Soil degradation: a problem threatening the sustainable development of agriculture in Northeast China

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ABSTRACT

Soil degradation that results from erosion, losses of organic matter and nutrients, or soil compaction are of great concern in every agricultural region of the world. The control of soil erosion and loss of organic matter has been proposed as critical to agricultural and environmental sustainability of Northeast China. This region is bread basket of China where the fertile and productive soils, Mollisols (also called Black soils), are primarily distributed. In this paper, we introduce the importance of Northeast China's grain production to China, and describe the changes of sown acreage and grain production in past decades. This paper also summarizes the distribution, area and intensity of water erosion, changes in the number of gullies and gully density, thickness of top soil layer, soil organic matter content, bulk density, field water holding capacity, and infiltration rates; the number of soil microorganism and main enzyme activities from soil erosion in the region are also summarized. The moderately and severely water-eroded area accounted for 31.4% and 7.9% of the total, and annual declining rate is 1.8%. Erosion rate is 1.24–2.41 mm/year, and soil loss in 1°, 5° and 15° sloping farmlands is 3 t/ha/year, 78 t/ha/year and 220.5 t/ha/year, respectively. SOC content of uncultivated soil was nearly twice that of soil with a 50-year cultivation history, and the average annual declining rate of soil organic matter was 0.5%. Proper adoption of crop rotation can increase or maintain the quantity and quality of soil organic matter, and improve soil chemical and physical properties. Proposed strategies for erosion control, in particular how tillage management, terraces and strip cultivation, or soil amendments contribute to maintain or restore the productivity of severely eroded farmland, are discussed in the context of agricultural sustainability with an emphasis on the Chinese Mollisols.

Keywords: soil loss; erosion control strategies; agricultural sustainability; water erosion; organic matter; Mollisol

Soil is a vital natural resource that is nonrenewable on the human time scale (Jenny 1980) and is a living, dynamic, natural body that plays many key roles in terrestrial ecosystems. The soil is a rich mix of mineral particles, organic matter, gases and nutrients, and is the home to billions of macro- and microscopic organisms. When filled with vital water, soil constitutes a fertile substrate for the initiation and maintenance of life (Hillel 1991). It is the essence of life and health for the well being of humankind and animals, and the major source of most of our food production. The maintenance of soil health is essential for sustained production of food, decomposition of wastes, storage of heat, sequestration of carbon, and exchange of gases. Soils also provide the geologic, climatic, biological, and human history (Brady and Weil 2000). However, only a limited amount of the soil can actually be used for producing food; when improperly managed, it can be however eroded, polluted or even destroyed.

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Table 1. Changes of sown acreage, total corn, soybean, rice and wheat production in Northeast China and China from 1996 to 2006

Year	Sown acreage (million ha)		Total production (million Mg)		Yield (kg/ha)	
	China	Northeast	China	Northeast	China	Northeast
1996	112.6	14.5	504.5	70.3	4894	4858
1997	112.9	14.6	494.2	62.3	4822	4258
1998	113.8	14.7	512.3	73.4	4953	4997
1999	113.2	14.7	508.4	70.3	4945	4792
2000	108.5	14.6	462.2	53.2	4753	3660
2001	106.1	15.9	452.6	60.0	4800	3773
2002	103.9	15.2	457.1	66.7	4885	4393
2003	94.1	14.9	430.7	62.7	4873	4216
2004	101.6	15.7	469.5	73.7	5187	4698
2005	104.3	16.0	484.0	74.2	5225	4638
2006	105.5	16.5	497.5	77.9	5322	4720
Average	106.9	15.2	479.4	67.7	4969	4455

Only 22% of the earth's land area of 14 900 million ha is potentially productive (El-Swaify 1994), and soils in 11% of the vegetative area and 38% of the cultivated area in the world have been degraded since 1945 (Gardiner and Miller 2004). This is an area of the size of China and India together. Approximately 24 billion tons of topsoil is lost annually, which is equivalent to about 9.6 million hectares of land (Bakker 1990). Therefore, soil degradation that results from wind and water erosion, salinization, losses of organic matter and nutrients, or soil compaction is of great concern in every agricultural region of the world.

Worldwide research and technology transfer efforts have increased the awareness that soil resources have both inherent characteristics determined by their formation factors and dynamic characteristics determined by human decisions and management practices. It is estimated that soil erosion accounts for 82% of human-induced soil degradation, affecting some 1643 million ha (Oldeman 1994).

