A preliminary study of soil erosion and land degeneration

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Abstract The relationship between soil erosion and land degeneration has been studied by the analysis of data from field observations and experiments. The study shows that soil erosion is the main cause of land degeneration and that it causes not only water and soil loss, but also a loss of organic matter and mineral fertilizer. Soil erosion control must therefore represent the fundamental basis for reducing land degeneration and for improving land productivity.

INTRODUCTION

Land degeneration resulting from soil erosion is a widespread phenomenon in China, and the annual loss of nitrogen (N), phosphorus (P), and potassium (K) caused by erosion is up to 40 million t. Especially in areas of severe erosion, land deterioration has become one of the most important factors which limit the development of the agricultural economy. There is therefore a need to increase and maintain land productivity in order to develop the agricultural economy and to investigate the relationship between land degeneration and water and soil loss.

THE RELATIONSHIP BETWEEN LAND DEGENERATION AND EROSION

The decline of soil nutrient content

Because the top soil is lost first by soil erosion, the nutrient content of the surface soil will also rapidly decrease. This decrease involves a reduction in the content of organic matter, nitrogen, phosphorus, potassium and other trace elements.

Organic matter The organic matter content declines with an increase in erosion depth and erosion intensity. According to field evidence, the humus content is typically 150-160 t ha^{-1} in non-eroded soils, 100-120 t ha^{-1} in slightly eroded soils, 70-80 t ha^{-1} in moderately eroded soils, and 50-60 t ha^{-1} in highly eroded soils (Xu Rui, 1989).

The decrease in the organic matter content is also coupled with a decline in the quality of the organic matter. Because of the selectivity of soil erosion, the fine grained material is washed away first along with the readily soluble organic matter which is mainly composed of humic acids. In addition, the more acid lower soil layers are brought to the surface and the content of stable organic matter decreases. All these processes result in a decline in humus quality.

Nutrient content Nitrogen, phosphorus and potassium are the main elements essential for crop growth and are usually present in proportion to the humus content of the soil; the greater the erosion rate, the less the humus content, and the lower the nitrogen content of the soil. In an eroded soil, the quantity of hydrolytic nitrogen is less than in a non-eroded soil. The rate of nitric acid and ammonia synthesis is also slower than in a non-eroded soil and there will be a deficit of absorbable nitrogen. According to field evidence, the organic phosphorus content decreases, but the insoluble phosphate content increases in eroded soils. The P_2O_5 content decreases by 20-40% in moderately eroded soils and by 40-60% in highly eroded soils, compared to non-eroded soils.

On the Loess Plateau of China, the nitrogen content of the soils is closely related to soil erosion intensity; the greater the erosion intensity, the lower the nitrogen content of the soil. Table 1 demonstrates that the nitrogen content of a wind-blown soil experiencing rapid erosion is decreased by 79% in comparison to a warp soil.

Table 1 The relationship between the nitrogen content of soils and erosion intensity.

Soil type	Erosion intensity	N content (%)	N in top 20 cm (t km^{-2})
Warp soil	Non-eroded	0.094	235.05
Black soil	Slight erosion	0.074	178.65
Yellow earth	Deep erosion	0.042	94.20
Wind-blown soil	Rapid erosion	0.017	49.35

In addition to the organic matter and N, P, K, some trace elements also decrease with an increase in soil erosion. Table 2, based on the work of Li Song (1987), shows that in the gullied loess plateau, on highly eroded sloping fields, the content of organic matter decreased by 66.9%, that of total nitrogen by 54%, potassium by 34.4% and calcium by 5.6%, as compared with that on perennial apricot orchards with only slight erosion.

The selective action of soil erosion will first remove the clay and fine grained aggregates, which contain more nutrients. This causes a higher content of nutrients in the eroded material than in the *in situ* soil. For example, the content of organic matter increases by 61.5%, total nitrogen by 11.0%, active potassium by 100.2%, in the gullied rolling loess region.

Table 2 The content of selected nutrients in the 0-5 cm soil layer.

Erosion status	Land use	Organic matter (%)	N (ppm)	K (ppm)	Mg (ppm)	Zn (ppm)	Mn (ppm)	Fe (ppm)
Deep	Sloping	0.46	31.8	391.8	53.2	0.33	3.57	1.68
Moderate	Biennial grass	0.89	57.9	621.0	62.5	0.67	7.00	2.20
Slight	Perennial apricot	1.39	60.3	643.2	68.8	0.50	6.40	1.70

In a similar manner to soil erosion, the decline in soil fertility means that soil nutrient content varies with an increase in slope gradient and slope length. Table 3 and Table 4 show that as slope gradient and slope length increase, the nutrient content of the soil will decline.

