Assessing the Effect of Grain for Green Policy in China: How Much Soil Erosion Will Be Controlled?

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Abstract: Since 1999, the **Grain for Green** policy has been implemented in Shaanxi, Sichuan and Gansu province, China. The aim of the policy is to control the soil erosion and desertification in the ecological vulnerable regions. This research assessed the impact of the Grain for Green policy on soil erosion using universal soil loss equation (USLE) in Yanhe basin, Shaanxi province. DEM, meteorological data, GIS land cover and Landsat ETM+ data were collected to calculate soil erosion in 2000 as the start year of the policy. Then the scenarios of the reforestation over 25d, 20d and 15d sloping farmlands were produced to predict the soil loss after the policy has been fully implemented. The results indicated that if over 25d, 20d or 15d slope farmlands were reforested, the percentages of soil erosion reduction would be 1.31%, 10.29% or 24.21% compared with 2000, respectively. For further soil erosion control, it was suggested to increase the vegetation coverage and improve the supporting practices for farmlands.

Key words: Grain for Green policy, soil erosion, USLE, farmland, slope

1. Introduction

Soil erosion by water is the most important land degradation problem in the world (Eswaran et al., 2001). Loess Plateau is the most heavily soil eroded region (Wang et al., 2005), the erosion modulus above 1000 t km^{-2} y^{-1} is 287,629 km^2, and the total soil loss is over 2.2 billion t y^{-1} (Meng, 1996). As an importance source of sediment, the Loess Plateau transports 0.6 billion t y^{-1} sand, or 37.5% of the total sediment to Yellow River (Ran et al., 2000).

In order to control the soil erosion and desertification in the ecological vulnerable regions, China started the policy of Grain for Green in the beginning of 21^{st} century, through reforesting or grass-planting on sloping farmlands. The steps of the policy including:

- 1999: the Grain for Green policy was implemented in Shaanxi, Sichuan and Gansu as experimental provinces;
- 2000: Shaanxi enacted 'Measures of Grain for Green Policy: Engineering and Design in Shaanxi Province';
- 2002: the policy was expanded to 25 provinces of China;
- 2003: the 'Regulations of Grain for Green' was put in force.

According to the 'Planning of the sloping farmland reforestation engineering in Yellow River

Basin', the Grain for Green policy was divided into 3 stages: 2000-2010, 2011-2030, and 2031-2050. In recent stage (2000-2010), all farmlands on the slope over 25 degrees will convert into forest or grassland, and the reforestation will also be put in practice for the sloping farmland below 25 degrees in the latter stages (Pei et al., 2003).

Although the aim the policy it to control the soil erosion, the impact of the Grain for Green policy on soil erosion has not been assessed in the Loess Plateau. The objective of this research is to estimate the soil erosion controlled by the Grain for Green policy, using Universal Soli Loss Equation (USLE) proposed by Wischmeier and Smith (1978). First of all, the soil erosion in 2000 was calculated, as the start year of the policy. Then based on the assumption of the reforestation over 25, 20 or 15 degrees sloping farmlands, the reforested farmlands scenarios were predicted when the policy had been fully implemented. Finally, the effects of soil erosion reduction were assessed based on the scenarios.

2. Study area and data

The study area is located in the Loess Plateau, north of Shaanxi province, China. There are three watersheds in the study area, Yanhe River, Qingjianhe River and Yunyanhe River, which are the branches of Yellow River. The area of the whole basin (Yanhe basin in short) is about 18131.77 km^2, annual mean precipitation is about 480mm, mean temperature is 9~14°C, annual mean evapotranspiration is 1500~2000mm. The total sediment of Qingjianhe River, Yanhe River, and Yunyanhe River are 37.0, 49.8 and 3.1 million t y^{-1}, respectively (Ran et al., 2000).

Fig. 1 indicates the location, DEM and slope of Yanhe basin. Three main branches are marked, the upper one is Qingjianhe River, the middle one is Yanhe River, and the lower one is Yunyanhe River.

The data used in this research include:

(1) Digital Elevation Model (DEM) data

The DEM data are provided by SRTM with spatial resolution of 90m. The missing values (void) were detected and filled up by interpolation. The slope of Yanhe Basin was computed in ArcGIS™ based on DEM data (Fig. 1), and resampled to 30m resolution.

(2) Land cover map

The land cover map of 2000 was derived from classification of Landsat ETM+ (Enhanced Thematic Mapper plus) data. The primary land cover types are farmland, forest, grassland, water, urban/city and bare land. Fig 2 shows the land cover map of the study area.

