4

Losses of Soil and Nutrients from a Purplish Soil on Slopping Lands as Affected by Rain Intensity and Farming Practices

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1. Introduction

Increasingly aggravated nonpoint source pollution resulting from intensified farming activities has drawn wide concerns from the society (Quan et al., 2002; Zhu et al., 2005). Among the farming activities, overdose of chemical fertilizers is blamed the most. Sichuan Basin, home of the so-called purplish soil, is one of major grain production basis in China where farming on sloping lands is prevailing and intensive. The purplish soil, a unique soil type developed from an array of easily-weathering purplish parent materials, widely spreads in the basin and dominantly forms the sloping lands. The soil is usually characterized with low contents of organic matter and plant nutrients with poor structure, course texture, high saturated infiltration rate, low conserving ability of soil moisture and nutrients and thus, is very erosive, resulting in shallow top soil layers of less than 20-30 cm lying directly on the underneath parent materials. During rainstorms, the soil is easily saturated with rain water and then quickly forms runoffs discharging into ground waters with rich nutrients, nitrogen (N) and phosphorus (P) in particularly (Zhang, 1992). This has put great pressure on the widespread water eutrophication.

Previous studies documented in literature have well addressed the patterns of soil erosion and surface runoff with which how and how much soil nutrients are lost from the sloping lands. Most of the research was focused on N loss in surface runoff from farmlands (Hamsen and Djurhuus, 1996; Cookson et al., 2000; Havis and Alberts, 1993; Torstensson and Aronsson, 2000; Bergström and Kirchmann, 1999), in subsurface runoff from uplands induced by rains and/or irrigation in north China (Wang et al., 2005; Wang et al., 2006), from paddy fields (Yu et al., 1999; Wang et al., 1996; Wang et al., 1999) and from uplands of the red soil regions (Sun et al., 2003; Ji et al., 2006) in southern China. The factors considered in the related literature included climate (rainfalls, rain intensity, and so on), soil property, land use, etc., under artificial rains impacting on bare soils to study the patterns of nutrient losses (Fu et al., 2003; Kang et al., 2003; Ma et al., 2002). Nevertheless, the workers seldom considered the total nutrient losses from both surface runoff and subsurface runoff in one study but more often in a separate way. There is little, if any, information available on cultivation practices, fertilizer techniques such as fertilizer source, rate, timing and placement affecting nutrient losses from farmlands.

Therefore, the objectives of the field studies were to investigate effects of different rain intensity, fertilizer rates and placement, cultivation practices, mulch materials and its interaction with cultivation practices on amounts of soil erosion, amounts and pathways of nutrient losses during corn growing season from a purple soil on a sloping land in the Sichuan basin.

