Soil Erosion in Southeastern China of Red Soil Area
—Causes, Effects and Countermeasures

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Abstract: Soil erosion causes soil degradation in the low hilly red soil region in the subtropical China. With the objectives to understand the cause, effects and countermeasures of soil erosion we conducted field studies at different scales. Land use changes contribute to the main causes for the serious soil erosion by water. The land use was changed significantly after the foundation of China and caused severe soil erosion. The first change was from the natural vegetation of secondary forest mixed of pine trees and broad-leaved trees into tea plantations (*Camellia sinesis*) during the period of the "Great Leap Forward" in late 1950s. The second change happened during the period of "Reformation of Rural Land Tenure System" in the late 1980s and the early 1990s, when farmers were allowed to make their own decision on land use. The tee trees and the untapped secondary forest were reclaimed for cash crops like peanut (*Archis hypogaea*) and fruit trees like edible citrus and chestnut (*Castanea mollissima*). Our catenary studies clearly prooved that the soil loss at a rate of 12 cm—16 cm per year led to the accumulation of sediments at the footslope under peanut cultivation irrespective of the soil parent material, either from Quaternary clay or from sandstone. The soil profiles showed that soil loss was at a rate of 12 cm—16 cm per year as accumulated at the toeslope position irrespective of the soil parent material, either from Quaternary clay or from sandstone. Selective transportation and distribution along the slope and clay lessivation in the soil profile resulted in the soil stratification in soil texture. These processes increased the environmental risks through intensified interflow after high input of agricultural chemicals.

The results from the erosional plots of different farming systems indicates that the maximum soil losses for conventional farming systems amount to 21.23 Mg • ha^{-1} • a^{-1}. The enrichment ratio of soil nutrients is higher than 1.2, ranging from 2.57 to 6.19 for soil organic matter and from 1.90 to 2.45 for soluble N. In a small watershed with an erosion gully, where the plinthic horizon was exposed due to water erosion, the soil loss ranges from 53.4 Mg • ha^{-1} • a^{-1} to 256.32 Mg • ha^{-1} • a^{-1}. The modulus of soil loss by far exceeds the annual soil loss reported in the loess plateau in China, equivalent to the annual soil loss of 85 mm in depth within ten year. The loss of available soil nutrients by runoff and soil sediment can be as high as 10.84 kg • ha^{-1} for NO_3-N and 16.72 kg • ha^{-1} for available K even though the soil has a very poor soil fertility. The innovative tillage and techniques of restoration of vegetation in bare land are developed to reduce soil erosion significantly. The soil loss under the minimum tillage with straw mulching is averaged 0.5 Mg • ha^{-1} • a^{-1} to 1.5 Mg • ha^{-1} • a^{-1}.

After restoration of the vegetation cover in the bare land soil loss due to erosion hardly happens. The complex techniques of engineering and biological measures are established for the establishment of plantation in the infertile acid soil. The new tillage techniques and the restoration of the plants not only reduce the soil erosion, but also improve soil fertility as well as the soil physical properties, which strengthen soils against soil erosion. Macro-aggregates >1 mm and plant available soil water are increased, four years after reclamation. Although seriously erosion has been retarded due to restoration and conservation of vegetation, soil erosion is still a serious form of soil degradation, accounting for 25% of the land area in the region as indicated by remote sensing images. Soil erosion by water must be considered for peanut cropping and when planning to reclaim soils or changing the land use. We are continuing the research at larger watershed scale for optimization of land use while minimizing soil erosion and its related environmental problems.

Keywords: soil erosion, farming system, restorative vegetation, southeastern China

1 Causes of soil erosion

Southeastern China covers an area of 1.14 million km^2, of which red soils derived from Quaternary red clay account for 0.13 million km^2. Red soils in this area are generally found on low hills with a relative elevation of 30 m—80 m and a gentle inclination (<10%). These sites are thus suitable for agricultural development. Reclamation of these soils is regarded a necessity for sustainable agricultural development if the increasing demand for food in the region is to be met (Zhao, 1992). After deforestation of the natural broad-leaf deciduous forest in the 1950s, the area was covered with secondary vegetation of grass and sparsely distributed pine trees. Later on the area was reclaimed for agriculture. Due to the low fertility and poor workability of the red clays, farmers preferred to work on the soils from other soil parent materials such as sandstone and granite.