Agricultural management strongly affects soil erosion, and soil erosion induces a decline of field productivity through removal, transport and deposition of topsoil, and thus agricultural sustainability (Izaurralde et al. 1998, Farquharson et al. 2003, Zhang et al. 2006a). The importance of increased soil organic carbon (SOC) is its effect in improving soil physical properties, conserving water, and increasing available nutrients. These improvements should ultimately lead to greater biomass and crop yield (Berzsenyi et al. 2000). There is considerable concern that if SOC concentrations in soils are allowed to decrease too much, then the productive capacity of agriculture will be compromised by deterioration in soil physical properties and by impairment of soil nutrient cycling mechanisms. Long-term experiments are often required to provide leading indicators of sustainability, which can serve as an early warning system to detect impairments that threaten future productivity (Clapp et al. 2000). A stable trend in yield is considered necessary to call a system sustainable, and the stability of yield is also an important characteristic to be considered when judging the value of one cropping system relative to others. Stability of yield can therefore be used as an integrator of the forgoing soil quality indicators (Berzsenyi et al. 2000, Arshad and Martin 2002).

Northeast China, the grain production base of China or 'bread basket of China' includes three provinces (Hei-long-jiang, Ji-lin, and Liao-ning) and eastern part of Inner Mongolian autonomous region. The average annual sown acreage and annual total corn, soybean, rice and wheat production in Northeast China from 1996 to 2006 accounted for 15.7% and 14.1% of China's total, respectively, although average yield per hectare was only 90% of the national average (Table 1). In 2007, the total grain production in the region was 15.1% of the nation's total, among them, 30.5% in corn, 55.7% in soybean and 9.6% in rice. The population in the region is 118 million people, and the average grain per capita is around 574 kg annually with over 1000 kg in Hei-long-jiang province (Figure 1). Nearly 60% of the grain produced in this region is exported to other regions of China as a com-

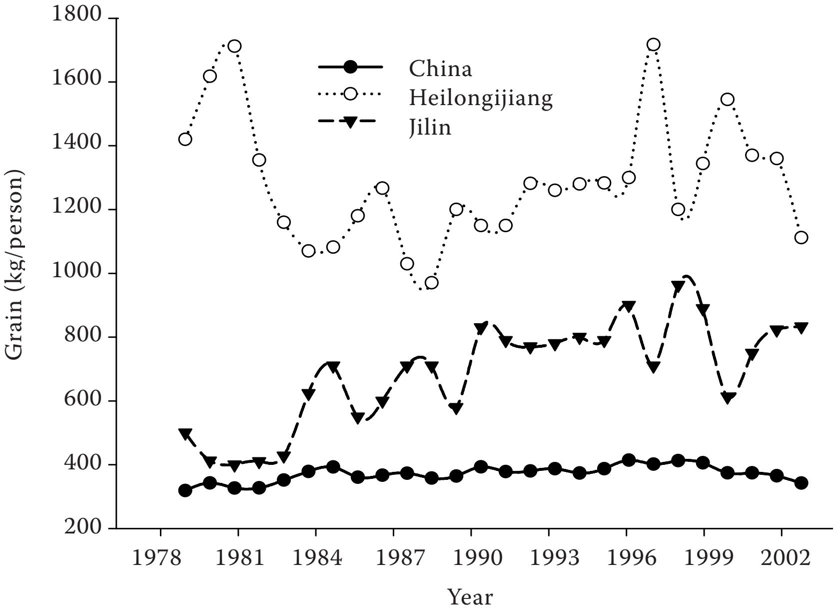

Figure 1. Grain per capita in China and Northeast China

modity which can feed about 216 million urban residents annually. The fertile and productive soils, Mollisols (also called Black soils) in China are distributed primarily in the region, which is one of the four largest contiguous Mollisol areas in the world. The majority (nearly 70%) of black soils in China are in Hei-long-jiang province; the total area of these soils is 7 million ha with about 4.4 million ha being cultivated, and it locates in the intergrade area from mountain to plain (Xing et al. 2004). However, due to intensive cultivation, SOM loss, and soil erosion, an associated yield suppression has been a serious problem threatening the future sustainability of agriculture in the region (Liu 2004).

In the following sections, we summarized the distribution, area and intensity of water erosion, changes in the number of gullies and gully density, thickness of top soil layer, soil organic matter content, bulk density, field water holding capacity and infiltration rates in the region. The number of soil microorganism and main enzyme activities from soil erosion in the region are also summarized. Proposed strategies for erosion control and SOC loss are discussed in the context of agricultural sustainability with an emphasis on the Chinese Mollisols.

The current scenario and changes of soil degradation

Distribution of water erosion. The soil erosion mostly results from water erosion and it is a key factor inducing the soil degradation in the region (Zhang et al. 2007). The total water erosion area in the region is 177 000 km^2, which accounts for 17.2% of the total area. Among these, 88 600 km^2 is in Hei-long-jiang province, 40 400 km^2 is in