2. Materials and methods

The ongoing field experiments, initiated in 2007, are located in Songtao town, Ziyang city, Sichuan province of China, the upper reaches of Tuo River, one of major branches of Yangtze River, lying between E104°34′12″-104°35′19″ and N30°05′12″-30°06′44″. The area is hilly with an elevation of 395 m above sea level, enjoying subtropical climate with an annual precipitation of 965.8 mm of which 70% is distributed from June to September. The annual average temperature was 16.8 ^{0}C ranging from the low of -3.6 ^{0}C to the high of 36.5 ^{0}C. The soil was a light textured purplish sandy soil and contained 5.1 g/kg organic matter, 0.56 g/kg of total N, 54.5 mg/kg of hydrolysable N, 0.94 g/kg of total P, 6.26 mg/kg of Olsen P, 13.8 g/kg of total potassium (K), and 97.3 mg/kg of ammonium acetate extractable K.
The experiment consisted of nine treatments and three replications, and was conducted in summer by growing corn and followed by winter wheat without fertilizers to homogenize the soil fertility for the next summer experiment. From 2007 to 2010, effects of different cultivation practices, rain intensities, fertilizer placement and interaction of cultivation practices and mulch materials on soil erosion, water runoff and nutrient losses from the sloping lands were studied. The first three experiments were carried out under artificial rainfalls with different intensities, and the fourth one was completely rain-fed. According to the local weather data, the maximum rain intensity in the region was 93.0 mm/h and 30.3 mm/10 min, an incidence of 3.7 rainfalls at 50-100 mm/h annually. Thus, the artificial rain intensities in this study were selected as 0.972, 1.741 and 2.255 mm/min up to 60 mm per rain event and lasted for 61.7, 34.5 and 26.6 min, respectively. During each rain event, no matter where the rain came from, artificial or natural, the surface runoff water, the eroded sediment, the subsurface runoff or seepage water were collected separately. The dry weight of sediment, and nutrients including N, P and K that were contained in the sediment, the surface runoff and the subsurface runoff water were analyzed.
The cultivation methods used in study were selected as down slope ridge cultivation, flat cultivation, contour ridge cultivation and strip cultivation. The first three were the recommended soil conservation practices for the local farmers. The strip cultivation, also a soil conservation technique, was in trial phase. Crop straw and plastic film are two commonly used mulch materials in the region, but the latter is more often used to keep soil moisture from surface evaporation under dry conditions and to raise soil temperatures in early growing seasons of crops. In the experiment examining interactive effects of mulch materials and cultivation methods on soil conservation and nutrient losses, they were combined into five treatments including down slope ridge cultivation + straw, flat cultivation + straw, contour ridge cultivation + straw, down slope ridge cultivation + plastic film and contour ridge cultivation + plastic film.
There were two N rates (300 and 450 kg N/ha), two K rates (0 and 150 kg K_2O/ha) and one P rate (150 kg P_2O_5/ha), consisting of three fertilizer treatments designated as N_1K_0 (farmers' practice), N_1K_1 (balanced fertilization), and N_2K_1(high N). Since P rate was the same in all the treatments, it did not appear in the treatment symbols. The N fertilizer used as urea (N 46%), P fertilizer as single superphosphate (P_2O_5 12%) and K fertilizer as KCl

(K_2O 60%). All P fertilizer was used once at seeding as basal application; K fertilizer was split into 50% at seeding as basal application and 50% before corn earing stage as top dressings; N fertilizer was split into four times, 10% as basal application at seeding, two 20% at seedling stage and 50% before earing stage as top dressings. In the fertilizer placement experiment, there was water irrigation after each top dressing in one fertilizer splitting treatment and without water irrigation in the other to compare effect of irrigation on corn yield and on soil erosion and nutrient losses.
The corn (*Zea mays*) cultivar in the study was Chengdan 18, obtained from the Crop Institute, Sichuan Academy of Agricultural Sciences. The corn, with a plant population of 42000 plants/ha, was usually seeded in early April and harvested in later July.

3. Results and discussion

3.1 Effect of rain intensity on soil, water and nutrient losses from the purplish soil

Rain intensity, empowering raindrops erosive forces, determines quantity or severity of soil erosion (Foster et al., 1985). This is clearly shown in Fig.1 that the average amounts of water runoff and sediment yield under a heavy rain (2.255 mm/min) were 2.2 and 1.3 folds of those under a medium rain (1.741 mm/min), and 74 and 72 folds of those under a small rain (0.972 mm/min), respectively. The subsurface runoff generated by heavy rain events was measured as 6.0 mm, 90% of medium rain events and 86% of small rains events, reflecting a negative correlation between subsurface runoff and rain intensity. This negative correlation can be attributed to the fact that it takes a longer time for rain water to infiltrate into the soil depth during a small rain event than during a large rain event. Also, heavy rains usually produce much greater surface runoff than small rains. As the rain intensity increased, the total runoff coefficient increased from 0.15 to greater than 0.5 at which surface runoff became dominated. The maximum amount of subsurface runoff accounted for only about one-third of the surface runoff.