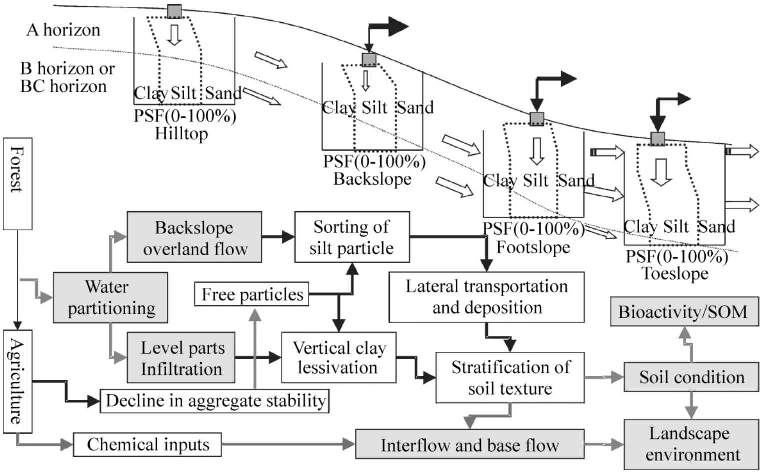
There were two changes in land use in recent times. The first change was from the natural vegetation of secondary forest mixed of pine trees and broad-leaved trees into tea (*Camellia sinesis*) trees during the period of the “Big Leap Forward Compaign” in late 1950s for the sandy soils (The Group of Regionalization for Utilization and Melioration of Red and Yellow Soils, 1985). The second change happened during the period of “Reformation of Rural Land Tenure System” in the late 1980s and the early 1990s, when farmers got the long-term tenure of the state-owned land and were allowed to make their own decisions on land use. The tea trees in the sandy soils and the secondary forest in the clayey soil were reclaimed for cropping cash crops like peanut and fruit trees like edible chestnut (*Castanea mollissima*). Reclamation and/or anthropogenic disturbances such as collection of fuel-wood and scrape-away of the grass coverage as fertilizer for paddy fields or fuel, as well as the proximity to a village, have made these soils prone to water erosion during the period of the first time of land use change. Areas of spectacular erosion were enlarged to the most at that time. The A- or B-horizon(s) of the soils were completely eroded and left the plinthic layers or C-horizons opened. Gullies have developed on the hillsides, resulting in an undulating geomorphology, more locally known as the “red desert” because no more plants could live on it and the erosion areas were large. During the second period of land use change, fuel wood was not problem anymore and the low hills were well protected from anthropogenic disturbances. But the intensive cropping increased the sheet erosion. The latest satellite image analysis shows that the area of Quaternary red clay affected by water erosion accounts for 13.9% of total area affected by erosion in Southeastern China or 44,100 km^2 (Pang, 1999).

Here we report the main results of soil erosion by soil survey along the slope and monitoring under different farming systems after reclamation of the wasteland and restorative vegetation on the site with plinthic layer exposed. The objectives were to understand the effects of land use changes on soil erosion and the countermeasures to soil erosion.

2 Effect of soil erosion on soil properties at the landscape scale

The results of soil survey along the slope indicated non-structured fine layered colluvial materials were accumulated on the footslope and toeslope positions (Zhang *et al*., 2002). The depths of the colluvial materials at the footslope and toeslope positions were 70 cm and 77 cm along the slope of soils developed from Quaternary red clay after 6 years of peanut cropping. The measured depth with erosional pin on the toeslope position was 8 cm deep during the period of peanut growth in 2001. Along the terraced slope of soils from Cretaceous sandstone by tillage the depth of colluvial material was 0 cm and 70 cm on the footslope and toeslope position after cropping of peanut since 1985. Along the slope of soils from mixed minerals under current chestnut allowed soil erosion as little as in secondary forest. The depth of colluvial materials of 50 cm on the footslope and 95 cm on the toeslope position was therefore attributed to form in 6 years during the period from 1992—1997 when peanut was intercropped with young chestnut tree. Therefore irrespective of parent materials the accumulative depth at the toeslope position of the gentle slope was about 12 cm —16 cm under peanut cropping without terrancing.