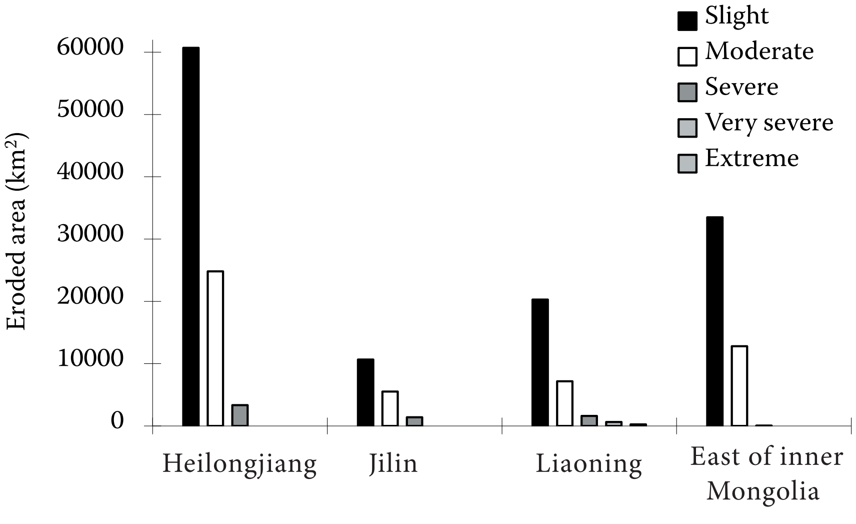

Figure 2. Current distribution of water erosion area and erosion severity classes from different provinces

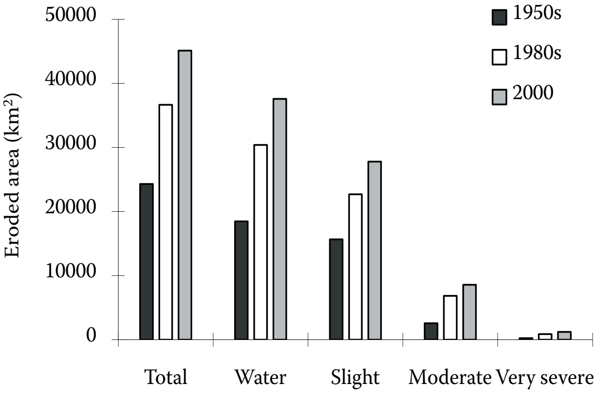

Figure 3. Changes of water erosion area in Hei-long-jiang province

the eastern part of Inner Mongolia Autonomous region, 30 700 km^2 is in Liao-ning province, and 17 300 km^2 is in Ji-lin province. Majority of the area is in the range of slight eroded class (Figure 2). The erosion area is still expanding with slow rates but with increased intensity. In typical Black soil region of Hei-long-jiang province, water-eroded area changed from 24 292 km^2 in 1950s to 36 649 km^2 in 1980s and increased to 45 107 km^2 in 2000. Slightly eroded area was 15 659 km^2, 22 684 km^2 and 27 785 km^2 in 1950s, 1980s and 2000, respectively (Figure 3). However, a positive trend is that both the area and intensity of the water erosion in Ji-lin and Liao-ning province have been decreasing, especially since 1985. From 1985 to 1999 in Ji-lin province, the area of water erosion decreased by 6522 km^2; the annual declining rate was 1.8%. Water erosion area was 17 576 km^2, among them 10 660 km^2 of slightly eroded class accounted for 60.7% of the total, while moderately and severely eroded areas were of 5523 km^2 and 1393 km^2, accounting for 31.4% and 7.9% of the total, respectively (Figure 4).

With the eroded area expanding in Hei-long-jiang province, the number of gullies as well as the gully density increased (Figures 5 and 6). However, we have not examined how the actual percentage of gully erosion adds to the overall soil loss in the region. The contribution of gully erosion is not easily predictable. It depends on the characteristics of the storm, the topography of the catchment and the land cover at the time the storm occurs (Morgan 2005).

Changes of thickness in top soil layer. A survey with 81 typical black soil profiles investigated by Zhang et al. (2007) showed that average thickness of top soil layer in 1982 was 43.7 cm, and the area with thickness of top soil layer was less than 30 cm; it accounted for 40.9% of the total in 2002. In Hei-long-jiang province, the thickness of top soil layer in 3–5° and 5–8° sloping farmlands is 17.6–23.5 cm and 12.4–15.1 cm while the erosion rate is 1.24–1.29 mm/year and 2.12–2.41 mm/year, and anti-erosion year is in the range of 58–108 years and 11–33 years, respectively. Estimation shows that soil loss in 1°, 5° and 15° sloping farmlands is 3, 78 and 220.5 t/ha/year. Thus, erosion would normally be expected to increase with increase in slope steepness and slope length as a result of respective increase in velocity and volume of surface runoff. Further, while on a flat surface raindrops splash soil particles randomly in all directions, on sloping ground more soil is splashed downslope than upslope and the proportion increasing with the slope steepness. Based on the above erosion rates, it is estimated that the top soil layer of

