Natural and anthropogenic rates of soil erosion

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ARTICLE INFO

Article history:
Received 4 March 2017
Accepted 10 April 2017
Available online 18 April 2017

Keywords:
Row crop agriculture
Soil conservation
Conservation tillage
No-till
Residue management
Permaculture
Isotopes
Conservation reserve program
Northeast China
National Resource Inventory
Hugh Hammond Bennett
Virgin Lands Campaign
Cerrado
Beryllium10

ABSTRACT

Regions of land that are brought into crop production from native vegetation typically undergo a period of soil erosion instability, and long term erosion rates are greater than for natural lands as long as the land continues being used for crop production. Average rates of soil erosion under natural, non-cropped conditions have been documented to be less than 2 Mg ha\(^{-1}\) yr\(^{-1}\). On-site rates of erosion of lands under cultivation over large cropland areas, such as in the United States, have been documented to be on the order of 6 Mg ha\(^{-1}\) yr\(^{-1}\) or more. In northeastern China, lands that were brought into production during the last century are thought to have average rates of erosion over this large area of as much as 15 Mg ha\(^{-1}\) yr\(^{-1}\) or more. Broadly applied soil conservation practices, and in particular conservation tillage and no-till cropping, have been found to be effective in reducing rates of erosion, as was seen in the United States when the average rates of erosion on cropped lands decreased from on the order of 9 Mg ha\(^{-1}\) yr\(^{-1}\) to 6 or 7 Mg ha\(^{-1}\) yr\(^{-1}\) between 1982 and 2002, coincident with the widespread adoption of new conservation tillage and residue management practices. Taking cropped lands out of production and restoring them to perennial plant cover, as was done in areas of the United States under the Conservation Reserve Program, is thought to reduce average erosion rates to approximately 1 Mg ha\(^{-1}\) yr\(^{-1}\) or less on those lands.

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1. Introduction

It is difficult to imagine an aspect of our natural world which encompasses such an immense measure of scale in both time and space as erosion of the earth’s surface. A student of erosion will find that one must think in terms of microseconds in order to understand the mechanics of impact of a single raindrop on a soil surface. In one erosion study, the impact pressures of raindrops on a soil surface were recorded at a rate of one data-point per 500 ns in order to capture those few microseconds of peak impact pressures (Nearing, Bradford, & Holtz, 1987). Toward the other end of the erosional time scale, the Quaternary landscapes of Iowa which formed over the last 10,000 to 12,000 years (Ruhe, 1969) may be considered relatively young, and the forces which carved the erosional surfaces of the Appalachian mountain range acted over millions of years (Thornbury, 1965). Erosion scientists study in spatial scales which span from millimeters for raindrops to...
megameters for continents. The erosion topic covers a lot of ground.

In addition to spanning broad scales of time and space, erosion also has enormous implications for our everyday world, although we often take them for granted. Perhaps the most basic of implications is, as Ruhe (1969) wrote, that “most landforms are products of erosion”. Not all are, but most are. Thus, we live on a landscape that is the product largely of erosion. A second implication of erosion is that it creates sediment, which is a pollutant. In fact, by sheer volume or mass, sediment is by far the greatest pollutant we have. The associated economic costs of sediment as a pollutant we have. The associated economic costs of sediment as a pollutant are debated, but undeniably sediment effects tremendous societal cost in terms of stream degradation, disturbance to wildlife habitat, flooding, and direct costs for dredging, levees, and reservoir storage losses (Ribaudo et al., 1989; Clark, 1985; Pimentel, 2006). Sediment is also an important vehicle for the transport of soil bound chemical contaminants from non-point source areas to waterways. According to the USDA-Soil Conservation Service (1989), soil erosion is the source of 80% of the total phosphorus and 73% of the total nitrogen in the waterways of the U.S. Sediment also carries agricultural pesticides and other land applied chemicals. Solutions to non-point source pollution problems invariably must address the problem of erosion and sediment control.

The most important, and insidious, implication of accelerated erosion, however, is the role it plays in soil degradation. Soil degradation is by its nature a gradual process, and the effects are not always evident until after the damage is done. Soil degradation is thought to have been a major contributor to the decline of civilizations (Lowdermilk, 1953), and soil erosion is currently the major contributor to the degradation of the global soil resource (Bridges & Oldeman, 1999). Current rates of soil degradation continue to be greater than rates of soil formation, and soil degradation threatens basic food production capabilities in certain parts of the world, even in the short term (Scherr, 1999).