Associated with soil erosion were the hydroecological processes of water partitioning at the landscape scale and the stratification of soil texture in the soil profiles due to vertical clay lessivation and lateral redistribution of silt-sized particles (Model 1). Silt-sized particles were selectively transported and redistributed along the slope. Soil erosion will not only decline soil fertility, but also change hydroecological processes at the landscape scale, resulting in environmental risks, e.g. via intensified interflow.



Model 1 A conceptual model of hydroecological processes in the low hills in central subtropical China, indicating the processes of water partitioning and stratification of soil texture due to sorting of silt and clay lessiviation and the impacts of the processes on environment. PSF, particle size fraction; SOM, soil organic matter.

3 Soil erosion under different farming systems

The experimental site was a piece of slightly eroded barren land with sparse mason pine and was tapped in 1992 as trial plots. The land is 45 m in relative altitude and with a slope of 5°. The soil on-site is red soil derived from the Quaternary red clay and belongs to argillic red soil under ferrallisols order (Soil Taxonomic Classification Research Group, 1991). With the original sparse grass land as control, five cropping systems were conducted with no replicates (Table 1). Each plot, 100 m^2 (20 m×5 m) in area, was enclosed by cement plates. Runoff was collected with runoff tanks.

Table 1 Farming system used in this experiment

Treatment	Cropping system	Soil management
A	Peanut-Chinese turnip	Farmer's practice
B	Corn + Soybean-Buckwheat-Rape	Conventional tillage
C	Sweet potato + Soybean-Rape	Narrow ridge tillage
D	Corn + Soybean- Buckwheat-Rape	Min-tillage with mulching
E	Sweet potato + Soybean-Rape	Wide ridge tillage
F	Sparse grass land	Untapped

Annual runoff and soil loss in the treatements ranged from 30 mm to 550 mm and 0.05 $t \cdot ha^{-1}$ to 21.2 $t \cdot ha^{-1}$, occurring mainly from April to June. They were significantly higher in conventional tillage (Treatments A and B) and in the years of 1995 and 1998 (Figures 1 and 2). Losses of soil elements and plant nutrients due to erosion can be assessed using enrichment ratios (ER) (Gachene *et al.*, 1997). The ER is defined as the ratio of the nutrient content in eroded sediment to that of the source soil. The ER was more than 1.2 for the detected nutrients, ranging from 2.57 to 6.19 for OM and from 1.90 to 2.45 for soluble N. ER were not significantly related to the soil loss in the treatments, but it were lower in the two conventional treatment than those in the other treatments.