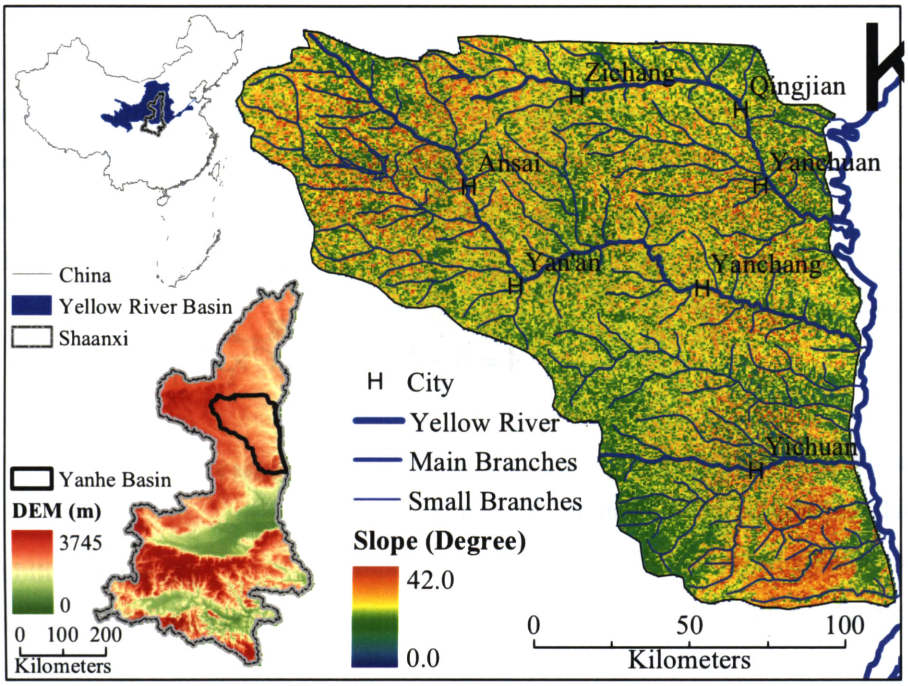

Fig.1 The location of study area

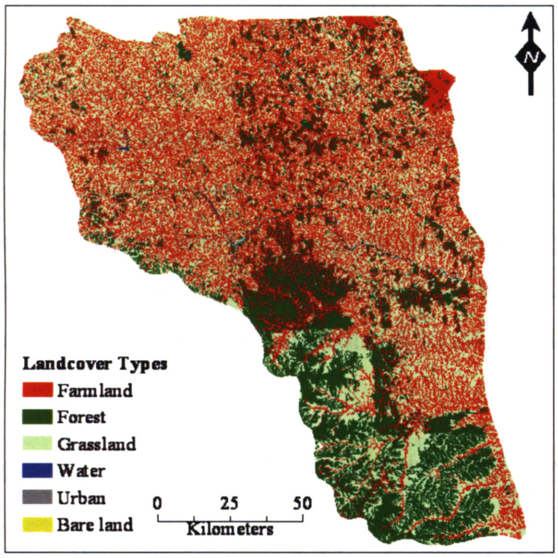

Fig. 2 Land cover map of Yanhe basin

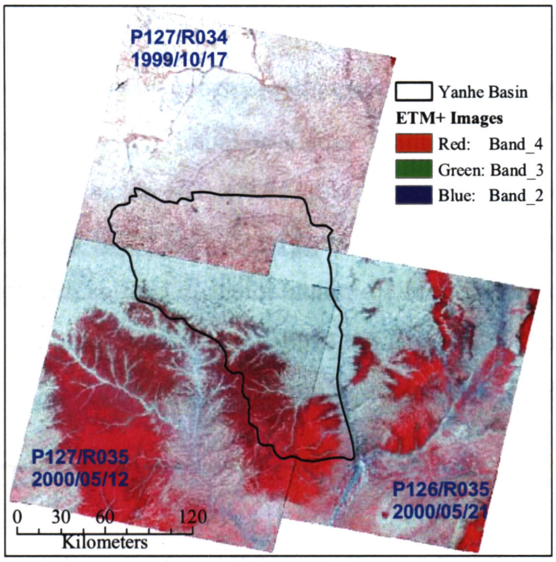

Fig. 3 Landsat ETM+ images

(3) Meteorological data

Only Yan'an station in Yanhe Basin is available. The daily rainfall data of 2000 was used for whole basin instead of interpolation by neighborhood stations, since interpolation would produce uncertain errors.

(4) Remote sensing data

Three Landsat ETM+ data were collected, one was acquired in 1999, the other two were 2000. The EMT+ data were geometrically referenced, radiometrically rectified and atmospherically corrected, and then produced reflectance images. The original spatial resolution of 28.5m was resampled to 30m. Fig 3 shows the mosaic of the three images covering the entire Yanhe basin.