Increases in human population have caused many areas of the world to undergo rapid changes from an essentially natural environment to one dominated by intensive agricultural. In this paper we will discuss the transition from natural lands to intensive agricultural production lands. A short overview of natural, geologic rates of erosion is given, followed by the discussion of erosion trends in the transition to intensive agriculture. Examples are given for experiences in the United States and Northeastern China.

2. Recent geologic rates of erosion

In order to understand modern rates of erosion in perspective, it is useful to have some understanding of geologic, or “natural”, rates of erosion. The evidence is clear that human activities substantially and often dominantly impact erosion rates, at least within certain temporal and spatial scales. In general, one would expect that geologic rates of erosion would be roughly equivalent to rates of erosion that we observe today in natural settings that have not had significant anthropogenic influence. There are two problems with relying on this logic, however. One is related to time, and the other to place. It is possible that geologic erosion rates may be greatly influenced by infrequent catastrophic erosion events that occur over a short time period, and which would often not be observed over the short time scales of observation we are usually able to make in natural areas today. The other issue is that the natural areas today do not represent a random selection of the natural world as it was prior to human influence, and in particular to agriculture. Humans have not randomly settled the earth. We have chosen those areas that suit specific needs for food production and living. The loess belts of the world, for example, are major grain producing regions. Loessial soils are highly erodible, and finding significant areas of uncultivated natural areas in loess deposits in humid areas would be difficult.

Geologic rates of erosion have been quantified using primarily stratigraphic information associated with sediment deposits. In the studies of Ruhe and Daniels (1965) and Walker (1966), sediment deposits were measured in a depositional area below a known source area. Both studies were conducted in Iowa, USA in an area that was glaciated until approximately 11,000 to 14,000 year BP (before present). The sediments in both cases were dated using radiocarbon techniques. Rates of erosion estimated for those studies were within the range of 0.8–1.9 Mg ha⁻¹ yr⁻¹ (Table 1). In a very different environment, Granger, Kirchner, and Finkel (1996) surveyed the accumulated volume of two fan deposits in the Fort Sage Mountains of northeastern California, and measurements of ¹⁴C in lake carbonates dated the base of the alluvial fans at 16,100 ± 400 years. Hillslope gradients in the sub-catchments were reported as ranging from 23% to 63%. The sediment volume data produced an estimate for the average erosion rate of 0.95–1.6 Mg ha⁻¹ yr⁻¹.

Studies on recent geologic erosion rates have also been made using ¹⁰Be techniques. ¹⁰Be is a cosmogenic nuclide that is produced by the bombardment of cosmic radiation on atomic nuclei in minerals near the earth’s surface (Lal & Peters, 1967). Erosion rates or changes in rates have been inferred both from measurements of ¹⁰Be concentrations on outcropping surfaces (Nishizumi et al., 1993; Bierman, 1994) and from ¹⁰Be in sediment deposits (Brown, Pavich, Hickman, Klein, & Middleton, 1988; Granger et al., 1996; Valette-Silver, Brown, Pavich, Klein, & Middleton, 1988). For both cases it can be shown (Granger et al., 1996) that the cosmogenic nuclide concentration, N, in either the outcropping surface
or in the eroding regolith is inversely proportional to the erosion rate, \( E \), according to the relationship

\[
N = \frac{P_0 \Lambda}{E}
\]

where \( P_0 \) is the nuclide production rate at the surface and \( \Lambda \) is the absorption mean free path. In certain erosional settings the \( ^{10}\text{Be} \) concentrations of sediments can be used to infer erosion rates. For situations where the time in which sediment is transported and stored in the watershed near the surface is short, and thus its exposure to continued cosmic rays is small compared to the erosional time scale \( \Lambda/E \), the concentration of \( ^{10}\text{Be} \) in sediments can be used in Eq. (1) to infer erosion rates. These conditions were approximated as described in the study of Granger et al. (1996), and erosion rates from the 2 watersheds above the alluvial fans discussed above were estimated. Granger et al. (1996) sampled stream sand and computed erosion rates very similar to those computed by the sediment fan volume method (Table 1).