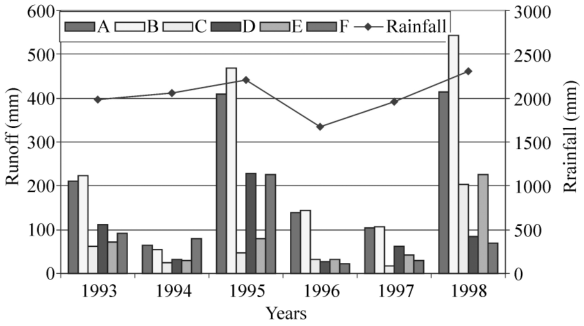


Fig.1 Rainfall and runoff under the farming systems

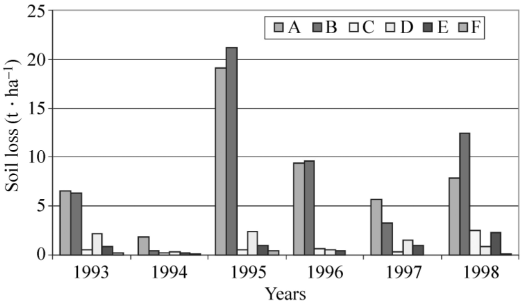


Fig.2 Soil loss under different farming systems

In two years of reclamation, the soils increased in micro-aggregates (> 0.002 mm) and inactive porosity (IAP), accordingly declined in capillary porosity (CP) and available water capacity (AWC) (Table 2). The greatest decrease occurred in Treatments A and B. Four years after reclamation, micro-aggregates (0.05 mm and 0.25 mm) and clay particles (<0.002 mm) increased. Macro-aggregates >1 mm was the highest in Treatment D, and the lowest in Treatments A and B. Compared to the original soil, AWC only increased in Treatment D though the differences in AWC in other treatments decreased than in the first two years after reclamation.

Table 2 Changes in soil structural properties after reclamation

Treatment	MASD /%			DOA /%	CP /%	IAP /%	AWC /%
1993							
A	37.2	48.3	7.9	50	22.2	19.0	8.2
B	32.3	49.9	12.9	42	22.7	17.6	7.8
C	34.0	48.6	11.9	47	22.5	16.8	9.4
D	36.1	52.4	4.3	53	23.2	18.1	9.5
E	37.2	46.6	9.7	55	23.5	15.9	9.7
F	39.9	54.9	0.1	56	31.4	15.4	15.7
1995							
A	41.7	31.9	4.1	59	15.1^{X}	25.8^{X}	6.8^{X}
B	48.5	33.4	6.5	54	17.3	24.9	6.8
C	44.0	34.6	4.7	61	22.5	20.2	7.8
D	41.3	33.0	5.6	60	17.0	23.1	9.0
E	45.4	30.7	5.6	63	22.6	19.1	7.9
F	37.3	42.4	0.0	55	20.3	23.5	8.9

X Data were measured at the depth of 20 cm to 40 cm.

MASD = micro aggregate size distribution; DOA = degree of aggregation;
CP = capillary porosity (30 μm—0.02 μm); IAP = inactive porosity (<0.02μm);
AWC = available water capacity (at 30 kPa to 1,500 kPa).

4 Soil erosion after restoration of vegetation

A long-term experimental plots were set up on a seriously eroded gully with C horizon exposed since 1987. A stand of 562.5 m^2 (Plot I) was replanted with local species, such as *Lespedeza bicolour, Castanopsis sclerophylla, Cinnamomum porrectum and Camptotheaca acuminata* while another area of 146.3 m^2 (Plot II) was protected as control while (Yang *et al*., 1994). On the gentle slopes, the seeds of *Lespedeza bicolor* (75 kg • ha^{-1}) were sowed into furrows ploughed along the contour lines. The furrows were 10 cm deep and spaced 40 cm apart. 450 kg • ha^{-1} —600 kg • ha^{-1} of calcium magnesium phosphate was strewn into the furrows before they were then filled up with soil. On the steep slopes, delve planting rather than furrow planting was applied in order to avoid loosening the soil. The delves were 15 cm in diameter, about 40 cm deep and spaced 45 cm apart. 10 mg • kg^{-1}—20 mg • kg^{-1} of P_2O_5 and organic matter like rice chaff were mixed into the dugout soil. The delves were filled with this soil mixture until 10 cm below ground. 10—20 seeds of Lespedeza bicolor were then sowed into each of the delves.

The cumulative annual runoff ranged from 56 mm to 291 mm on Plot I and from 303 mm to 1,056 mm on Plot II (Figure 3). Thus cumulative annual runoff was 2.1 to 9.8 times higher on Plot II than on Plot I. The higher the annual rainfall, the greater the difference in runoff between the two plots. In the years with rainfall below average of 2,016 mm, the annual runoff coefficient ranged from 2% to 8% for Plot I and 5% to 19% for Plot II. In the years with rainfall exceeding the average, the annual runoff coefficient ranged from 3% to 13% for Plot I, and 21% to 48% for Plot II.

