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SOIL EROSION AND ITS IMPACTS ON ENVIRONMENT IN YIXING TEA PLANTATION OF JIANGSU PROVINCE

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ABSTRACT: Soil erosion on sloping field has led to a lot of environmental problems. In order to reveal the seriousness of the damage of soil erosion on sloping fields ^{137}Cs tracer method was used to estimate soil erosion rate. ^{137}Cs reference inventory of 2200Bq/m^2 in Yixing, southern Jiangsu Province, was estimated and a model for estimating erosion of cultivated soil was established in order to avoid overestimating soil erosion rates. Then based on the soil erosion rates and measured soil physical and chemical properties, direct and indirect impacts of soil erosion on environment were further discussed. Direct impacts of erosion on environment included on-site and off-site impacts. The on-site impacts were that soil layer became thin, soil structure was deteriorated and soil nutrients decreased. The off-site impacts were that water bodies were polluted. The indirect impacts of soil erosion on environment were the increase of fertilizer application and energy consumption, and change of adaptability of land uses. Although erosion intensity was not serious in the study area, its environmental impacts should not be ignored because of great soil nutrient loss and coarseness of soil particles.

KEY WORDS: ^{137}Cs reference inventory; erosion model; soil erosion; equivalent erosion module

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1 INTRODUCTION

It has been more than 20 years since ^{137}Cs tracer method was applied to estimate soil erosion (MCHENRY and RITCHIE, 1977; RITCHIE and MCHENRY, 1985; MONLGOMERY *et al.*, 1997). And various models for estimating erosion rate have been established (RITCHIE and MCHENRY, 1985, 1990; WALLING and HE, 1999; YANG *et al.*, 1998, 2000; ZHANG *et al.*, 1990). The models for estimating erosion rate of cultivated soil were assumed or implied that the distribution of ^{137}Cs was only within the cultivated layer. However, our study indicated that ^{137}Cs was not only distributed in the cultivated layer but also penetrated to the depth below the cultivated layer in some soil profiles. In order to avoid overestimating the erosion rate, the model for estimating erosion rate of cultivated soil was established.

Soil erosion is a kind of non-point pollution sources. Soil erosion and its impacts on environment have been studied from different views using various methods (LIU and LIU, 1999; GAO *et al.*, 2000; CHEN and PENG, 2000). The direct impacts of soil erosion on environment have been considered in previous studies. But few studies dealt with the indirect impacts of soil erosion on environment. Therefore, the direct and indirect impacts of soil erosion on environment were studied in this paper.

The natural conditions of the southern Jiangsu Province, China are very suitable for tea trees growth so there exist extensive tea plantations. The cultivations of tea led to a certain scale of soil erosion and nutrients loss. But little information on soil erosion and its impacts on environment of this area has been known. A tea plantation, which is located in Hufu Town, Yixing County, Jiangsu Province and belongs to Taihu Basin, was chosen as study area. In the study area, landform is low mountains and hills, and climate is warm and moist. Mean annual temperature and precipitation is 15.6℃, 1385.8mm, respectively, mean annual rain days are 136 days. Soil type is yellow and red sand loam with weak acidity (EBHTR, 1999).

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2 MATERIAL AND METHODS

2. 1 Samples Collection

Soil samples were collected in Yangxian Tea Plantation in March of 2001. At each sampling point the soil profile was dug and divided into the horizons. The soil samples were collected to 40cm by an interval of 5cm. About 1-kg soil was collected for each horizon. Totally 75 soil samples were collected in the site.

2. 2 Measuring ^{137}Cs Content

After dried in room temperature, ground, passed a 2-mm sieve and oven-dried to a constant weight at 105℃, the soil samples were placed to plastic containers, a hyper-pure germanium crystal detector (GEM-25210, which was made by EG&G ORTEC Company, USA) coupled to a multi-channel γ-ray spectrometer was used to measure ^{137}Cs content. Count time was 16 000 seconds.

2. 3 Determining ^{137}Cs Reference Inventory

Once fallout reached land surface, man-made radioactive nuclide ^{137}Cs was strongly absorbed by surface soil particles. Its further movement is related to physical movement of soil particles (MCHENRY and RITCHIE, 1977; RITCHIE and MCHENRY, 1985; MONLGOMERY *et al.*, 1997). The current spatial distribution of ^{137}Cs in landscape can reflect the extent of soil erosion and deposition. Compared the ^{137}Cs inventory of an individual sampling point with the reference inventory, if the former was less than the latter erosion occurred in this point, otherwise deposition occurred.