3. Method

Water soil erosion is predominated by climatic characteristics, topography, soil properties, vegetation, and land management (Vrieling, 2006). The Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1978) and Revised Universal Soil Loss Equation (RUSLE, Renard et al., 1997) were developed to estimate the potential soil erosion. Both of the models were used widely in Loess Plateau (Fu, 1997; Liu et al., 1999; Zhang et al., 2004; Pan and Dong, 2006). By USLE and RUSLE, soil erosion is calculated as:

$$A = R \times K \times L \times S \times C \times P \quad (1)$$

where

A = annual soil loss (t ha^{-1} year^{-1})

R = rainfall erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1})

K = soil erodibility factor (t h MJ^{-1} mm^{-1})

L = slope length factor (unitless)

S = slope steepness factor (unitless)

C = cover and management factor (unitless)

P = conservation supporting practices factor (unitless)

3.1 Rainfall erosivity factor (*R*)

The rainfall erosivity factor (R) represents the effect of rainfall intensity on soil erosion (Wischmeier and Smith, 1978). The calculation of R-factor requires detailed and continuous rainfall data, since it is computed by the sum of the erosivity of individual storms, whose total energy (derived from maximum 30-minute intensity (I_{30})) is directly related to the erositity. However, the detailed data for each storm is not available in Yanhe basin. An alternative of R calculation was given by Arnoldus (1981), using monthly rainfall data:

$$R = \left[4.17 \times \sum_{i=1}^{12} \left(P_i^2 / P \right) \right] - 152 \quad (2)$$

where P_i is the monthly rainfall (mm) in month i, and P is the annual rainfall (mm).

The rainfall data of Yan'an in 2000 was used to represent the whole basin. The total rainfall of Yan'an in 2000 was 367.3mm. Based on Fig. 4, which indicates the monthly accumulative rainfall (excluding snow) measured at Yan'an in 2000, R equals 108.501 MJ mm ha^{-1} h^{-1} year^{-1}.

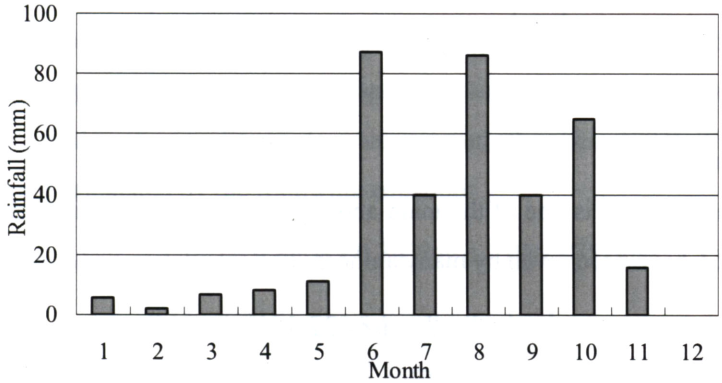

Fig. 4 Monthly rainfall data measured at Yan'an in 2000

3.2 Soil erodibility factor (*K*)

The soil eroditiliby factor (*K*) represents the long-term soil and soil profile response to the erosive power associated with rainfall and runoff. Romken (1983) gave a calculation of soil erodibility factor (*K*) as following:

$$K = 0.0034 + 0.387\exp\left(-0.5\left(\left(\log D_g + 1.5333\right)/0.7671\right)^2\right) \quad (3)$$

where D_g is the size of soil particulates. Based on the soil components measured at Ansai (Table 1, provided by Zhang et al., 2004 and Meng, 1996), the K is 0.390 t h MJ^{-1} mm^{-1}.

Table 1 The soil components measured at Ansai

Component	Percent (%)	Size (mm)
Sand	19.0	>0.05
Silt	65.2	0.005-0.05
Clay	15.8	<0.005
Organic matter	0.63	/

3.3 Slope steepness factor (*S*)

Using DEM data, the pixel slope is calculated as:

$$\theta_i = \max\left(\tan^{-1}\left(\frac{h_i - h_j}{D}\right)\right) \quad (4)$$

where θ_i (°) is the slope of the pixel i, h_i is the DEM altitude of the pixel, h_j is the j-th altitude at 8-direction neighbored to the pixel i, D is the distance between pixel i and j. In the horizontal and perpendicular directions, $D = d$ (d is the pixel size); in diagonal directions, $D = \sqrt{2}d$. The slope of Yanhe basin is shown in Fig. 1.