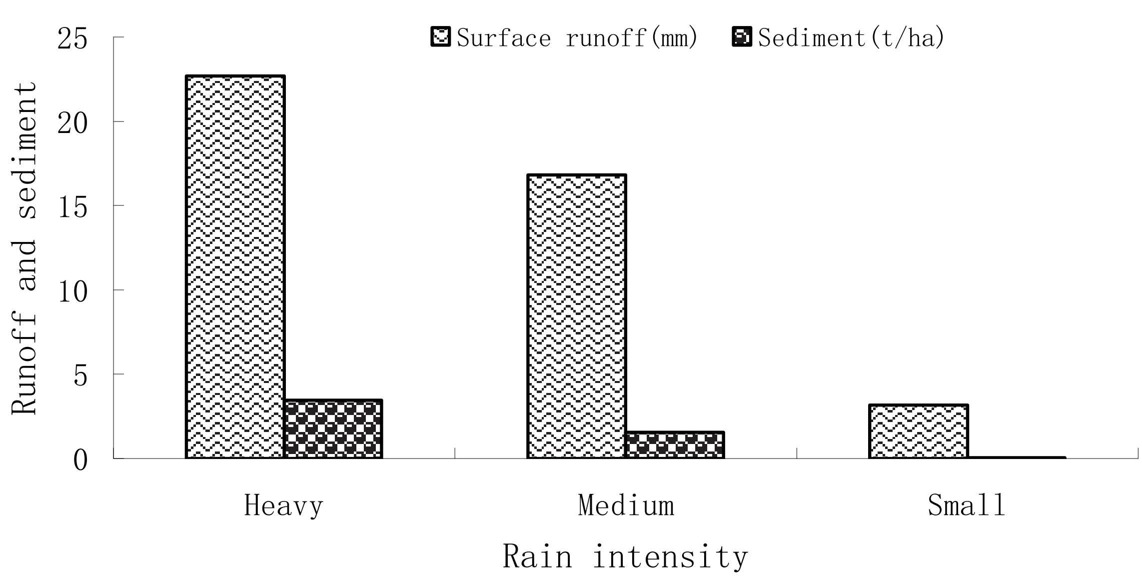

Fig. 1. Influence of rain intensity on amounts of runoff and sediment yield

The total losses of soil N and P from the soil were closely related to rain intensity, while their soluble portions (readily available forms) varied and highly nutrients specific (Table 1). Though P removal from the soil through runoff water tended to be rain intensity dependent, this portion was minor compared to its total loss. The majority of lost P was removed with sediment (often >90%) due to its nature in soil that it is always tightly adsorbed/fixed by the soil particles/colloids. Thus, the extent of P loss paralleled with the yield of sediment generated. The principal pathway of N lost from soil was just opposite to P, i.e., mainly

Rain intensity	Surface runoff		Subsurface runoff		Sediment		Total	
	N	P	N	P	N	P	N	P
Heavy	0.81	0.03	2.68	0.01	1.80	3.18	5.29	3.21
Medium	0.32	0.01	2.87	0.01	0.90	1.48	4.09	1.50
Small	0.04	0.00	3.66	0.00	0.03	0.04	3.73	0.04

Table 1. Amounts (kg/ha) and pathways of N and P losses as affected by rain intensity

through runoff rather than through the sediment. Amounts of N lost were increased with a decrease in rain intensity and found its way into the subsurface runoff. It is suggested that the best method to control soil N loss by rains is to control water runoff, especially for subsurface runoff, while for P it is best to control soil erosion.

3.2 Different cultivation practices on soil, water and nutrient losses from the purplish soil

Among three types of commonly used cultivation practices (flat, down slope ridge and contour ridge cultivation) on sloping lands in the southwest China, the flat cultivation caused the most serious soil erosion and water losses (Table 2). Runoff water from the flat cultivation was 1.8 folds of that produced by the down slope cultivation and 25 folds of that by the contour ridge cultivation. The amount of soil eroded from the flat cultivation was 1.9 folds of that by the down slope cultivation in contrast to nil from the contour ridge cultivation during a small rain. The susceptibility of the flat cultivation to form surface runoff may be resulted from the soil characteristics of easy encrustation under direct raindrops striking. The encrustation on soil surface restricted rain water infiltration into soil depths and eventually generated surface runoff. Compared to the flat cultivation, the contour ridge cultivation performed best in control of soil erosion under any rain intensities, but excellently controlled water runoff only under small to medium rain intensities. Under heavy rains, however, the contour ridge cultivation behaved slightly better than the down slope cultivation in reducing water runoff by 2.5%.