Therefore, it is critical for the ^{137}Cs tracer technique to identify suitable reference sites and obtain reliable ^{137}Cs reference inventory. So a nearly level and undisturbed bamboo-covered site on a crest, experiencing hardly erosion and deposition, was chosen as the reference site. Its ^{137}Cs inventory was 2169Bq/m^2. The level dry farmlands were considered as the fields with a little erosion or deposition, which ^{137}Cs inventory might approach the reference inventory, so that the soil samples were sampled there. Their ^{137}Cs inventories fluctuated between 2100Bq/m^2 and 2200Bq/m^2. Additionally, a Chinese chestnut forest on a level terrace, which was not far from the bamboo and has not been disturbed since 1950, and where very slight erosion might have happened, was also investigated. Its ^{137}Cs inventory was 2010Bq/m^2. Therefore, the local ^{137}Cs reference inventory was estimated to be about 2200Bq/m^2. Generally the fallout of ^{137}Cs is related to the precipitation (RITCHIE and MCHENRY, 1990). Because the precipitation in southern Jiangsu Province is greater than that in the Loess Plateau, the amount of ^{137}Cs fallout in southern Jiangsu Province should be higher than that in the Loess Plateau. Compared with the reported ^{137}Cs reference inventory of 2008Bq/m^2 in the Loess Plateau (ZHANG *et al.*, 1990), the local ^{137}Cs reference inventory of 2200Bq/m^2 was reasonable.

2. 4 Establishing Soil Erosion Model

In the study it was found that ^{137}Cs was not only distributed uniformly within cultivated layer in all the sample profiles as a result of tillage but also penetrated to the depth below cultivated layer in most sampling profiles as the result of vertical movement of water (Table 1). It was supposed that if there was no soil movement, ^{137}Cs distribution of all the soil profiles was the same. Soil erosion only caused the ^{137}Cs loss from the surface soil and did not change the distribution of underground soil. Both ^{137}Cs reference inventory (C_{ref}) and ^{137}Cs inventory in the cultivated soil profile that erosion occurred (C_t) could be divided into two parts. One part was uniformly distributed within the cultivated layer (C_{ref1} and C_{t1}) and the other part penetrated to the depth below cultivated layer (C_{in}), that is:

$$C_{ref} = C_{ref1} + C_{in} = D \times \rho \times H_c + C_{in}$$

$$C_t = C_{t1} + C_{in} = D \times \rho \times (H_c - h) + C_{in}$$

Then the loss of ^{137}Cs inventory is:

$$\Delta C = C_{ref} - C_t = D \times \rho \times h$$

So

$$h = H_c \times (C_{ref} - C_t) / (C_{ref} - C_{in}) \quad (1)$$

where h is total thickness of soil erosion (mm); D, soil bulk density (g/cm^3); ρ, average concentration of ^{137}Cs activity in cultivated layer (Bq/kg); H_c, depth of cultivated layer (mm); C_{in}, ^{137}Cs inventory penetrated to the depth below cultivated layer at the specific sampling point (Bq/m^2).

Table 1 ^{137}Cs inventory in the tea plantation (Bq/m^2)

Depth (cm)	B_0	B_1	B_2	B_3	B_4	B_5
0 – 5	295	275	293	348	307	318
5 – 10	348	301	291	301	422	356
10 – 15	329	301	357	213	345	268
15 – 20	348	343	137	199	299	0
20 – 25	278	161	0	0	216	0
25 – 30	76	0	0	0	150	0
30 – 35	0	0	0	0	66	0
35 – 40	0	0	0	0	0	0

Note: The thickness of cultivated layer is 20cm.

After obtaining the total thickness of soil loss (h) during the past t years using Equation (1), the mean annual thickness of soil loss and the corresponding erosion rate can be calculated, according to Equations (2) and (3), respectively.

$$h_r = h / t = h / (T - 1963) \quad (2)$$

$$E_r = 1000 \times D \times h_r \quad (3)$$

where h_r is mean annual thickness of soil loss (mm/a); E_r, soil erosion rate ($t/km^2 \cdot a$); T, sampling year ($T > 1963$), 1963 was the year characterized by the greatest ^{137}Cs flux.