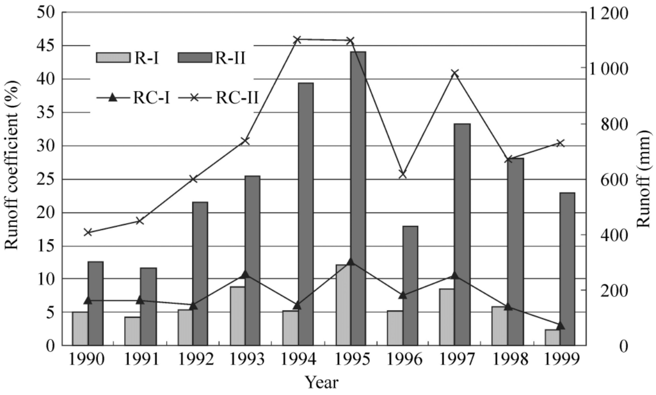


Fig.3 Runoff (R) and runoff coefficient (RC) from No. I(–I) and No. II (–II) plots

The runoff coefficient of a single rainfall event is related to rainfall amount, rainfall intensity and land use. For Plot I, the rainfall coefficient was under 40%, and in fact generally under 10% while the same coefficient ranged from 15% to 80% for Plot II.

Soil loss on Plot II was strikingly high (Figure 4), with 53.4 Mg • ha^{-1} in 1991 and 256.32 Mg • ha^{-1} in 1995. The second highest soil loss was recorded in 1992 with 223.2 Mg • ha^{-1}, the year with highest total rainfall (1998) “only” causing a soil loss of 133.9 Mg • ha^{-1}. The highest single event of soil loss on Plot I was in 1992 with 42.96 Mg • ha^{-1}, followed by 15.1 Mg • ha^{-1} in 1995.

Highest daily soil loss was 35.7 Mg • ha^{-1} on Plot II. On three occasions in 1995 and 1998, daily soil loss on Plot II was greater than 20 Mg • ha^{-1}. The high soil loss corresponded to heavy rainfall over 100 mm • d^{-1}. When daily rainfall was under 100 mm, the daily soil loss did not exceed 12 Mg • ha^{-1}. The daily average soil loss on Plot I ranged from 1.4 Mg • ha^{-1} to at most 4 Mg • ha^{-1} in 1995. Average values were below 1 Mg • ha^{-1}.

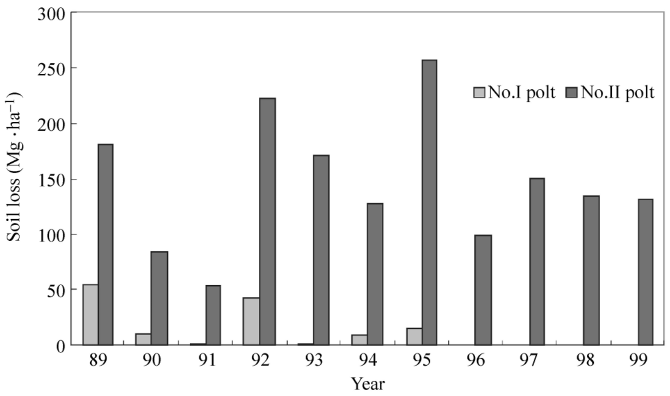


Fig.4 Cumulative soil losses by water in No. I and No. II plot and annual rainfall

On Plot II, differences between annual cumulative soil loss by suspension and deposition depended on the rainfall (Figure 5). In 1991, 1993, 1994, 1996 and 1999, when the number of rainy days were high but the total annual rainfall was average, soil loss by suspension was much lower than that by deposition. The proportion of suspension loss to deposition loss ranged between 20% and 40%. In the years where heavy rainfall lasted for several days, soil loss by both suspension and deposition was high and the proportion of suspension loss to deposition loss ranged from 51% to 56%. On Plot II, the clay (<0.002 mm), fine sand (0.1 mm—0.05 mm) and coarse silt (0.01 mm—0.05 mm) dominated in both eroded soil and sediment. Compared to the original soil, the fraction of clay in the sediment decreased by 12%, whereas fractions of fine sand and fine silt increased.