Since runoff and sediment are actually the carriers responsible for nutrients migrating out from soil in a rain event, they both determine the amounts and pathways of nutrient losses (Table 2). Among three cultivation practices, the flat cultivation resulted in the highest amount of P loss through the increased sediment loss, while the contour cultivation most effectively lowered P loss via reduction of sediment loss. Amount of N loss from the soil, however, was the least from the down slope cultivation because it facilitated surface runoff and impeded water infiltration to leach soil N from the profile. The results imply that the contour ridge cultivation was highly effective in controlling soil erosion but less effective in reducing N leaching from the purplish soil like playing seesaw.

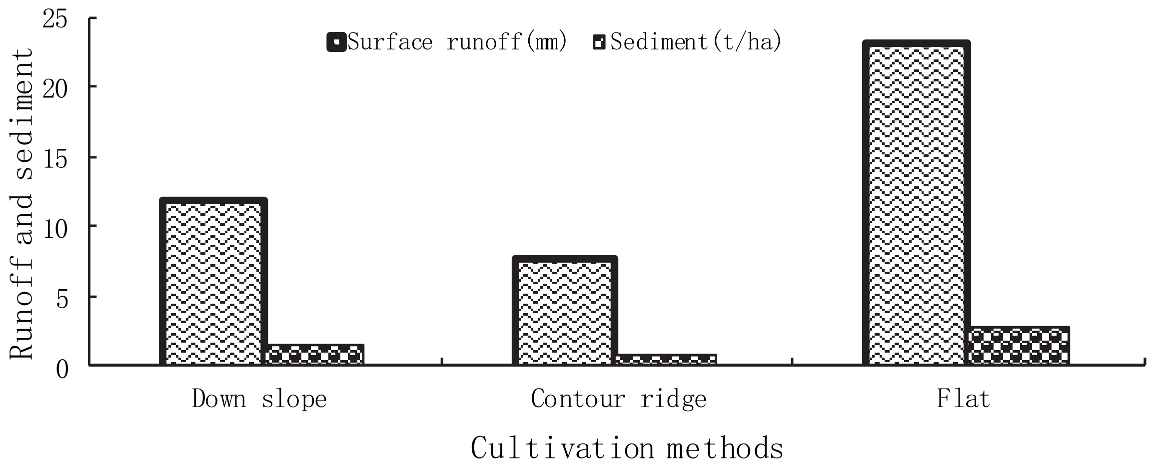

Fig. 2. Amounts of runoff and sediment yield as affected by cultivation methods

Cultivation	Surface runoff		Subsurface runoff		Sediment		Total	
Down slope	0.24	0.01	2.89	0.00	0.84	1.46	3.97	1.47
Contour	0.26	0.01	3.63	0.01	0.45	0.80	4.34	0.81
Flat	0.66	0.02	2.70	0.00	1.43	2.43	4.80	2.45

Table 2. Amounts (kg/ha) of N and P losses through different pathways as affected by cultivation practices

3.3 Effect of balanced fertilization on soil, water and nutrient losses from the purplish soil

Different combinations of N and K fertilizers based on the same P rate had remarkable effect on soil, water and nutrient losses from the purplish soil (Table 3). If K was omitted from the fertilizer treatment, water runoffs and soil erosion, when measurable, from the minus K treatment were always significantly higher than those from the other two treatments under small to medium rain intensities. During a heavy rain event, the N_1K_0 treatment produced equivalent amounts of water runoffs and soil sediment to N_1K_1 treatment, which were significantly higher in the surface runoff and the sediment and lesser in the subsurface runoff than the N_2K_1 treatment. Averaging the data generated from the three rain intensities, the overall runoff coefficient was o.41 for N_1K_0, 0.30 for N_1K_1 and 0.28 for N_2K_1 treatment. The results proved that balanced fertilization with addition of K could considerably reduce water runoff and soil erosion due to the fact that addition of K improved corn growth and land cover which in turn reduced the raindrops impact on soil surface, impeding soil encrustation, increasing water percolation and eventually minimizing total runoff and soil erosion.