2.5 Measuring and Estimating Soil Nutrient

A part of dried soil sample was taken and ground to pass 0.149-mm sieve to measure soil nutrient content: soil organic matter (OM), total nitrogen (TN) and total phosphorus (P_2O_5) (CSSACDC, 1983).

Absolute amount of soil nutrients loss per unit area and relative amount of soil nutrients loss per unit area were used to indicate soil degradation due to soil erosion. Absolute amount of the jth kind of soil nutrient loss in topsoil (NE_{j1}) is calculated by:

$$NE_{j1} = N_{j1} \times D_1 \times h_r \quad (4)$$

where N_{j1} is the jth nutrient content of topsoil; D_1, bulk density of topsoil.

Relative amount of soil nutrient loss is the percentage of absolute loss amount of soil nutrient to the total amount of soil nutrient in the cultivated layer. It is calculated by:

$$E_j(\%) = NE_{j1} / N_j = N_{j1} \times D_1 \times h_r / \sum N_{ji} \times D_i \times h_i \quad (i = 1, 2, \ldots, n) \quad (5)$$

where N_j is the total amount of soil nutrient in the cultivated layer; N_{ji}, the jth nutrient content of the ith horizon in the cultivated layer; D_i, bulk density of the ith horizon; h_i, thickness of the ith horizon; n, the total number of horizons in the cultivated layer.

2.6 Equivalent Erosion Module

Because soil and environment are different in each region, their soil erosion modules could not completely reflect the impacts of soil erosion on environment. In order to reveal seriousness of the impacts of soil erosion on environment, an equivalent erosion module was put forward. It could compare the damage of soil erosion in different erosion regions.

Equivalent erosion module was measured based on the total amount of specific material in loss soil. Gaven amount of soil loss in different place were E_1 and E_2 respectively and the specific material content in the loss soil were correspondingly X_1 and X_2. Then loss amount of equivalent specific material is expressed by:

$$M_x = E_1 \times X_1 = E_2 \times X_2 \quad (6)$$

where M_x is total loss amount of specific material per unit area in a particular period; E_1 and E_2 are mutual equivalent erosion module.

2.7 Measuring Soil Coarseness

Loose and porous soil is the most favorable for regulating water, air, heat and fertilizer and is beneficial to plant roots development and growth. However, soil erosion has led to the change of soil particle-size distribution. The ratio of sand to the sum of silt and clay is named as the coarseness of soil particles. It was shown that the greater the ratio was, the more the coarse particles were, and less the fine particles were. The diameter of sand is 1 – 0.05mm, of silt is 0.05 – 0.005mm and of clay is < 0.005mm according to the standard of China (LI *et al.*, 1983). And soil particle-size distribution was measured by hydrometer (CSSACDC, 1983).

2.8 Estimating Fertilizers and Energy Consumption

Soil erosion can lead to nutrient loss of topsoil. Additional fertilizers should be used to compensate for nutrient loss in order to keep soil fertility and high soil productivity. If chemical fertilizer was applied to compensate for nutrient loss the requirement of the ith kind of chemical fertilizer (F_i) (F_i was named as substitution fertilizer) is calculated by:

$$F_i = NE_{j1} / F_{ij} \quad (7)$$

where F_{ij} is percentage of the jth kind of nutrient in the ith kind of chemical fertilizer.

It needed great energy consumption to exploit raw material and produce chemical fertilizer. Therefore one of the indirect impacts of soil erosion was the increase of energy consumption. Energy consumption for producing substitution fertilizer (EN_i) is calculated by:

$$N_i = F_i \times EF_i \quad (8)$$

where EF_i is energy consumption for producing per unit weight of the ith kind of chemical fertilizer.

3 RESULTS AND DISCUSSION

3.1 Soil Erosion in the Tea Plantation

Based on ^{137}Cs inventory and Equations (1) to (3), the thickness of soil erosion per year and soil erosion rate in tea plantation were calculated (Table 2). There the depth of cultivated layer was 20cm based on the local cultivation operation and mean soil bulk density was 1.3 g/cm^3.

The tea trees were planted on a reformed gentle slope farmland that was tilled and fertilized twice a year. ^{137}Cs was uniformly distributed within cultivated layer. Because of less coverage and equal slope soil erosion increased. And erosion rate of the tea fields was larger than that of the bamboo in nature (214t/km^2 · a) (ZHANG *et al.*, 2002).