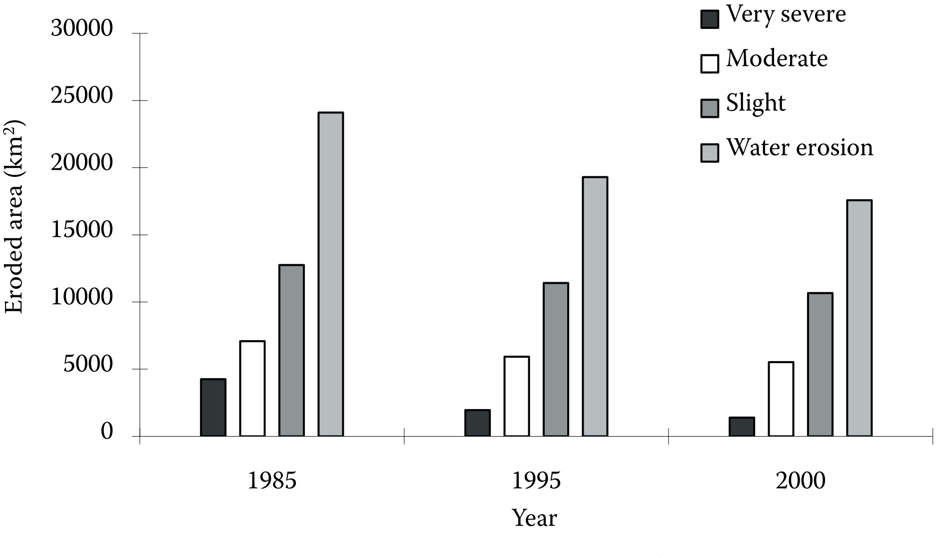

Figure 4. Changes of water erosion since 1980s in Ji-lin province (km^2)

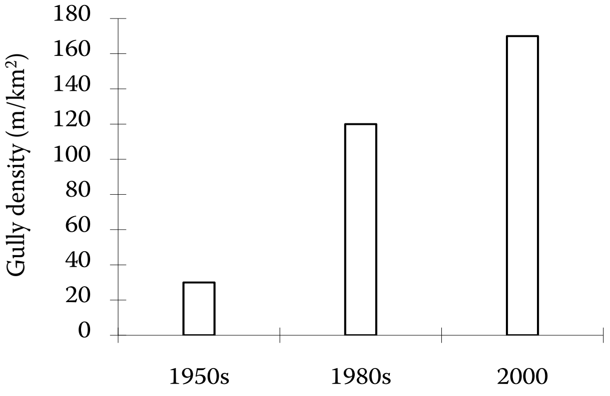

Figure 5. Gully density changes from the area of 118 736 km^2 in Hei-long-jiang province

22 700 km^2 of sloping farmlands will be removed within 100–200 years, 30 500 km^2 of sloping farmlands will be removed within 50–100 years, and 5585 km^2 of sloping farmlands will be removed within 50 years.

Changes of soil organic matter content. The organic constituents of the soil are important because of their influence on aggregate stability. Soils with less than 2% organic carbon can be considered erodible (Evans 1980) and soil erodibility decreases linearly with organic content increasing over the range of 0–10% (Voroney et al. 1981). After examining four fields with different cultivation histories (uncultivated soil, five-year cultivation, fourteen-year cultivation, and fifty-year cultivation), Liu et al. (2003) found that the SOC content of uncultivated soil at the 0–17 cm depth was nearly twice that of soil with a 50-year cultivation history, 3.5 times at the 18–32 cm depth, and 4.5 times at the 33–43 cm depth. At the depths of 0–17 cm and 18–32 cm, no significant SOC difference between 5- and 14-years of cultivation was observed, indicating a rapid reduction of SOC at initial cultivation at these two depths. They also showed that a significant decline of total SOC occurred in the first 5 years of cultivation where the average SOC loss per year was about 2300 kg/ha for the 0–17 cm horizon. The possible explanation is that the topsoil in the layer of 0 to 17 cm was greatly disturbed by agricultural managements such as soil tillage, which markedly decreased the physical protection of the SOC stability and accelerated SOC decomposition (Lützow et al. 2006). The difference between average annual SOC loss in 5- and 14-year cultivation was 950 kg/ha; between 14- and 50-year cultivation it was 290 kg/ha (Liu et al. 2003). The latter would correspond to the release of approximately 38 t CO_2/ha to the atmosphere. These data clearly show the rapid reduction of SOC for the initial soil disturbance by cultivation and a relatively gradual loss later.

Another investigation by Wang et al. (2002) showed that after 100 years of reclamation, the soil organic matter content from 0–20 cm top layer of black soil in northern part of Hei-long-jiang province declined from the original 150.6 g/kg to 50.2 g/kg, and the reduction was 66.7%. Based on our general survey across the whole area of black soils from Hei-long-jiang province in 2002, we found that SOC content declined dramatically at the initial stage of cultivation, and started to decline slowly after 50-year cultivation (Figure 7). We also found that from 1982 to 2002, the average annual declining rate of soil organic matter was 0.5%, while annual declining rate of soil organic matter in the areas with severe soil erosion was 1.35%. Thus soil erosion can reduce SOC content and lead to soil deterioration, and finally reduce soil productivity.