Another approach at measuring recent geologic rates of erosion was taken by Norton (1986) in east-central Ohio, where he measured variations in the thickness of the loess to estimate a rate of 0.035-0.06 Mg ha\(^{-1}\) yr\(^{-1}\) over the past 17,000 to 28,000 years.

3. The transition to intensive agriculture

Although there has been some debate regarding the effects of human activities on rates of erosion (Ruhe & Daniels, 1965), the general consensus of scientific investigations would indicate that the modern rates of erosion exceed those that occurred prior to intensive agriculture. There is much anecdotal evidence of the devastating effects which agricultural induced erosion has had in terms of soil degradation and the decline of agricultural productivity in various parts of the world through history (Bennett, 1939; Lowdermilk, 1953).

Intensive agriculture was introduced into Europe long ago, however, evidence for changes in erosion rates with the introduction of widespread agriculture in Europe shows a trend. Based on observations of colluvium in southern Lower Saxony in central Europe, Bork (1989) concluded that only minor sheet erosion occurred prior to the Middle Ages. His studies also found no evidence of rill and gully erosion prior to that time. Areas of colluvium deposits dating from the time prior to the Roman age were small, and were considered by Bork to be associated with small areas of cultivation. His evidence concluded that soil erosion occurred in specific areas only after the clearing of the forests, and only for as long as the areas were used for agriculture. He also found that soil erosion increased significantly only after large areas of the forest were cleared between the 7th and 14th centuries.

A recent example of the transition to agricultural lands is the Virgin Lands Campaign initiated by the Soviet Union in 1954. In Kazakhstan, between 1954 and the early 1960s, 25.5 million ha of virgin grasslands were cultivated and planted in wheat (FAO, 1995), which compares to 18.8 million ha of wheat harvested in the United States in 2014 (US Department of Agriculture, 2015a). Yields of wheat averaged 1.07 Mg ha\(^{-1}\) yr\(^{-1}\) from 2010 through 2014, compared to 3.05 Mg ha\(^{-1}\) yr\(^{-1}\) in the United States during the same period. Current wheat production in Kazakhstan is found remaining primarily on Chernozem soils (Black Soils), or Mollisols in the US classification system, in wetter parts of the country. The Virgin Lands Campaign also severely impacted Uzbekistan and Turkmenistan.

In Brazil, the savanna, or Cerrado, is undergoing relatively rapid deforestation (Marris, 2005). The Cerrado is approximately two million km\(^2\) in size, which constitutes 22% of the total area of Brazil. More than half of the area has been transitioned from native vegetation to agricultural land (Klink & Machado, 2005). From 2002 through 2010 deforestation rates in the Cerrado exceeded that of the Amazon, with rates on the order of half a percent per year of the total area being brought into production (IBAMA/MM/UNDP, 2011). A recent study by Oliveira, Nearing, and Wendland (2015) found that the runoff coefficients of experimental plots increased from less than 1% under native Cerrado vegetation to approximately 20% when the vegetation was removed, while measured soil loss rates went from 0.1 to 12.4 Mg ha\(^{-1}\) yr\(^{-1}\).

Many experimental studies have been conducted that show the influence of cropping on erosion rates. For example, a study using artificially delineated watersheds of 1.6 ha in El Reno, OK, USA over a two decade period compared erosion from cropped land to land with native vegetation (Zhang & Garbrecht, 2002). The average annual erosion rate for the native grassland was 0.033 Mg ha\(^{-1}\) yr\(^{-1}\), while the lowest rate of erosion for the cropped land was for a no-till system was 0.275 Mg ha\(^{-1}\) yr\(^{-1}\). Data from the other, more commonly used cropping systems were much higher, being 2.26 Mg ha\(^{-1}\) yr\(^{-1}\) for a conservation disk-tillled system and 5.70 Mg ha\(^{-1}\) yr\(^{-1}\) for a system using moldboard plow.