Table 3 The relationship between the content of N, P, K and slope length based on data from the Tianshui Experimental Station, 1963.

Slope (m)	Active N (%)	Active P (%)	Active K (%)
10	0.0640	0.592	1.046
20	0.0512	0.247	0.670
40	0.0498	0.203	0.560

Table 4 The relationship between the organic matter and the N content of soils and slope angle based on Li Yongji (1987).

Slope angle (°)	Organic matter (%)	Available N (mg/100 g)
9	1.81	0.104
24	1.32	0.080
33	0.59	0.032

The destruction of soil structure

Soil structure, which affects the aeration, the water retention capacity and the thermal conductivity of a soil, is one of the main controls of crop growth and directly reflects the level of land productivity. The content of stable aggregates decreases in eroding soils. According to data from the Jiuyangou valley, the content of water absorbing aggregates in the top 30 cm of the soils of a sloping field with deep erosion is decreased by 45.9% compared to that of a terraced field with slight erosion (Table 5). Furthermore, soil erosion results in a great loss of mature soil. In the deeply eroded areas of the middle reaches of the Yellow River, the annual soil loss exceeds 2.0 cm and this is far in excess of

Table 5 Soil aggregate content of land with different erosion rates.

Extent of erosion	Type of land	Aggregate content in soil layer (%):			
		0-15 cm	15-30 cm	30-50 cm	0-30 cm
Deep	Sloping field	1.66	0.48	0.50	1.07
Slight	Terraced field	2.89	1.06	1.13	1.97

the rate of soil formation. The reduction in organic matter results in increased soil density and marked decreases in soil permeability, soil aeration, and water holding capacity.

Soil moisture

Reductions in the soil aggregate and organic matter content of soils result in a rapid decrease of permeability and water holding capacity and cause an increase in the runoff coefficient of sloping surfaces. This change, in a similar way to soil and water loss, is proportional to slope gradient. The decrease in infiltration and water holding capacity causes a reduction of soil moisture. According to field observations, the available water in deeply eroded sloping field soils was reduced by an average of 20% compared to terrace soils with slight erosion. In addition, the deficiency of nutrients and the lower soil solution concentration in the eroded soils causes higher evapotranspiration by field crops, so that the total water consumption of crops on eroded land is about 2-3 times that on non-eroded land. The reduction of soil moisture and the increase of water consumption causes frequent droughts in eroded areas.

THE CHANGE OF LAND PRODUCTIVITY WITH SOIL EROSION

The ultimate damage caused by soil erosion is the reduction in land productivity. The crop yield decreases because the crop growth is checked by reduced soil moisture and soil fertility and by soil structure deterioration that reduce the supply of water, fertilizer, air and heat to the crop. With the development of soil erosion, the mature topsoil in which there is more fertilizer is continuously lost. The loss of fertilizer supplied and accumulated over many years means that levels of organic matter, N, P, K and other trace elements cannot be maintained at a high level. The greater the loss of soil and water, the greater will be the reduction in crop productivity.

The change in the content of most nutrient elements in the soil exhibits

Table 6 Nutrient losses (kg m^{-2}) and crop yield reductions associated with different erosion intensities.

Slope (°)	Runoff (m^3 mu^{-1})	Erosion (kg mu^{-1})	Nutrient loss (kg mu^{-1}): Organic matter	N	P	K	Crop yield (%)
5	91.3	1840	16.3	0.623	0.019	0.652	100
10	101.5	2724	20.1	0.646	0.021	0.722	87.89
15	124.7	3929	24.5	0.661	0.022	0.765	78.91
20	131.6	4595	27.8	0.676	0.023	0.800	78.52
25	140.9	5185	30.5	0.688	0.024	0.822	74.22

A mu is a Chinese unit of area: 1 ha = 15 mu.

a similar pattern to soil and water loss. This results in a decrease of crop yield with increased soil erosion. Table 6 based on the work of Lu Shenwu & Lu Daliang (1988), shows that nutrient loss from fields increases rapidly with soil erosion whilst the crop yields are inversely related to soil erosion intensity.

An artificial soil removal experiment undertaken in the gullied loess plateau within an area of poor soil has shown that when the top 20 cm of soil was removed, the yields of wheat and sweet potato were reduced to 69.3% and 75.4%. When 150 cm of soil was removed, the yields were only 24.6% and 12.2% of those from non-eroded land under the same cultivation conditions.