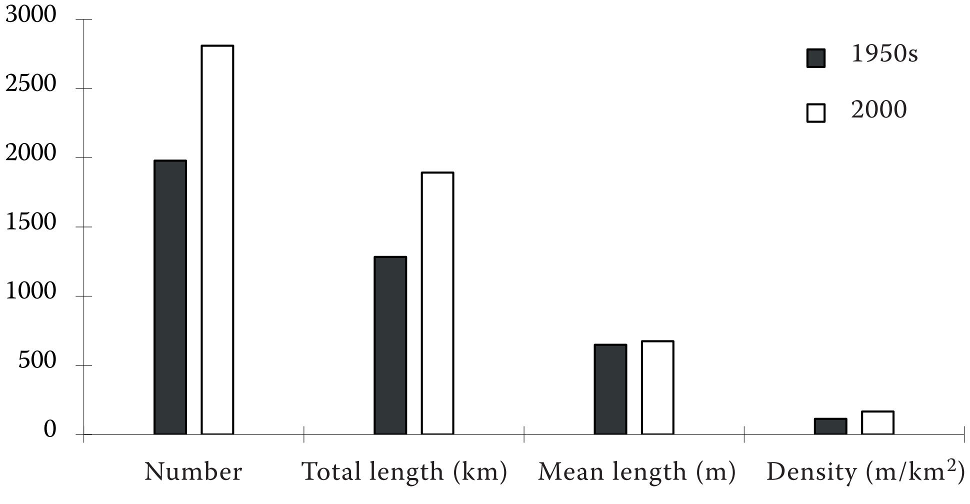

Figure 6. Number, length and density of gullies in typical black soil region

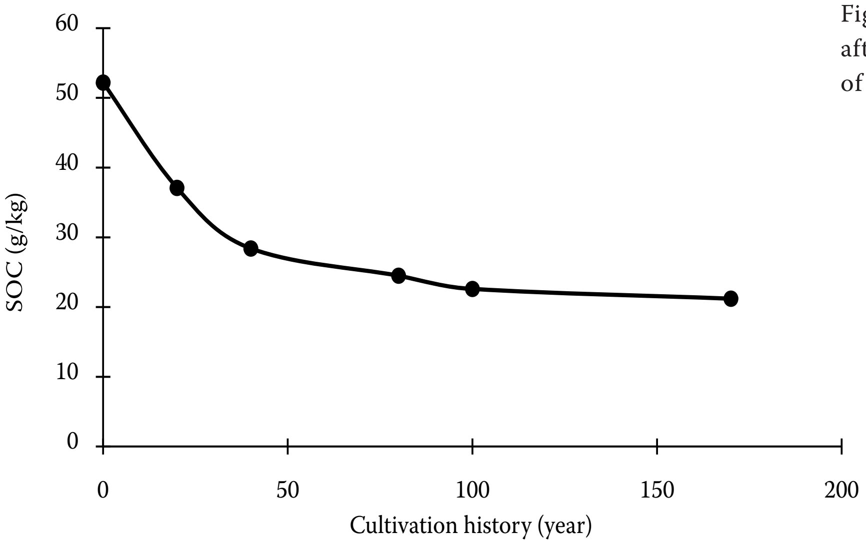

Figure 7. Soil organic carbon (SOC) after cultivation in the black soil area of Hei-long-jiang province

Changes of other soil properties. The increased bulk density, reduced field water capacity and reduced infiltration rates are the main physical properties deteriorated in eroded soil. Table 2 lists the variations of soil physical properties in farmlands with different erosion degree. For cation exchange capacity (CEC) of Chinese Mollisol the surface soil declined with cultivation from 45.8 cmol/kg for uncultivated soil, to 42.6 cmol/kg for the soil of 5-year cultivation, 38.1 cmol/kg for 14-year cultivation, and 31.5 cmol/kg for 50-cultivattion. However, bulk density increased with long-term cultivation. A significant difference was found between soils from the 50-year cultivation and other three soils, but no difference was observed among the uncultivated, 5-year cultivated, and 14-year cultivated soils (Liu et al. 2003). These results indicated that long-term cultivation in the Mollisol region of China may have resulted in soil compaction and was probably related to the loss of SOC. Compared with non-eroded soil, eroded soils have somewhat lower numbers of total microorganism, bacteria and actinomyces, but slightly more fungi (Table 3). The number of total microorganism, bacteria and actinomyces in eroded soil is 76.8, 76.4 and 81.1% of the non-eroded soil respectively, while the number of fungi is by higher 70.8% than that of the non-eroded soil. In addition, the activities of urease, phosphatase and invertase also declined (Table 4).

Strategies for loss of SOC and erosion control in the region

The prevention of soil erosion and SOC loss relies on selecting appropriate strategies for soil conservation, and from the technical aspects, best approaches will be to adopt suitable tillage system, apply efficient fertilization and implement sustainable crop rotations.