Thus, the scientific evidence clearly points to the fact that modern civilization, through agriculture, has caused a greatly accelerated rate of erosion on the world’s productive agricultural land. The 1990 United Nations study on land degradation estimated that an area equal to 38% of today’s global cultivated area has been damaged to some degree by agricultural practices since 1945. We literally mine the soil for food. In the Midwest Corn-belt region of the United States, and where the conservation ethic and conservation technologies are arguably as strong as anywhere on the earth, we still lose more than a kilogram of soil for every kilogram of grain produced. Even where we attain that elusive target level of erosion control that we call “Soil Loss Tolerance”, we still lose topsoil at a faster rate than it is formed. Economists and politicians can and do argue the long-term costs of soil erosion relative to the short-term and continuing costs of soil conservation practices. Regardless of the arguments made and the formulas used, two facts are unavoidable. Human population is increasing and the soil resource necessary to sustain that population is steadily decreasing.

4. The United States

Sedimentary evidence of the impact of early agriculture in the U.S. has been documented. Valette-Silver et al. (1986) studied the \(^{10}\text{Be} \) content of undisturbed estuarine sediments in three tributaries of the Chesapeake Bay in the eastern United States. In this case the research focused on \(^{10}\text{Be} \) that forms in the atmosphere and is deposited with rain and snow, as opposed to the \(^{10}\text{Be} \) that forms in-situ in quartz grains as was studied by Granger et al. (1996). The concentration of \(^{10}\text{Be} \) in sediments was considered to be an indicator of erosion rates of \(^{10}\text{Be} \) enriched soil surface material from the watersheds. Two of the three cores sampled showed a very clear relationship between two sharp increases in
times during which major changes in agricultural activities in the area occurred. The first change was associated with a clearing of less than 5% of the forested area for purposes of tobacco farming. This change took place in the northern part of the Chesapeake Bay area in approximately 1730, and in the southern part in 1650. The second change occurred in the northern part of the area in 1780 and in the southern part in 1840, where a total of 40–50% of the land was cropped in order to produce both grain and tobacco. The Furnace Bay core, which was taken from the northern part of the bay area, showed an abrupt change in $^{10}$Be for the times of 1730 and 1780. The Magothy River core, which was taken slightly to the south of Furnace Bay, showed an abrupt change in $^{10}$Be for the times of 1650 and 1840. Thus, the $^{10}$Be concentrations indicated an abrupt change in sediment production from the watersheds at the same time as agricultural activities were introduced. Sediment thickness measurements in the same cores showed a similar trend (Brush & Davis, 1984; Brush, 1984).

Large regions of the United States faced the problem of soil erosion when virgin lands were brought under production by expansion of agriculture in the latter half of the 19th century and the early 20th century. In the words of Hugh Hammond Bennett (1939); often referred to as the "Father of Soil Conservation" in the United States, "In fifteen decades, Americans have transformed a wilderness into a mighty nation... And with astounding providence, Americans have plundered the resource that made it possible to realize their dreams". This problem became widely recognized in the 1920s and led to the formation of the Soil Erosion Service in 1933. The United States continues to have a strong soil conservation ethic and programs that largely originated from that time.

Certainly the soil conservation movement of the 20th century in the United States was initiated in response to what was perceived as a substantial change in soil erosion and sediment production due to the rapid spread of agriculture that resulted from increased population. Hugh Hammond Bennett wrote and campaigned extensively on the problems of soil erosion and the benefits of soil conservation to combat what he viewed as a "national menace" caused by natural lands being brought into production for agriculture (see Bennett, 1939). Many areas of the United States underwent significant changes during its first two centuries of agriculture. Much of the Piedmont of the southeastern US was a large area for cotton farming in the 1800’s. Today much of that land will not economically support cotton farming, and is currently growing pine trees for paper pulp production. Bennett (1939) estimated that as much as 4 million hectares (10 million acres) of that land had been essentially ruined in terms of the farming of row crops, and had been planted in pine trees.

Bennett (1939) dire estimates from early in the century for the Piedmont region of the eastern US appear to be supported by more recent studies of the region. Trimble (1999) estimated that an average of 18 cm (7.1 in.) was removed from the topsoil of the Piedmont over the past 200 years of agriculture in the area. This translates to an erosion rate of approximately 11 Mg ha$^{-1}$ yr$^{-1}$ on average for the region of 142,570 km$^2$. Similarly, Brown et al.’s (1988) study of $^{10}$Be concentrations in river sediments would indicate accelerated rates of post-settlement erosion rates for the Piedmont region.