The slope steepness factor is calculated as (Renard et al., 1997):

$$S=\begin{cases}10.8\sin\theta+0.03 & (\theta<5.14°)\\ 16.8\sin\theta-0.50 & (\theta\geq5.14°)\end{cases} \tag{5}$$

3.4 Slope length factor (*L*)

Slope length factor (*L*) is one of the main and most variable factors in both USLE and RUSLE. The calculations of *L* have been given by many authors. The calculation provided by USLE is:

$$L=(\lambda/22.13)^{m} \tag{6}$$

where *L* is soil loss normalized to soil loss on the 22.13m long slope, λ (m) is slope length. Slope length is defined as the horizontal distance from the origin of overland flow to the point at which either the slope gradient decrease sufficiently for deposition to begin or the runoff water enters a well defined channel (Kim et al., 2005). The calculation of λ is based on the technique proposed by Ma et al. (2003). The exponent *m* was recommended as 0.2, 0.3, 0.4 and 0.5 for slope gradients less than 1%, 1-3%, 3.5-4.5%, and 0.5 or greater. RUSLE (Renard et al., 1997) also gave the calculation of the *m*, in which it would continue to increase with the slope steepness:

$$m=\beta/(1+\beta) \tag{7}$$

$$\beta=(\sin\theta/0.0896)\Big/\left(3.0(\sin\theta)^{0.8}+0.56\right) \tag{8}$$

Liu et al. (2001) discussed the steep situation (slope gradient over 9%, θ>5.14°) between USLE and RUSLE in Loess Plateau, and found even when slope gradient was 57.7% (θ=30°) in Ansai, *m* value was about 0.4. However, there seems no convinced model covering all situations in Loess Plateau, and here the RUSLE calculation was used for *L* calculation. The *SL* map is shown in Fig. 6.

3.5 Cover and management factor (*C*)

The cover and management factor (*C*) is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow land (Wischmeier and Smith, 1978). Based on land cover data of Yanhe basin (Fig. 2), all land cover types have specific *C* values according to Table 2 (Liu and Luo, 2006).

Table 2 The land cover types and their *C* values

Land cover type	Area (km^2)	Percent (%)	*C*
Farmland	6659.78	36.73	0.46
Forest	3752.28	20.70	0.005
Grassland	7643.17	42.15	/
Water	30.87	0.17	0.0
Urban	43.17	0.24	0.08
Bare land	2.50	0.01	1.0
Total	18131.77	100.0	/

In Table 2, forest has the fixed C value. However, the vegetation coverage is directly related to soil erosion. Theoretically, when vegetation coverage c is above 78.3%, there would be little erosion; when $c < 0.1\%$, there is almost no resistance to water erosion (Romken, 1983). Then the C values for forest and grassland are calculated by the following equation:

$$C_{Forest,Grassland} = 0.6508 - 0.343 \log c \quad (0<c<78.3\%) \tag{9}$$

when $c >= 78.3\%$, $C = 0$; $c <= 0.1\%$, $C = 1$. According to the land cover map, the mean coverage of forest and grassland are 56.1% and 31.0%, and then the mean C values are 0.051 and 0.139, respectively.

Using Landsat ETM+ data, the coverage of vegetation is calculated by the following equations

$$c = \frac{NDVI - NDVI_S}{NDVI_V - NDVI_S} \tag{10}$$

$$NDVI = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}} \tag{11}$$

where c is vegetation coverage, $NDVI$ is the normalized difference vegetation index derived from reflectance at near-infrared and red (R_{NIR} and R_{RED}) bands. $NDVI_S$ is the $NDVI$ value of totally bare soil, and $NDVI_V$ is the $NDVI$ of 100% covered vegetation. Based on Chen et al. (2005), $NDVI_S$=0.05 and $NDVI_V$=0.72. The Landsat EMT+ images used in this study were daily data of Oct 17, 1999, and May 12 and 21, 2000 (Fig. 3). Then the vegetation coverage calculated from these single dates would represent the usual condition of year 2000.

3.6 Conservation supporting practices factor (*P*)

The supporting practices factor (P) represents the erosion prevention practices, such as altitude cropping, strip cropping and terraced cropping. In Shaanxi province, the percent of terraced farmland is about 20.9%; sloping farmland is about 58.3% (Zhang et al., 2005). Liu and Luo (2006) provided the