Crop rotation. Crop rotation can have a major impact on soil health, due to emerging soil ecological interactions and processes that occur with time. These include, compared to monoculture, improved soil structural stability and nutrient use efficiency, increased crop water use efficiency and soil organic matter levels, reduced long-term yield variability, better weed control, and disruption of insect and disease life cycles, all of which may further improve soil productivity (Varvel 2000, Carter et al. 2002, 2003, Kelley et al. 2003).

Table 2. Physical properties of topsoil (0–20 cm) with different erosion severity

Severity of erosion	Bulk density (g/cm^3)	Field capacity (%)	Infiltration rate k_{10} (mm/min.)
No erosion	0.79	57.7	10.55
Slight	0.93	52.6	8.74
Moderate	1.04	49.6	5.34
Severe	1.09	46.2	4.45
Extreme	1.35	28.0	1.63

Table 3. Number of microorganism in non-eroded and eroded soils (1994)

Soil	Bacteria	Actinomyces	Fungi	Total
Non-eroded	5.829×10^6	3.049×10^5	2.035×10^4	616.13×10^4
Eroded	4.455×10^6	2.495×10^5	3.475×10^4	473.53×10^4

During a 9-year crop rotation experiment in the Chinese Mollisol, Liu et al. (2003) found that cropping systems significantly altered SOC content. The SOC in the treatments of the wheat-sweet clover and wheat-soybean with addition of pig manure or wheat straw was significantly higher than that of the commonly used wheat-soybean rotation (wheat straw removed), particularly in the 0–17 cm horizon. For the overall SOC content (means of SOC of all three horizons), soil with addition of wheat straw was by 22% greater than that of wheat-soybean alone, and similar differences occurred in overall SOC in the wheat-sweet clover rotation and wheat-soybean rotation with addition of pig manure. However, all three treatments increased SOC content in the 18–32 cm soil depth relative to the wheat-soybean rotation.

Liu et al. (2003) also showed that the wheat-sweet clover rotation not only increased the SOC content in all soil depths, but also had the greatest amount of SOC and had a decrease in soil bulk density. The wheat-soybean rotation with addition of wheat straw had a total of SOC of 62.3 t/ha, or 7.5% increase of SOC compared with that in the typical wheat-soybean rotation in the region. The increase of total SOC storage (sum of all three horizons) was 10.7% for wheat-soybean rotation with addition of manure, and 14.4% for wheat-soybean rotation with addition of wheat straw. The total amount of SOC increase (11.7 t/ha) in wheat-soybean rotation with addition of wheat straw would correspond to sequestration of approximately 43 ton CO_2/ha from atmosphere. Fang et al. (2005) indicated that 2240 to 5000 t C was released into atmosphere annually ever since cultivation began in black soil of China, and maximum soil carbon sequestration potential could be as much as 1550 t if appropriate measures were undertaken and especially crop rotations. These results indicated that improved crop rotation strategies can increase the organic carbon reserve and improve soil structure and quality of the black soils, thereby sequestrating CO_2 from the atmosphere and mitigating against the greenhouse effect. Further, the adoption of appropriate crop rotations to increase the quantity and quality of soil organic matter might enhance soil chemical and physical properties, and help to ensure the long-term sustainability of agriculture in this region of China.

Tillage. Soil tillage management can affect factors controlling soil respiration, including substrate availability, soil temperature, water content, pH, oxidation-reduction potential, kind and number of microorganisms, and the soil ecology (Robinson et al. 1994, Kladivko 2001).

Tillage operations strongly control the soil environment by altering the soil geometry. These effects influence many physical, chemical and biological properties of the soil and thereby the conditions for crop growth (Alvarez and Alvarez 2000). Ridge cultivation along the slope with less input results in destruction of the granular particle structure, soil compaction, and low water storage and surface hydraulic conductivity. Also, with the increase in the number of small tractors due to the household contract system, the hardpan layer is getting thicker because of a constant tillage depth, leading to the decline of water infiltration and storage in the region (Zhang et al. 2006b). Practices indicated that contour tillage can reduce runoff, increase infiltration, and reduce soil loss from sloping land compared with cultivation parallel to the slope (Tables 5 and 6). Contour tillage is the simplest measure to control soil erosion and suitable to farmland with slope less than 10°. After changing the ridge direction from up-and-down the slope to the contour, amount of runoff after three years was reduced by 67–75%, and fertility was increased by 57% with yield increase of 25%.

