. 2008. Tailoring conservation agriculture to the needs of small farmers in developing countries. J. Crop Improv. 19: 137ï155. doi: 10.1300/J411v19n01_07

West, T. O., and Post, W. M. 2002. Soil organic carbon sequestration by tillage and crop rotation: a global data analysis. Soil Sci. Soc. Am. J. 66: 1930ï1946.

West, T.O., and W.M. Post. 2002. Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. Soil Sci. Soc. Amer. J. 66(6):1930-1946.

Wilhelm, W.W., and Wortmann, C.S. 2004. Tillage and rotation interactions for corn and soybran grain yield as affected by precipitation and air temperature. Agron. J. 96: 425ï432.

Wilson, G. V., Dabney, S. M., McGregor, K. C., and Barkoll, B. D. 2004. Tillage and residue effects on runoff and erosion dynamics. Trans. ASAE 47: 119ï128.

World Commission on Environment and Development (WCED), 1987. Our common future: Towards sustainable development. Oxford University Press. (http://www.un-documents.net/ocf-02.htm.

Yang P. P., Yang M. X., Dong W. X., Chen S. Y., Hu C. S. 2011. Effect of conservation tillage on wheat and soil nutrient distribution and absorption. Chinese J. Eco-Agric. 19: 755ï759.

Yeates, G.W. and Hughes, K. 1990. Effect of three tillages regimes on plant- and soil nematodes in an oats/maize rotation. Pedobiologia 34:379-387.

Zhang, B., H.B. He, X.L. Ding, X.D. Zhang, X.P. Zhang, X.M. Yang, and Filley, T.R. 2012. Soil microbial community dynamics over a maize (*Zea mays* L.) growing season under conventional- and no-tillage practices in a rainfed agroecosystem. Soil Till. Res. 124:153-160.