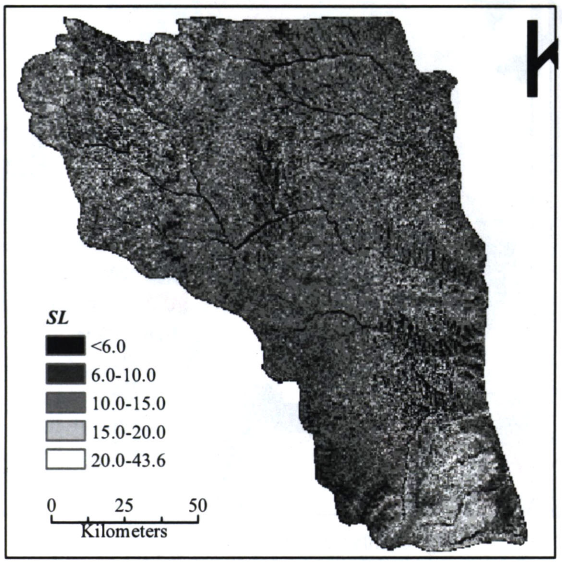

Fig. 5 *SL* map

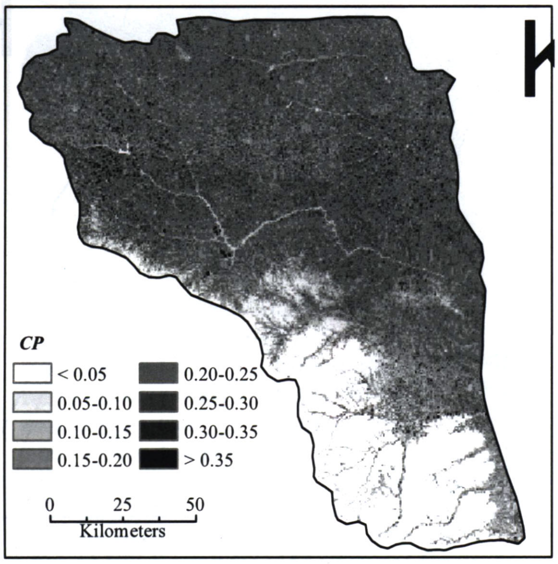

Fig. 6 *CP* map

P-factor values for supporting practices of all farmlands (Table 3). However, the distribution of all supporting practices is unknown in Yanhe basin, because it is difficult to recognize the supporting practices using 28.5m resolution remote sensing data. In this study, all farmlands used the *P*-factor values as strip farmland (for slope above 25d, *P* equals 1.0). The others land cover types, such as forest, grassland and urban, the *P* value is 1.0 since there are no supporting practices. The *CP* map of Yanhe basin is shown as Fig. 6.

Table 3 *P* values for various supporting practice factors

Slope (°)	Slope aspect farmland	Altitude farmland	**Strip farmland**	Terraced farmland
0.0–5.0	1.0	0.5	**0.3**	0.1
5.1–9.0	1.0	0.7	**0.4**	0.16
9.1–16.0	1.0	0.9	**0.5**	0.3
16.1–20.0	1.0	1.0	**0.7**	0.4
20.1–25.0	1.0	1.0	**0.9**	0.55

3.7 Scenarios of the reforested farmlands

Based on the three stages of the 'Planning of the sloping farmland reforestation engineering in Yellow River Basin', the prediction of reforested farmlands assumed that the sloping farmlands would be reforested gradually by the slope. In this study, three indices were given for the reforestation practice: > 25d, > 20d and >15d slope representing the recent stage, next stage and final aim of the Grain for Green policy, respectively. The scenarios of the reforested farmlands were produced by these three indices (Fig. 7, the scenarios of whole Yanhe basin; and Fig. 8, detailed scenarios and slope contour lines). The area of reforested farmlands for >25d, >20d and >15d scenarios are 53.43 km^2, 578.27 km^2, and 2244.73 km^2, respectively.