Under the same cultivation, a narrow ridge is better than a wide ridge in erosion control. Crop

Table 4. Soil enzyme activities in non-eroded and eroded soils (1994)

Soil	Urease (NH_3-N mg/g soil)	Phosphatase (phenol mg/g soil)	Invertase (0.1mol/l $Na_2S_2O_3$ mg/g soil)
Non-eroded	1.01	0.307	5.06
Eroded	0.99	0.254	4.06

Table 5. Comparison of water and soil loss in different ridge direction

Ridge direction	Slope steepness (degree)	Amount of runoff (m^3/ km^2/year)	Amount of erosion (kg/ha/year)	Thickness of loss (cm/year)
Inclined	7.3	72.9	220	0.54
Up-and-down	4.8	143.2	103	0.26
Contour	0	41.3	5.57	0.01

Minimum tillage is also a good approach to control erosion. Studies indicated that compared to conventional tillage, the use of minimum tillage can reduce water erosion by 93% and wind erosion by 71% due to greater infiltration and more water stable aggregates

rotation reduces water and soil loss mostly due to improvement of soil structure and enhancement of water infiltration.

Terraces and strip cultivation. Terraces are earth embankments constructed across the slope to intercept surface runoff. They convey runoff to a stable outlet at a non-erosive velocity and shorten slope length (Morgan 2005). Terraces can be classified into three main types: diversion, retention and bench. Bench terraces have been used as a conservation measures for over 2000 years in China. However, the use of terraces in conserving soil erosion was only applied in the past two decades in northeast China. Although terrace can reduce erosion substantially compared to unterraced land, soil loss still remains above tolerable levels. Their success depends on them being well constructed, and equally important, well maintained. In the areas of rural depopulation or increased availability of alternative sources of income to agriculture, the labor needed is often not available to undertake the necessary repairs (Critchey et al. 2001). An investigation on land with a 5° slope indicated that the terrace reduced bulk density by 0.12 g/cm^3, increased total porosity by 2.0–2.9% and had an infiltration rate of 0.4 mm/min with minimum runoff and nutrient loss.

In intercropping with strip tillage, the soil is prepared for planting along narrow strips, with the intervening areas left undisturbed. Typically, up to one third of the soil is tilled in a single plough-plant operation. This practice usually includes a 2–3 m of perennial forage such as alfalfa and 5 m crop strip. A sustainable crop rotation is also required. Crop rotation systems are more effective at reducing long-term yield variability than monoculture systems, and may further improve soil productivity (Varvel 2000, Kelley et al. 2003). If crop rotation was implemented, Ke-shan (2002) reported that the yield of soybean, millet and potato could be increased by 100%, 17% and 45%, respectively.

Fertilization and manure. An investigation conducted in the area with 20% corn and 80% soybean by the Hei-long-jiang institute of water and soil conservation (2002) showed that the average corn and soybean productivity was less than 1125 kg/ha, 1125–2250 kg/ha, and 2250–3000 kg/ha in severely, moderately, and slightly eroded soil, respectively. The corresponding top soil thickness was 8–15 cm, 15–25 cm and 30 cm, and organic matter content was 1–2%, 2–3% and 3–4%, respectively. A spatial variability of yield measured in 102 sites from a 1.4 ha area by Zhang et al. (2006c) showed a yield of 1030 kg/ha in the upper part of slope land with severe erosion, and 2110 kg/ha in non-eroded land; i.e. 50% of yield was reduced by soil erosion.

Based on 2-year experiments with artificial topsoil removal, Sui et al. (2009) indicated that yields declined more with increased depth of topsoil removal. Compared with non-eroded soil, yields of soybean with the application of chemical fertilizers were reduced by 3.2, 5.3, 50.2, 68.9% in 2005, and by 6.8, 12.4, 23.1, 36.3% in 2006 at the 5, 10, 20, and

Table 6. Effect of ridge direction on soil loss and pollutant export*

Ridge direction	Amount of runoff (m^3/ha)	Amount of sand loss (t/ha/year)	Total nitrogen (kg/ha/year)	Total phosphorus (P_2O_5) (kg/ha/year)	Total potassium (K_2O) (kg/ha/year)	Organic matter (kg/ha/year)
Up-and-down	833	13.5	19.35	17.70	370	446
contour	699	9.0	14.70	10.95	256	325