The most comprehensive estimates of soil loss in the United States are made by the USDA-Natural Resources Conservation Service in a process referred to as the National Resources Inventory (NRI). This inventory was conducted in 1982, 1987, 1992, 1997, 2002, 2007, and 2012 (US Department of Agriculture, 2015b). The purpose of the inventory is to estimate the amount of sheet and rill erosion (combined) and the amount of wind erosion that occurs on non-federal lands in the United States, excluding Alaska. Non-federal lands constitute 76.5% of the total surface area of the United States (excluding Alaska), federal lands constitute 20.8%, and the remainder is covered by water (US Department of Agriculture, 2015b). Essentially all of the cropped land in the U.S. is non-federal. Most of the federal land is either forested or range land, with a smaller percentage in pasture (US Department of Agriculture, 2015b).

Sheet and rill erosion is estimated in the NRI using the USLE, and wind erosion is estimated using the USDA Wind Erosion Equation (WEE). The estimate is made using nationwide statistical sampling of approximately 300,000 area segments, which range from 16.2 to 259 ha (40–640 acres) in size (Fuller, 1999; Nusser & Goebel, 1997). Data collected for sample points within the area segments include land cover, land use, soil classification, conservation practices, vegetative cover, climate factors, slope length, slope steepness, and soil loss estimates. Erosion estimates are made in the NRI only for privately owned (non-federal) cropped, Conservation Reserve Program (CRP), and pasture lands in the US. The CRP is a set-aside program wherein the US government pays farmers to take highly erodible land out of production in order to conserve soil.

The NRI estimates showed a steady decline in erosion rates on cropped lands between 1982 and 1997, with little change thereafter (Table 2). This reduction was in large part due to the extensive adaptation of conservation tillage systems for row-crop agriculture and to the CRP and other government conservation incentive programs. There is little doubt that erosion decreased in the United States over those decades.

The estimates of total sheet and rill erosion shown in Table 2 are reasonable in terms of quantifying on-site soil losses, but does not tell the entire erosion story. First of all, the USLE model used in the NRI only predicts soil loss by sheet and rill erosion, and does not address gully or ephemeral gully erosion. Also, the estimates made are for soil loss only, and do not address off-site sediment yield. The NRI is based on random statistical sampling. Once a sampling point is designated, a field technician using a Geographical Positioning System locates the point in the field, and from that point delineates the flow path that passes through that point from the top of the hillslope to a point of deposition downslope. This flow path is then used to designate slope length and steepness values for the USLE erosion predictions. If the point falls within a depositional area on the landscape, then erosion is designated as zero, since the USLE does not predict deposition. Thus the NRI only predicts hillslope soil loss, and it does not predict the amount of sediment entering streams to be available for transport through the river system.

5. Northeastern China

The northeastern part of China has undergone greater changes in land cover than have any other parts of China in the past three centuries, and those changes accelerated greatly during the 20th century (Ye, Fang, Ren, Zhang, & Chen, 2009). Along with those changes have come serious soil erosion problems (Bian, Yang, Sheng, Jiang & Changchun, 2009; Liu et al., 2010; Xu, Xu, Chen, Xu & Zhang, 2010). Northeast China was the ancestral home of the Manchu people, who established the Qing dynasty that ruled China from 1644 until 1912. Initially the Qing encouraged migration of Han Chinese farmers into Northeast China when many of the Manchu people followed their leaders south of the Great Wall, which caused a dramatic reduction in population in the northern areas. However, a series of droughts and floods in north China in the 1650s drove a migration of Han settlers into the region, and in 1668 the Qing restricted migration of Han Chinese to the area (Ye & Fang, 2011). This period of restriction of migration and
expansion into the area was in effect from 1668 through 1860. Thus for a period of approximately 200 years expansion of croplands from the native grasslands in the region was relatively slow. The area of cropland in Liaoning, Jilin, and Heilongjiang provinces, which constitute northeastern China, grew only from approximately 5,396 km² (0.7% of area) to 27,178 km² (3.5%) between 1683 and 1908 (Ye & Fang, 2011).