Rain intensity	Fertilizer[1]	Surface runoff	Subsurface runoff	Total runoff	Sediment
		------------------------mm----------------------------			t/ha
Small	N_1K_0	0.00	15.00	15.00	0.00
	N_1K_1	0.00	10.04	10.04	0.00
	N_2K_1	0.00	10.69	10.69	0.00
Medium	N_1K_0	15.48	15.21	30.69	63.39
	N_1K_1	2.89	13.59	16.48	12.32
	N_2K_1	5.99	14.87	20.86	16.66
Heavy	N_1K_0	19.8	7.76	27.55	72.09
	N_1K_1	19.25	6.34	25.59	72.74
	N_2K_1	10.66	10.58	21.24	22.54

[1] There were two rates of N applied, 300 and 450 kg N/ha as referred to N_1 and N_2; two rates of K fertilizer applied, 0 and 150 kg K_2O/ha as referred to K_0 and K_1; the rate of P was 150 kg P_2O_5/ha for all treatments. The same applies to Table 4 and Table 5.

Table 3. Amounts of runoff and soil erosion through different pathways as affected by rain intensity

Rain intensity	Fertilizer	Runoff N (kg/ha)			Sediment N (kg/ha)		Total loss
		Surface	Subsurface	Subtotal	Subtotal	Available	
Small	N_1K_0	0.00	7.54	7.54	0.00	0.00	7.54
	N_1K_1	0.00	7.29	7.29	0.00	0.00	7.29
	N_2K_1	0.00	8.07	8.07	0.00	0.00	8.07
Medium	N_1K_0	0.52	7.06	7.58	0.43	0.03	8.00
	N_1K_1	0.08	5.82	5.90	0.09	0.01	5.99
	N_2K_1	0.11	8.57	8.68	0.11	0.01	8.79
Heavy	N_1K_0	0.40	7.68	8.08	0.54	0.03	8.62
	N_1K_1	0.25	6.28	6.53	0.27	0.04	6.81
	N_2K_1	0.61	8.16	8.77	0.26	0.02	9.03

Table 4. Amounts of N loss through different pathways as affected by rain intensity and fertilization

Different combinations of N and K fertilizers affected N loss from surface runoff, subsurface runoff, total runoff in an order of balanced fertilization (N_1K_1)< farmers' practice (N_1K_0) < high N rate (N_2K_1) (Table 4). The runoff N from the balanced fertilizer treatment was less or significantly less than from the other two treatments under any rain intensity when there was any runoff generated, illustrating that balanced fertilization was able to effectively reduce N loss through runoffs while high N rate intensified its loss. The total N carried away with the sediment in the balanced fertilizer treatment tended to be much lower than in the other two treatments in a medium or heavy rain event. As a whole, the N lost with the sediment was increased with an increase in rain intensity.

The average amount of N loss from different treatments and rain intensities was measured as 7.6 kg N/ha, equivalent to 2.5% of N applied to the corn field, among which the subsurface runoff N dominated, accounting for 88.3%-100% dependent on rain intensity. N loss through the rest pathways was relatively minor (<12%).

The main pathway of P loss in a rain event was somewhat different from N. Since P loss was mainly carried away by sediment, a small rain event that produced little or no sediment yield did not pose much risk to P loss (Table 5).

Rain intensity	Fertilizer	Runoff P (kg/ha)			Sediment P (kg/ha)		Total loss
		Surface	Subsurface	Subtotal	Subtotal	Available	
Small	N_1K_0	0.000	0.005	0.005	0.00	0.000	0.005
	N_1K_1	0.000	0.004	0.004	0.00	0.000	0.004
	N_2K_1	0.000	0.010	0.010	0.00	0.000	0.010
Medium	N_1K_0	0.013	0.010	0.023	0.68	0.005	0.699
	N_1K_1	0.002	0.007	0.009	0.13	0.001	0.139
	N_2K_1	0.004	0.011	0.014	0.17	0.001	0.184
Heavy	N_1K_0	0.013	0.005	0.018	0.73	0.006	0.745
	N_1K_1	0.005	0.007	0.013	0.44	0.002	0.456
	N_2K_1	0.012	0.004	0.016	0.34	0.003	0.359

Table 5. Amounts of P loss through different pathways as affected by rain intensity and fertilization

In a medium rain event, amounts of surface runoff P and sediment P were in an order of farmers' practice > high N rate > balanced fertilization; while in a heavy rain event, it was shifted to farmers' practice > balanced fertilization > high N rate. Addition of K effectively reduced P loss.