PRACTICES FOR CONTROLLING LAND PRODUCTIVITY REDUCTION

Based on the above analysis, it is clear that soil erosion causes a rapid reduction in land productivity in eroded areas. Controlling erosion is therefore an effective way of maintaining and increasing land productivity by decreasing the nutrient loss, improving soil structure and raising the water holding capacity of soil. At present, the most common methods in China for water and soil loss control are plant cover, conservation tillage, and terraced fields.

Plant cover practices

Increasing the degree of plant cover is an important and effective practice for improving and maintaining soil fertility. By reducing raindrop splash, slowing flow velocity, increasing permeability and binding the soil with their root systems, plants can effectively reduce water and soil loss and control the decline of land productivity. According to field experiments, compared with a sloping field, the amount of soil erosion decreased by 100% in good closed forest of conifer species, 88.5% in a perennial yellow locust forest and 89.9% in a shrub forest. Reductions in runoff and sediment yield were respectively 69.9% and 83.6% in a black locust forest more than five years old, 44.3% and 74.8% in alfalfa land and 38.0% and 72.4% in sweet clover land (Hua Shaozu, 1982). Table 7 shows that many nutrients increased in the good closed plant cover land compared with the sloping field with deep erosion but the same slope gradient (Li Song, 1987).

Table 7 Plant cover and soil nutrient content.

Plant cover	Organic matter (%)	Total N (%)	Content in available form (ppm): N	K	Mg	Zn	Mn	Fe
Crop land	0.46	0.042	31.8	391.8	53.2	0.33	3.57	1.68
Biennial grass	0.89	0.072	57.9	621.0	62.5	0.67	7.00	2.20
Perennial apricot	1.39	0.087	60.3	643.2	68.8	0.50	6.40	1.70

Terraced fields

Terraces are an effective means for preventing water and fertility loss, because of not only their role in conserving soil moisture, increasing infiltration and decreasing soil erosion, but also in their role of improving soil structure and conserving soil nutrients. Table 8, based on data from Suide Soil Conservation Experimental Station, shows that when a sloping field was terraced, the nutrient content recovered rapidly (Tang Keli *et al.*, 1987). Furthermore, the aggregate content of the top 30 cm of the soil in the terraced field is 45.7% higher than that in the sloping field and the soil moisture is 15-20% higher also.

Table 8 Nutrient recovery in the soil of a terraced field.

Age of terrace	Organic matter:		Total N:		Available P:		Hydrolytic N:	
(years)	Content (%)	Ratio	Content (%)	Ratio	Content (%)	Ratio	Content (%)	Ratio
1	0.40	100	0.036	100	6.4	10	26.2	100
3-4	0.66	165	0.050	139	9.6	150	46.9	170
4-5	1.07	267	0.062	172	25.0	391	64.9	248

Conservation tillage

This practice is only suitable for fields with gentle slope gradients and its function of conserving water and soil will decrease markedly on steep land (gradient > 15°). The main forms used in China are contour tillage, level trench planting and contour checks. Level trench planting on slopes is very effective in conserving water and soil. Usually it can reduce runoff and erosion by 58-76% and 9.4-97.2% respectively and increase crop yield by 2.8-12.0%. Reductions of runoff and sediment yield associated with contour checks are 74.1% and 92.0% respectively.

The effectiveness of each practice is a function of rainfall amount and intensity. With heavy rain, soil and water loss is more serious, and the reduction in runoff and sediment yield is smaller. Usually, the reductions are more than 90% when the rain is not excessive. According to the investigations reported by Gong Shiyang & Jiang Deqi (1977), with the same rainfall, the effectiveness in reducing runoff and erosion is in the order terrace > forest land > grass land.

CONCLUSION

Land deterioration is one of the main features of areas where soil and water loss is serious. Soil erosion is the most important cause of land productivity reduction because of the associated soil nutrient loss, soil texture deterioration and soil moisture decrease. The overall result of these changes is poor conditions for crop growth which in turn lead to a continuous decline in production. The selectivity of erosion restricts the accumulation of nutrients and causes the loss of fertilizer applied. The reduction of land productivity is accelerated by soil erosion. Land degeneration caused by erosion can be prevented by removing the causes or by controlling the soil and water loss from sloping land. Each measure has its range of suitability and conservation tillage is only suited to fields with gentle gradients and the planting of trees and grass to uncultivated land. Terraces have a wide suitability, but when the slope angle increases the input required for terracing will increase. Frequently, a combination of different measures will be most appropriate.

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