The beginning of the 20th Century brought the “Land Cultivation Campaign”, by which immigration to the area increased significantly, and after the founding of the People’s Republic of China in mid-century the pace of settlement further accelerated (Bian et al., 2009). China experienced food shortages during and immediately after the Second World War. For that reason in 1947 and in the decade or so to follow 46,000 demobilized soldiers were sent to NE China to establish mechanized farms (Liu, 2001). These numbers were augmented in 1958 when approximately 100,000 retired soldiers from all over the China came and helped to establish several large military-owned farms (Wang, 2011). Another 200,000 youth, originally from the Shandong, Sichuan, and Hebei provinces, immigrated to the region from 1958 to 1968 (Liu, 2001).

Immigration into the area continued with the “Down to the Countryside Movement” in the late 1960s and early 1970s. This was one of the largest urban-to-rural immigration movements in China’s history. During that time approximately 540,000 school graduates (most of them graduated from high schools and others from middle schools) from cities of Beijing, Tianjin, Shanhai, and Hangzhou were settled into the Great Northern Wilderness in northeastern China, In addition, 100,000 named scientific and technical people who graduated from universities or technical secondary schools joined the land reclamation and farms establishment (Liao, 2009).

By 2002 agricultural production land in NE China reached 182,140 km² (23.2%), after having reached a maximum of approximately 211,516 km² (27%) in 1990 (Ye et al., 2009). Much of the land in the region is productive for grain, including corn, wheat, and soybeans. Currently the area is producing approximately 19% of the grain output for the country (Table 3). It is a major grain exporting region and the region therefore currently plays a critical role in feeding the Chinese population.

The Kazakhstan story (Section 3) may have had a direct influence on what happened in NE China. The Soviet and Chinese governments were allies, and the Chinese government looked to the Soviets for technical advice. According to older residents in NE China, Soviet advisors came to the area in the mid-1950s to advise the Chinese soldiers and workers on establishing the large tracks of newly cultivated land. Erosion control was established according to Soviet influence, which, based on experiences in central Asia, was focused on wind erosion. Very long rows of trees were planted without regard to topography in order to establish large agricultural fields that could be efficiently cultivated.

However, northeastern China is not central Asia. Average annual rainfall ranges from about 400–900 mm (Zhang, Xie & Wei, 2010), compared to the average of 250 mm in Kazakhstan. With cultivated rows running across the landscape with no regard for the topography, sheet, rill, and ephemeral gully erosion is a serious problem (Bian et al., 2009; Liu et al., 2010; Liu, Yan, Shen, Wang & Wei, 2008; Xu et al., 2010).

The dominant soil in northeastern China (NE China) is commonly referred to as Black Soil, and is widely distributed in the undulating hilly areas and transition zones from the Xiaoxing’anling and Daxing’anling Mountains to the SongNen plain (Fig. 1) (Liu et al., 2008). Based on the genetic soil classification of Chinese Soil Taxonomy (GSCC) these soils are Udic Isohumisols, and consist of four subgroups: typical black soils, meadow black soils, chernozems, and surface-gleyed black soils. Black Soils would be classified as Mollisols in US Soil Taxonomy.

The three black soil regions in NE China have been classified as the Hu-Lun-Bei-er black soil region (I) dominated by chernozems in the west, the Song-nen black soil region (II) dominated by both typical black soils (IIa) and chernozems (IIb) in the middle part, and the San-jiang black soil region (III) dominated by both surface-gleyed black soils and meadow black soils in the east (Fig. 1). Both Hu-Lun-Bei-er (I) and San-jiang (III) black soil regions are flat, and the primary land uses are grassland and rice cultivation, respectively.

The Song-nen black soil region (II) may be divided into two parts (Table 4). The eastern part is the Song-nen typical black soil sub-region with 9,400,000 ha, and is characterized by undulating hills. Most of this area is currently cultivated as agricultural land for planting of corn, soybean, and spring wheat under slopes with up to 9% steepness with very long slope lengths. The western part is the Song-nen albic black soil (chernozem) sub-region with 11,400,000 ha, dominated by plains.