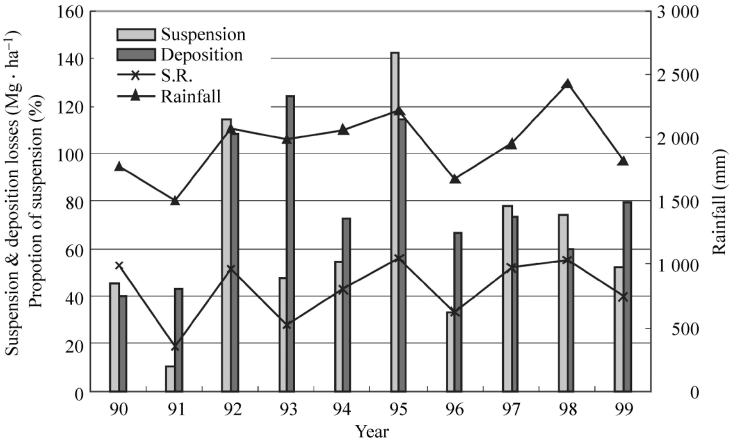


Fig.5 Cumulative soil losses by suspension and deposition and suspension ratio (S.R.) of soil losses in No. II plot with relation to annual rainfall

The ER was particularly high for available K and hydrolizable N, that is 3.11 and 2.05 respectively. Available P was not detectable in both the eroded sediment and the original soil. ER values for total N, P, K were 1.57, 1.71 and 1.40 respectively. Significantly higher values ($p < 0.01$) of CaO, MgO, Al_2O_3, and available K in runoff were found in Plot I rather than in Plot II.

In 1991, soil loss amounted to 780.7 kg (dry soil) on Plot II and cumulative runoff was around 278 mm. Runoff on Plot I in the same year totaled 95.6 mm. Calculations indicate that nutrient loss through sediment loss amounted to 3.46 kg • ha^{-1} for NO_3-N and 6.87 kg • ha^{-1} for available K on Plot II. The losses caused by runoff amounted to 7.38 kg • ha^{-1} for NO_3-N and 9.85 kg • ha^{-1} for available K. Thus runoff rather than sediment loss causes the greater nutrient loss. For Plot I, nutrient loss due to runoff was 2.82 kg • ha^{-1} for NO_3-N and 9.76 kg • ha^{-1} for available K. Consequently, total loss of NO_3-N and available K on Plot II amounted to 10.84 kg • ha^{-1} and 16.72 kg • ha^{-1} respectively, which was 3.84 and 1.71 times higher than on Plot I.

5 Conclusion

Land use changes contribute to the main causes for serious soil erosion by water. During the period of first land use change in 1950s, gully erosion took place due to the anthropogenic disturbace of surface soil by collection of fuelwood and for fertilizer in the pady fields. During the second phase of land use change in late 1980s and early 1990s, peanut was widely cropped after deforest, resulting in a large area of sheet erosion. The soil survey in the area showed that soil loss was at a rate of 12 cm—16 cm per year as accumulated at the toeslope position irrespective of the soil parent material, either from Quaternary clay or from sandstone. Selective transportation and distribution along the slope and clay lessivation in the soil profile resulted in the soil stratification in soil texture. These processes increased the environmental risks through intensified interflow.

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After restoration of the vegetation cover in the bare land soil loss due to erosion hardly happens. The complex techniques of engineering and biological measures are established for the establishment of plantation in the infertile acid soil. The new tillage techniques and the restoration of the plants not only reduce the soil erosion, but also improve soil fertility as well as the soil physical properties, which strengthen soils against soil erosion. Macro-aggregates >1 mm and plant available soil water are increased, four years after reclamation. Although seriously erosion has been retarded due to restoration and conservation of vegetation, soil erosion is still a serious form of soil degradation, accounting for 25% of the land area in the region as indicated by remote sensing images (Fu & Wan, 2000). Soil erosion by water must be considered for peanut cropping and when planning to reclaim soils or changing the land use. We are continuing the research at larger watershed scale for optimization of land use while minimizing soil erosion and its related environmental problems.

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