Table 2 ^{137}Cs inventory and erosion rates

Profile No.	^{137}Cs inventory (Bq/m^2)	Mean annual thickness of erosion (mm/a)	Erosion rate (t/km^2 · a)
B_0	1675	1.50	1946
B_1	1380	2.12	2751
B_2	1077	2.69	3492
B_3	1061	2.72	3541
B_4	1806	1.17	1524
B_5	942	3.01	3913

According to the classification standard of soil erosion (CMWC, 1997), the soil erosion in the tea plantation was middle level.

Soil samples B_1 to B_3 were collected along the downslope direction and B_4 to B_5 were collected along the contour. B_0 was collected from the shared passageway of the two fields (Fig. 1). From the observed data it was shown that the soil erosion rate decreased gradually from the summit to foot slope. On upper slope the soil movement was primarily net soil erosion, but on middle and lower parts of slope both soil loss at the sampling point and deposition of loss soil from upper slope occurred. Hence the net soil erosion on upper part of slope was greater than that on middle and lower parts.

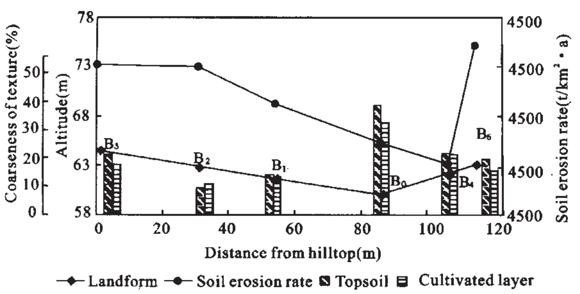

Fig. 1 Landform and erosion rate and coarseness of particles in the tea plantation

Difference in cultivation practices led to the change of soil erosion rate. Although B_4 and B_5 were in 6° slope and B_1 to B_3 in 3° slope, on the whole, the extent of erosion on 3° slope was higher than that on 6° slope, which demonstrated that contour planting practice could effectively reduce erosion.

In order to know off-site impacts of soil erosion on environment, the net soil loss amount should be known. It was determined by the erosion amount of sampling point at the foot of slope. Erosion rate of B_0 was regarded as total net soil loss of two tea fields (1946 t/km^2 · a). The erosion characteristic in the low mountainous and hilly area of southern Jiangsu Province was that less soil left far from the area that erosion occurred.

The above results were proved by other scholars' researches. For example, annual sediment import of Taihu Lake was 440×10^3t (SHI, 1999) and soil erosion area of Taihu Basin was 2.96×10^3km^2 (GUO, 1997). If sediment delivering rate was taken as 0.1 (SHI, 1996) the average soil erosion rate of Taihu Basin was 1486t/(km^2 · a). This result approached the soil erosion of B_0 representing the net soil loss of the tea plantation.

3.2 Direct Impacts of Soil Erosion on Environment

3.2.1 Soil layer becoming thin

One direct impact of soil erosion on environment was that soil layer becomes thin. Mean annual thickness of soil erosion in the tea plantation was 1.17 – 3.01 mm/a. From the point of view of JOHNSON *et al.*, (1987), soil formation rate of cultivated soil was 0.83mm/a. It was thus clear that the soil loss rate of the tea plantation was greater than soil formation rate. Therefore, soil resources in this area would inevitably degrade and diminish. Furthermore, because the thickness of soil in this area was very thin compared with that in the Loess Plateau of China, the erosion did harm to the local agricultural foundation.

3.2.2 Coarseness of soil particles

Measured results are shown in Table 3.

Table 3 Coarseness of soil particles in topsoil and cultivated layer

Profile No.	Soil depth (cm)	1 – 0.05 (mm)	0.05 – 0.005 (mm)	< 0.005 (mm)	Coarseness (%)
B_0	0 – 5	28.2	44.7	27.0	39.3
	0 – 20	24.1	47.1	28.8	31.7
B_1	0 – 5	12.6	49.5	37.9	14.4
	0 – 20	11.6	48.2	40.2	13.1
B_2	0 – 5	8.9	50.4	40.7	9.8
	0 – 20	9.5	48.5	42.0	10.6
B_3	0 – 5	17.1	45.1	37.8	20.6
	0 – 20	14.8	46.7	38.5	17.4
B_4	0 – 5	18.1	47.8	34.1	22.1
	0 – 20	17.4	46.6	36.0	21.1
B_5	0 – 5	16.5	43.4	40.1	19.8
	0 – 20	13.4	42.6	44.0	15.4

Note: The depth of topsoil is 5cm and depth of cultivated layer is 20cm.