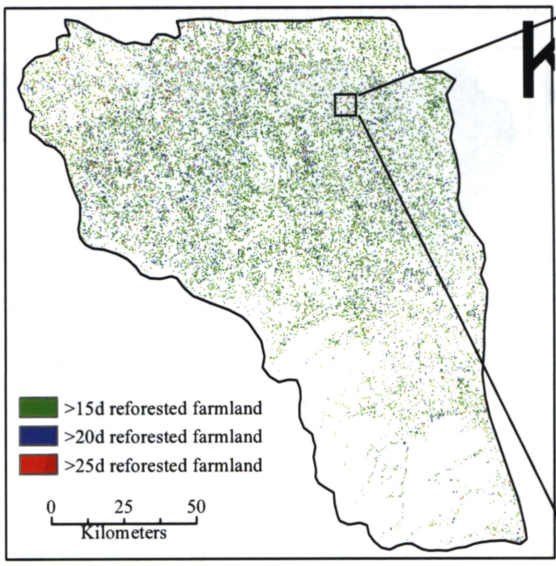

Fig. 7 Scenarios of reforested farmlands

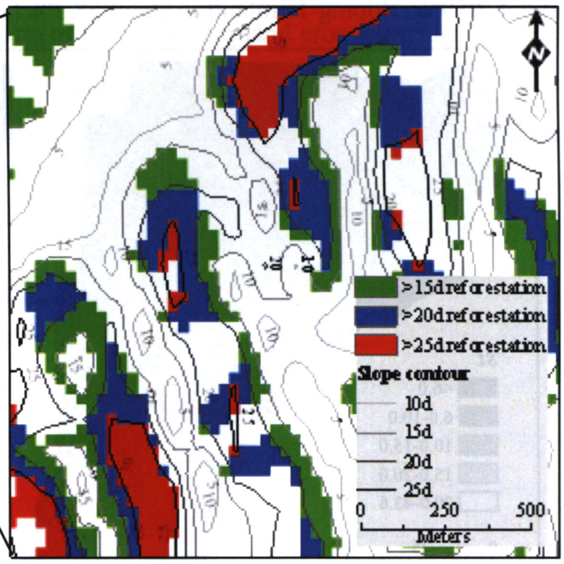

Fig. 8 Enlarged reforested farmlands

In USLE, the *R*, *K*, and *SL* factors of the scenarios are the same as 2000. The *P* values are assigned to 1.0 for reforested lands since there will be no supporting practices. The vegetation coverage of the reforested lands is set to 43.6% according to the mean coverage of the forest and grassland in 2000, since the reforested farmlands planted forest and grass 50% by 50% in Shaanxi province (Xie et al., 2002).

4. Results

Using the *R*, *K*, *SL* and *CP* factors of 2000 and three scenarios, the soil erosion maps were calculated based on USLE model. According to the criteria of soil erosion intensity provide by Chinese Ministry of Hydrology (Table 4), the computed *A* (t ha^{-1} $year^{-1}$) was converted into the erosion modulus (t km^{-2} y^{-1}). The classified results were shown in Fig. 9~12.