In NE China, 3821 sample units (Fig. 2) were selected by using the unequal probability area sampling method. Each sample unit was divided into pieces of land defined as a land parcel which has the same land use and the same conservation practice. Factors of the CSLE were determined for each parcel within the sample unit, and digital DEMs of 1:10,000 records of soil data and national soil survey maps were used to develop national K factor maps by using Wischmeier and Smith’s (1978) methods, and then the K factor was adjusted by using unit plot or cropland plot data throughout China.

Soil loss was calculated for each sample unit using the CSLE, and soil loss was estimated at land parcel, sample unit, county, province, and national levels for different land use by statistical methods. Results for NE China are shown in Table 4.

Much of the land in NE China is productive and stable agricultural cropland. However, much of this relatively new agricultural land is clearly at risk of loss of productivity due to erosion by water (Bian et al., 2009; Liu et al., 2008, 2010; Xu et al., 2010). Given the importance of the area in providing the food needed to feed the Chinese population, and its economic importance to the region and to China as a whole, short term investment in erosion

<table>
<thead>
<tr>
<th>Year</th>
<th>Cultivated cropland</th>
<th>CRP land</th>
<th>Pastureland</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982</td>
<td>9.30</td>
<td>–</td>
<td>2.24</td>
</tr>
<tr>
<td>1987</td>
<td>8.52</td>
<td>4.60</td>
<td>2.08</td>
</tr>
<tr>
<td>1992</td>
<td>7.31</td>
<td>1.26</td>
<td>2.00</td>
</tr>
<tr>
<td>1997</td>
<td>6.61</td>
<td>0.83</td>
<td>1.79</td>
</tr>
<tr>
<td>2002</td>
<td>6.77</td>
<td>0.83</td>
<td>1.68</td>
</tr>
<tr>
<td>2007</td>
<td>6.52</td>
<td>0.83</td>
<td>1.55</td>
</tr>
<tr>
<td>2012</td>
<td>6.70</td>
<td>0.90</td>
<td>1.55</td>
</tr>
</tbody>
</table>

*CRP is land in the USDA Conservation Reserve Program.
control could reap huge long-term benefits to the nation of China.

6. Discussion

When land is brought into crop production from native vegetation it typically undergoes a period of soil erosion instability where erosion rates can be quite high. Much of this is because of the disturbance of the soil surface and associated increase in soil erodibility, but another factor in this process is that some areas that are newly cultivated are not sustainable in the long term. This was evident, for example in the Piedmont area of the United States.

Table 3
Land use for year 2008\(^a\) and grain crop yields\(^b\) and population for year 2012.

<table>
<thead>
<tr>
<th></th>
<th>Land area (10(^4) ha)</th>
<th>Cropland (10(^4) ha)</th>
<th>Horticultural (10(^4) ha)</th>
<th>Forestland (10(^4) ha)</th>
<th>Grassland (10(^4) ha)</th>
<th>Yields (10(^4) t)</th>
<th>Population (10(^4))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nation total</td>
<td>96,000</td>
<td>13538.5</td>
<td>1481.2</td>
<td>25,395</td>
<td>28731.4</td>
<td>58957.97</td>
<td>135404</td>
</tr>
<tr>
<td>Heilongjiang</td>
<td>4370</td>
<td>1594.4</td>
<td>4.5</td>
<td>2325.7</td>
<td>207.1</td>
<td>5761.49</td>
<td>3834</td>
</tr>
<tr>
<td>Jilin</td>
<td>1874</td>
<td>703</td>
<td>6.8</td>
<td>886.4</td>
<td>62.1</td>
<td>3343.00</td>
<td>2750</td>
</tr>
<tr>
<td>Liaoning</td>
<td>1480</td>
<td>504.19</td>
<td>47.78</td>
<td>563.53</td>
<td>109.78</td>
<td>2070.5</td>
<td>4389</td>
</tr>
<tr>
<td>NE China total</td>
<td>7724</td>
<td>2801.59</td>
<td>59.08</td>
<td>3775.63</td>
<td>385.98</td>
<td>11174.99</td>
<td>10973</td>
</tr>
<tr>
<td>NE China to nation</td>
<td>8.05</td>
<td>20.69</td>
<td>3.99</td>
<td>14.87</td>
<td>1.34</td>
<td>18.95</td>
<td>8.10</td>
</tr>
<tr>
<td>Total %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) This the national land use survey by using SPOT data for year 2008 with resolution of 2.5 m. The survey was carried out by Ministry of Land and Resources of China and the results were issued on Dec. 30 in 2013. [http://www.mlr.gov.cn/tdzt/tdgl/decdc/].