The change of soil particle-size distribution went with soil erosion. Especially erosion accelerated coarseness of soil particles. In the study soil coarseness was related to soil erosion to a certain extent. It showed that soil coarseness was controlled not only by soil erosion but also by other factors. For example, runoff velocity, discharge and sediment content of runoff might play a direct role in soil coarseness. Because in the upper slope runoff velocity, discharge and sand content in runoff were lower, only fine particles were eroded and were carried to middle of slope by runoff. At the middle of slope runoff velocity, discharge and sand content increased because speed-up runoff, washing capacity of runoff was stronger and capacity of carrying sediment was over-saturation. Therefore, part of fine particles coming from upper deposited in the area and soil particles were getting finer.

At the foot of slope because natural factors and human cultivation actions (such as digging discharge ditch) enlarged the capacity of washing and carrying sand, soil coarseness was obvious. Especially at B_4 and B_1, erosion rates were lower, but soil particles were coarse because fine particles were easily carried away by runoff and coarse particles were deposited there. Moreover, fine particles were carried to the surface layer due to cultivation activities such as tillage. For a long time the soil coarseness in B_4 and B_1 was greater although erosion rate was not greater.

The soil coarseness in 6° slope was larger than that in 3° slope because the slope was steeper, runoff was quicker and washing was stronger. It showed that the contour planting could capture sand from the upper slope and cut down erosion effectively but might not prevent soil particles from coarsening. Therefore in order to prevent soil particles from coarsening it was necessary to increase land coverage and decrease runoff.

In the ditch discharge of runoff was largest and only coarse particles remained there and fine particles were carried away by runoff. Therefore, soil coarseness in B_0 was the most obvious in all sampling points.

3.2.3 Nutrient loss

Soil erosion led to soil nutrient loss and lack of nutrients in soil that erosion occurred. Nutrients content, absolute and relative losses in topsoil were shown in Table 4. Compared soil erosion rate with nutrient loss it was evident that a negative correlation between contents of OM, TN and TP and soil erosion exists. The nutrient contents were lower in soil that soil erosion occurred and amounts of nutrient loss were greater while soil erosion was more serious.

Table 4 Nutrient content and loss of soil nutrients in topsoil

Profile No.	Nutrient content (g/kg)			Mean annual absolute nutrient loss (kg/ha·a)			Mean annual relative nutrient loss (%)		
	OM	TN	TP	OM	TN	TP	OM	TN	TP
B_0	69.58	1.51	3.04	1354.0	29.4	59.2	1.112	1.084	0.871
B_1	61.05	1.44	2.31	1679.6	39.6	63.6	1.210	1.184	0.945
B_2	44.55	1.95	1.98	1555.9	68.1	69.2	1.690	1.832	1.320
B_3	51.33	1.04	3.29	1817.6	36.8	116.5	1.378	1.193	2.539
B_4	72.89	2.41	3.77	1111.0	36.7	57.5	0.722	0.851	0.583
B_5	69.61	2.23	3.12	2723.8	87.3	122.1	2.242	2.268	1.523

The soil nutrient contents were high because fertilizers were applied twice a year. A part of nutrient loss associated with soil erosion has been compensated and the seriousness of soil fertility degradation has been mitigated by fertilizer application. Even so decrease of soil fertility was still difficult to avoid. Relative nutrient loss increased from 0.58% to 2.27%.

The potential harmfulness of soil erosion in southern Jiangsu Province could be revealed by equivalent erosion module associated with the nutrient loss and by comparison with nutrients loss of the Loess Plateau and that of the red soil area. The topsoil contents of OM, TN in loess are 3.49g/kg, 3.2g/kg (IASDS, 1982) and the topsoil contents of OM, TN and TP in the red soil are 9.1g/kg, 0.5g/kg and 0.5g/kg respectively (EBICAS, 1982). OM and TN in the fertile tea field were from 13.1 to 21.5 times and from 3.3 to 7.5 times as much as that in the loess. And OM, TN and TP in the tea field were from 4.9 to 8.0 times, from 2.1 to 4.8 times and from 4.0 to 7.5 times as much as that in the red soil. Based on equivalent nutrient loss in the loss soil (Equation (6)), such as TN, erosion rate of 3913t/(km^2·a) in the tea field was equal to that of 27 390t/(km^2·a) in the Loess Plateau and that of 17 452t/(km^2·a) in the red soil area. Based on equivalent erosion module the soil erosion intensity in the tea plantation belonged to serious erosion.