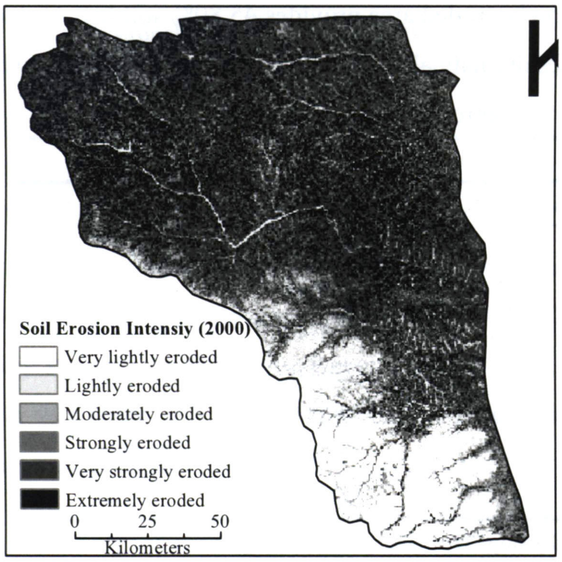

Fig. 9 USLE result 2000

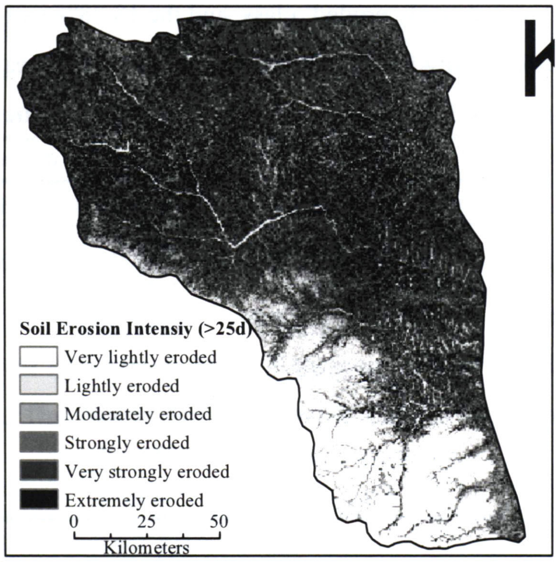

Fig. 10 USLE result for >25d reforested farmlands

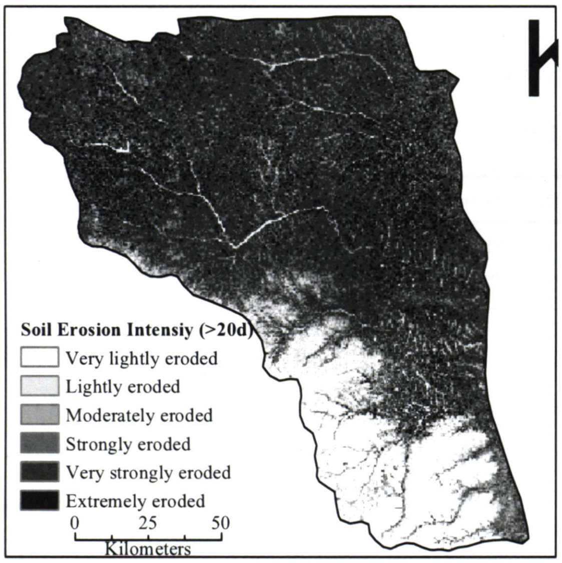

Fig. 11 USLE result for >20d reforested farmlands

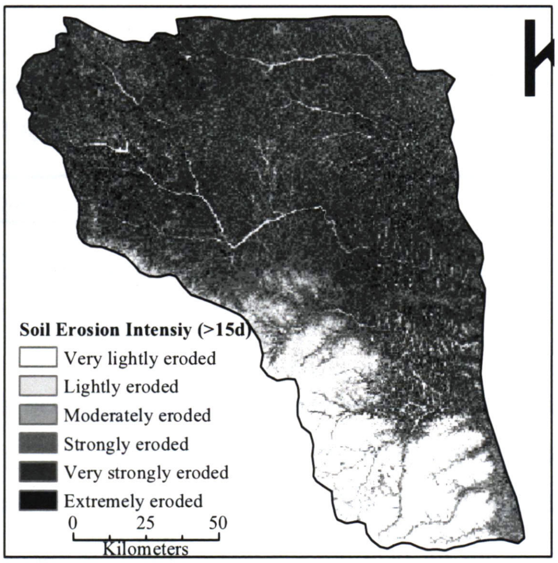

Fig. 12 USLE result for >15d reforested farmlands

Table 4 The criteria of soil erosion intensity

Degree of soil erosion	Average erosion modulus ($t\ km^{-2}\ y^{-1}$)	Average loss thickness ($mm\ y^{-1}$)
Very lightly eroded	<1000	<0.74
Lightly eroded	1000–2500	0.74–1.9
Moderately eroded	2500–5000	1.9–3.7
Strongly eroded	5000–8000	3.7–5.9
Very strongly eroded	8000–15000	5.9–11.1
Extremely eroded	>15000	>11.1

4.1 The soil erosion in 2000

The statistics of the soil erosion in 2000 were shown in Table 5~7. Mean erosion modulus is 9430.25 t km^{-2} y^{-1}, and total soil loss is 170986972 t y^{-1} in 2000 (Fig. 9). The whole Yanhe basin is in 'very strongly eroded' class, and the 18.28% extremely eroded area provides 45.80% soil loss (Table 5). For sloping farmland, the erosion modulus increases dramatically with the slope rising (Table 6), which implies the necessity of the Grain for Green policy to control soil loss in Loess Plateau.

Table 5 The degree of soil erosion of 2000

Degree of soil erosion	Soil loss($t\ y^{-1}$)	Soil loss (%)	Eroded area (km^2)	Eroded area (%)
Very lightly eroded	438752	0.26	2941.70	16.22
Lightly eroded	2000230	1.17	1158.90	6.39
Moderately eroded	9077390	5.31	2383.51	13.15
Strongly eroded	16700200	9.77	2503.60	13.81
Very strongly eroded	64463000	37.70	5829.17	32.15
Extremely eroded	78307400	45.80	3314.89	18.28
Total	170986972	100	18131.77	100

Table 6 The statistics of the slope farmlands of 2000

	0°–5°	5°–10°	10°–15°	15°–20°	20°–25°	>25°	Total
Area (km^2)	409.40	1626.53	2379.12	1666.46	524.84	53.43	6659.78
Percent in farmland (%)	6.15	24.42	35.72	25.02	7.88	0.80	100.0
Percent in total area (%)	2.26	8.97	13.12	9.19	2.89	0.29	36.73
Mean erosion modulus ($t\ km^{-2}\ y^{-1}$)	891.6	4552.3	10107.7	20215.2	37169.6	52069.2	/

Table 7 The land cover types and their mean erosion modulus of 2000

Land cover type	Mean erosion modulus ($t\ km^{-2}\ y^{-1}$)
Farmland	13182.8
Forest	4451.6
Grassland	8674.3
Water	0.0
Urban	2086.7
Bare land	39774.0

4.2 Scenario of >25d

For the scenario of over 25d slope farmlands being reforested, the mean erosion modulus is 9306.31 t km^{-2} y^{-1}, and total soil loss is 168739772 t y^{-1} (Fig. 10). The whole Yanhe basin is in 'very strongly eroded' class. Compared with 2000, soil loss reduces by 1.31%; versus the farmlands over 25d slope is 0.29% in the whole Yanhe basin. The statistics of soil erosion map for the >25d scenario are shown in Table 8.