\(^b\) Data is from national statistical bureau. Grain crops include cereals, rye and legumes. [http://data.stats.gov.cn/].

Table 4
Average soil loss rates by sheet and rill erosion for the different land uses in NE China.

<table>
<thead>
<tr>
<th>Province</th>
<th>Cropland Mg ha(^{-1}) yr(^{-1})</th>
<th>Horticultural</th>
<th>Forest</th>
<th>Grassland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heilongjiang</td>
<td>12.28</td>
<td>5.75</td>
<td>1.74</td>
<td>1.27</td>
</tr>
<tr>
<td>Jilin</td>
<td>23.72</td>
<td>9.74</td>
<td>2.38</td>
<td>5.22</td>
</tr>
<tr>
<td>Liaoning</td>
<td>14.38</td>
<td>10.9</td>
<td>3.79</td>
<td>4.12</td>
</tr>
<tr>
<td>NE China avg.</td>
<td>15.52</td>
<td>10.37</td>
<td>2.19</td>
<td>2.78</td>
</tr>
</tbody>
</table>
where much of the formerly cropped land has reverted to forests, commercial or otherwise, and in Kazakhstan where much of the lands cultivated during the 1950s and 60s are no longer used for wheat production. Once land is cultivated, long term erosion rates are greater than for natural lands as long as the land continues being used for crop production. Average rates of soil erosion under natural, non-cropped conditions have been documented to be less than 1.9 Mg ha$^{-1}$ yr$^{-1}$ (Table 1), while on-site rates of erosion of lands under cultivation in the United States are currently estimated to be on the order of 6.7 Mg ha$^{-1}$ yr$^{-1}$ (Table 2). Soils formed under natural, non-agricultural conditions prior to cultivation can be considered to have been in a balance with natural rates of soil formation. It can therefore be expected that with the increased rates of erosion caused by agriculture this balance will shift toward a depletion of the soil resource.

Lands that were brought into production in northeastern China during the last century are thought to have average rates of erosion of as much as 15 Mg ha$^{-1}$ yr$^{-1}$ or more (Table 4). These very high rates of erosion is not sustainable in the long term. In parts of the region where rates are much greater than the average, soil production may be in jeopardy. If they follow the pattern that has taken place in other parts of the world at other times, some of the land currently under production will not remain so for the long term, unless major changes are made to tillage and management practices that are currently in place, which include the current use of low rows of corn and soybeans planted up and down slopes using conventional tillage practices.

There is no doubt that soil conservation practices, and in particular reduced tillage and residue management, has been found to be effective in reducing rates of erosion, as was seen in the United States when the average rates of erosion on cropped lands decreased from on the order of 9 Mg ha$^{-1}$ yr$^{-1}$ to 6 or 7 Mg ha$^{-1}$ yr$^{-1}$ between 1982 and 2002. Even these rates of erosion are much greater than what they might be under natural conditions. The use of a no-till cropping and management system has the potential in many cases to reduce erosion rates to much more acceptable levels (e.g., Zhang & Garbrecht, 2002). However, because of limitations associated with soil moisture and temperature a full no-till approach will not work well in all environments.

Taking cropped land out of production and restoring it to perennial plant cover, as was done in areas of the United States under the Conservation Reserve Program, may reduce erosion rates back to approximately 1 Mg ha$^{-1}$ yr$^{-1}$ or less. One long term solution for sustainable agriculture, therefore, would be the development and adoption of permaculture, where food may be grown and harvested as perennial grain-producing or other crops (e.g., Akhtar, Lodhi, Khan & Sarwar, 2016). Permaculture is a potential that has not been extensively explored, in large part because of the lack of financial incentive on the part of large-scale agri-business.

References


Bierman, P. R. (1994). Using in situ produced cosmogenic isotopes to estimate rates

![Fig. 2. Sample units in NE China used for the national soil erosion survey.](image-url)