3.3 Indirect Impacts of Soil Erosion on Environment

3.3.1 Consumption of fertilizers and energy

It was assumed that application of ammonium bicarbonate (nitrogen content is 17%) or urea (nitrogen content is 45%) compensated for the nitrogen loss, calcium superphosphate (P_2O_5 content is 17%) (CHENG and NIU, 1990) compensated for the phosphorus loss and energy consumption of producing 1-t nitrogenous fertilizer (N) and 1-t phosphate fertilizer (P_2O_5) in China chemical fertilizer industries were 2402.76×10^4kJ/t and 849.76×10^4kJ/t respectively (EBHATE, 1983). Using equations (7) and (8), consumption of chemical fertilizer and energy compensated for the nutrient loss due to erosion was shown in Table 5.

Even if estimated on the lowest level, the consumption of energy was 137.04×10^4kJ/(ha·a), which could be converted into 46.76 kg/(ha·a) standard coal (low level calorific value of standard coal is 29 308 kJ/kg (ITDNSBPRC, 1998)).

3.3.2 Other impacts of soil erosion on environment

Besides the on-site soil degradation, the great nutrient loss associated with soil erosion led to other off-site costs.

Although soil erosion intensity in southern Jiangsu Province was less serious than that in the Loess Plateau and in red soil area of China, absolute nutrient loss carried by loss soil was very high. This was because the topsoil of the study area was generally more fertile than the soil of the Loess Plateau and the red soil area. When loss nutrients went into water bodies it would cause surplus of water nutrients, threatened the security of aquatic ecological system and led to a series of serious environmental problems, such as the eutrophication of water bodies.

Table 5 Consumption of fertilizers and energy compensating for nutrient loss due to erosion

Calculation method	Increase in fertilizer application (kg/ha·a)			Energy consumption ($\times 10^6$kJ/ha·a)		Total energy consumption ($\times 10^6$kJ/ha·a)
	Ammonium bicarbonate	Urea	Calcium superphosphate	Nitrogenous fertilizer	Phosphate fertilizer	
On the lowest level	215.88	81.56	383.33	0.8818	0.4886	1.3704
On medium level	255.26	96.43	461.89	1.0427	0.5887	1.6314
On the highest level	513.53	194.00	814.00	2.0976	1.0376	3.1352

Soil erosion also impacted land suitability. In order to prevent soil from degrading application of chemical fertilizers were increased. It led to soil over acid. It was suitable for tea trees to grow well in the soil with pH4.5 – 6.5. Over acid soil would not be suitable for planting tea and would harm the quality of tea.

4 CONCLUSIONS

Human activities made the risks of soil erosion increase and physical and chemical properties of soil change. It restrained plant growth and endangered human living environment. The damages of soil erosion in the southern Jiangsu Province were as follows. 1) Soil on which erosion occurred became thin, so that soil resources degrade inevitably. 2) Finer particles of topsoil were removed and left away with runoff. Thus the sand content increased and soil particles were coarse. 3) Soil nutrient elements decreased when fertile topsoil was removed and sterile subsoil was exposed. 4) Loss nutrients was accumulated at the foot of slope or moved into water bodies along with runoff or sediment. It affected water quality and caused eutrophication of water bodies. 5) Consumption of materials and energy increased in order to compensate for nutrient loss.

In order to raise soil productivity, fertilization and irrigation were applied to compensate for nutrient loss and to supply water. Although these methods slowed down the pace of soil degradation due to erosion, it increased the cost of agriculture production. Moreover the soil coarseness associated with erosion was difficult to be overcome. Because once fine soil particles were eroded and carried away by runoff they left the place and lost forever. And the processes of soil particles weathering and decomposing are rather long. When the fine particles lost from the fields continually the remainders became coarser and coarser step by step. Especially if soil erosion rate was larger than natural soil formation rate the soil would be washed to nothing. The activities that people try his best for increase of soil fertility and soil productivity also came to nothing. Moreover if remedial measures were not proper they would have adverse effect on environment. Consequently, in order to effectively prevent soil from degrading and to eternally use soil resources the most essential way is to control soil erosion.

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