Table 8 The degree of soil erosion of >25d reforestation scenario

Degree of soil erosion	Soil loss(t y^{-1})	Soil loss (%)	Eroded area (km^2)	Eroded area (%)
Very lightly eroded	438752	0.26	2941.70	16.22
Lightly eroded	2000230	1.19	1158.90	6.39
Moderately eroded	9077390	5.38	2383.51	13.15
Strongly eroded	16700200	9.90	2503.60	13.81
Very strongly eroded	64998000	38.52	5882.60	32.44
Extremely eroded	75525200	44.76	3261.46	17.99
Total	168739772	100	18131.77	100

4.3 Scenario of >20d

For the scenario of over 20d slope farmlands being reforested, the mean erosion modulus is 8460.29 t km^{-2} y^{-1}, and total soil loss is 153400072 t y^{-1} (Fig. 11). The whole Yanhe basin is still in 'very strongly eroded' class. Compared with 2000, soil loss reduces by 10.29%; versus the farmlands over 20d slope is 3.18% in the whole Yanhe basin. The statistics of soil erosion map for the >20d scenario are shown in Table 9.

Table 9 The degree of soil erosion of predicted >20d reforestation

Degree of soil erosion	Soil loss(t y^{-1})	Soil loss (%)	Eroded area (km^2)	Eroded area (%)
Very lightly eroded	438752	0.29	2941.70	16.22
Lightly eroded	2000230	1.30	1158.90	6.39
Moderately eroded	9077390	5.92	2383.51	13.15
Strongly eroded	19052500	12.42	2815.64	15.53
Very strongly eroded	66813900	43.56	6095.40	33.62
Extremely eroded	56017300	36.52	2736.62	15.09
Total	153400072	100	18131.77	100

4.4 Scenario of >15d

For the scenario of over 15d slope farmlands being reforested, the mean erosion modulus is 7147.29 t km^{-2} y^{-1}, and total soil loss is 129593062 t y^{-1} (Fig. 12). The whole Yanhe basin will upgrade into 'strongly eroded' class. Compared with 2000, soil loss reduces by 24.21%; versus the farmlands over 15d slope is 12.37% in the whole Yanhe basin. The statistics of soil erosion map for the >15d scenario are shown in Table 10.

Table 10 The degree of soil erosion of predicted >15d reforestation

Degree of soil erosion	Soil loss(t y^{-1})	Soil loss (%)	Eroded area (km^2)	Eroded area (%)
Very lightly eroded	438752	0.34	2941.70	16.22
Lightly eroded	2000230	1.54	1158.90	6.39
Moderately eroded	9247280	7.14	2417.61	13.33
Strongly eroded	28763400	22.20	4448.00	24.53
Very strongly eroded	61112400	47.16	5672.12	31.28
Extremely eroded	28031000	21.63	1493.44	8.24
Total	129593062	100	18131.77	100

5. Discussion and conclusion

This research assessed the impact of 'Grain for Green' policy of China on the soil erosion control. Using DEM, land cover, meteorological data and remote sensing data, the soil erosion map of Yanhe basin was calculated as the start year of the policy based on USLE model. The soil erosion modulus is about 9430.25 t km^{-2} y^{-1}, and the whole basin is in 'very strongly eroded' class in 2000. According to Ran et al. (2000), the erosion modulus around Yanchuan and Ansai are over 10000 t km^{-2} y^{-1}, along Yanhe river, the modulus is over 5000 t km^{-2} y^{-1}, and in Yunyanhe river watershed, the modulus is between 1000~5000 t km^{-2} y^{-1}. It proved that the USLE calculation in this research is quite reasonable.

Based on the stages of the policy implementation, three scenarios were produced, assuming >25d, >20d and >15d sloping farmlands would have been reforested gradually. Then the soil erosion value was estimated for each scenario. The results indicated that when >25d sloping farmlands were reforested, the total soil loss would reduce by 1.31%. Such little improvement might due to the low percent of >25d sloping farmlands (0.29%). If >20d sloping farmlands were reforested, the total soil loss would reduce by 10.29%, but the whole Yanhe basin would still be in 'very strongly eroded' class. Once >15d sloping farmlands were reforested, the total soil loss would decrease by 24.21%, and the whole basin would upgrade to 'strongly eroded' class. The assessment suggested that if only reforestation over 25d sloping farmlands, the effect of soil loss control would be unsatisfied; when over 15d sloping farmlands were reforested, the soil loss would be controlled effectively.

However, even if all the farmlands over 15d slope were reforested, the soil erosion in Yanhe basin would still be very heavy. In the USLE model, the only factors could be altered are C and P. Besides the Grain for Green policy, it is suggested to increase the vegetation coverage and improve the supporting practices for farmlands (terraced field engineering instead of strip farmlands) for further soil erosion reduction in Loess Plateau region.

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