*slope steepness of 7° with rainfall of 560 mm/a

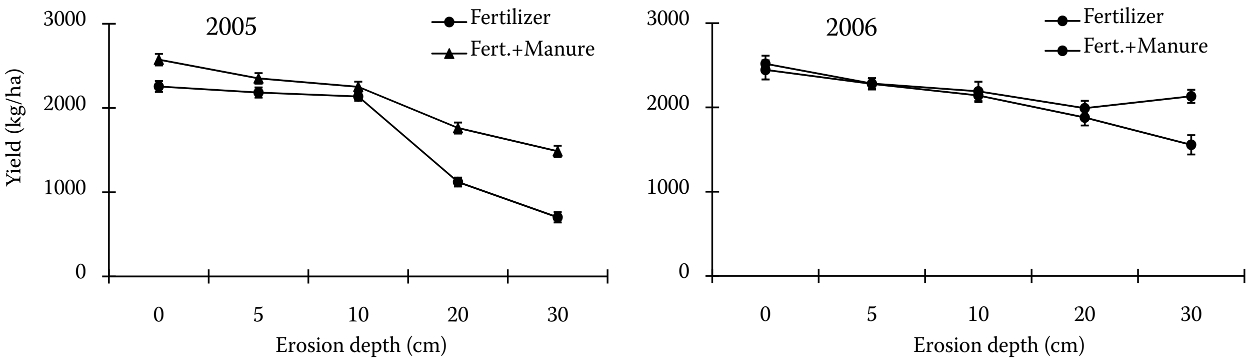

Figure 8. Yield of soybean with soil removal

30 cm topsoil removal rates, respectively. For corn with the application of chemical fertilizers, yields were reduced by 10.5, 13.0, 46.6, 67.4% in 2005, and by 8.7, 12.7, 45.9, 79.1% in 2006 at the 5, 10, 20, and 30 cm topsoil removal rates, respectively. Significant yield differences were found between non-eroded soil and eroded soils with 10, 20 and 30 cm topsoil removal, while no significant differences were found between non-eroded soil and 5 cm topsoil removal (Figures 8 and 9). Under the same chemical fertilizers, addition of manure improved crop yields, particularly in the deeper topsoil removal treatments. For soybean, in non-eroded soil compared with chemical fertilizers alone, the addition of manure increased yields by only 14.1 and 3% in 2005 and 2006, respectively, while yields were increased by 117 and 36.9% following the removal of 30 cm of topsoil. For corn though, addition of manure increased yields by 7.9% and 22.3% in 2005 and 2006 in non-eroded soil, respectively, while yields were increased by 50.6% in 2005 and 239% in 2006 following the removal of 30 cm of topsoil. The addition of manure also increased corn yield by 56.5% in 2005 and by 37.2% in 2006 in the 20 cm topsoil removal treatment. This indicates that under severely eroded soil, as with 30 cm topsoil removal in the present studies, the addition of manure can increase soybean yield by 0.36–1.17 fold and corn yield by 0.51–2.39 fold. It was surprising to find that the yields of soybean in 2005 and of corn in 2006 under 5 cm topsoil removal treatment with the addition of chemical fertilizers and manure were greater than those of non-eroded soil with addition of chemical fertilizers (Figures 8 and 9). Thus, the effect of erosion on crop productivity is complicated and addition of cattle manure was an excellent amendment to restore productivity. This might be due to the contribution of manure to the stability of the soil aggregates and nutrient release.

Based on the investigation and simulation above, if yield reduction is 15%, a loss of grain production from the typical 7 million ha farmland will be 7.2 billion t, and if the yield reduction by gully

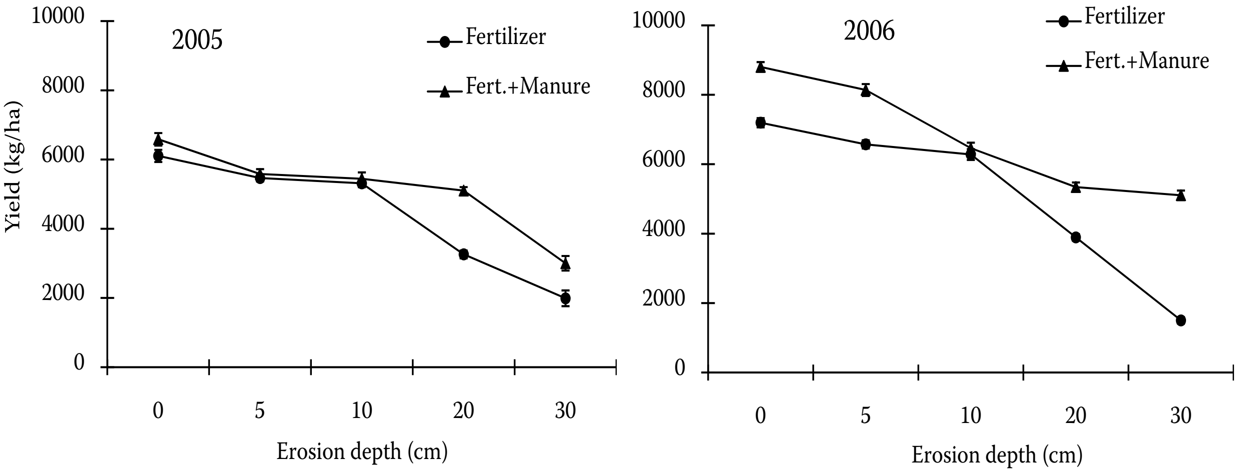

Figure 9. Yield of corn with soil removal

is counted, then the total yield reduction will be 10.2 million t, which accounts for 14.1% of the current production. The use of chemical fertilizers with cattle manure for improving crop yields on eroded soils is very important in the region of Chinese Mollisols.

In general, the successful implementation of soil conservation measures as argued by Morgan (2005) is only possible through a combination of scientific, socio-economic and political considerations. Future investigations are needed to examine the drivers affecting soil erosion processes and crop productivity, and to establish evaluation indicators and optimize management practices with best economic benefits.

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