As shown in Table 6, loss of K from soil was increased with an increase in rain intensity. In a small rain event, there was no surface runoff K because of no surface runoff, but all the K lost went through the subsurface leaching. The balanced fertilizer treatment (N_1K_1) significantly reduced amount of K leached out compared to the minus K treatment (N_1K_0), but further increased N rate did not help reduce K leaching. In a medium rain event, addition of K significantly reduced K loss from both surface runoff and sediment but only slightly reduced K loss from the subsurface leaching. The overall effect of K fertilization on preserving soil K pool against its loss was excellent in medium rains. In a heavy rain event, however, the balanced fertilization treatment only slightly lowered K loss compared to the minus K treatment while increased N rate behaved much better.

Rain intensity	Fertilizer	Runoff K (kg/ha)			Sediment K (kg/ha)		Total loss
		Surface	Subsurface	Subtotal	Subtotal	Available	
Small	N_1K_0	0.00	0.777	0.78	0.00	0.00	0.78
	N_1K_1	0.00	0.397	0.40	0.00	0.00	0.4
	N_2K_1	0.00	0.717	0.72	0.00	0.00	0.72
Medium	N_1K_0	0.79	0.82	1.61	12.56	0.09	14.17
	N_1K_1	0.27	0.647	0.92	2.49	0.02	3.41
	N_2K_1	0.33	0.79	1.12	3.51	0.03	4.63
Heavy	N_1K_0	0.86	0.427	1.29	15.40	0.12	16.69
	N_1K_1	0.60	0.487	1.08	14.03	0.05	15.11
	N_2K_1	0.67	0.403	1.07	7.29	0.07	8.36

Table 6. Amounts of K loss through different pathways as affected by rain intensity and fertilization

Similar to N and P, the pathways of K lost from the soil were through surface runoff, subsurface leaching and eroded sediment. When there was no surface runoff such as in small rains, subsurface runoff or leaching was the only way for K removal from soil. As long as there was surface runoff generated, K could be removed through both runoff and leaching. The partitioning of K in the water phase of runoffs and the solid phase of eroded sediment was highly dependent on rain intensity, land cover, soil property, the size of soil readily available K pool serving both crop growth and leaching. In this study, the soil available K lost in medium to heavy rain events accounted for 7%-27% of total K loss, which was very comparable to what was observed in the common fields (Meng, 2007). This indicated that most of K was lost through soil sediment, accounting for 73% - 93%. Yet, the soil available K removed by the sediment was very low, only 0.02-0.12 kg/ha or 0.4%-1.0% of its total loss. This may be a result of extraction of available K from the sediment by rain water and then dissolving into runoff water which was evidenced by much higher K measured in the surface runoff (Table 6).

3.4 Effect of fertilizer placement on soil, water and nutrient losses from purplish soil

There were three methods of fertilizer placement employed in this study, one time application of all fertilizers at seeding, a splitting application that incorporated all P, K and 10% of total N in to soil at seeding, and top-dressing of remaining N twice (20% and 20%) at seedling development and once (50%) before earring stage, of which one treatment coupled with water irrigation after top-dressing and the other treatment without irrigation. From the field observation and measurement, the N contained in the surface runoff was affected by the fertilizer placement to a rather small extent, especially at later stage of corn growth (Fig. 3). The two types of splitting fertilizer applications were always better than one time application in reducing N loss though surface runoff at early corn growing stages. The splitting application coupled with water irrigation could further reduce N loss through surface runoff except one measurement that was caused by a heavy rain right after fertilization. Owing to high N loss (averaged as 3.68mg/kg in surface runoff and 31.74 mg/kg in the leachate) from the plot of one time application, the corn plant suffered from N deficiency at later growing stages and yield loss (data not shown). Thus, one time N application, despite its simplification, is a highly risky practice that sacrifices for environment, crop yield and economic returns.

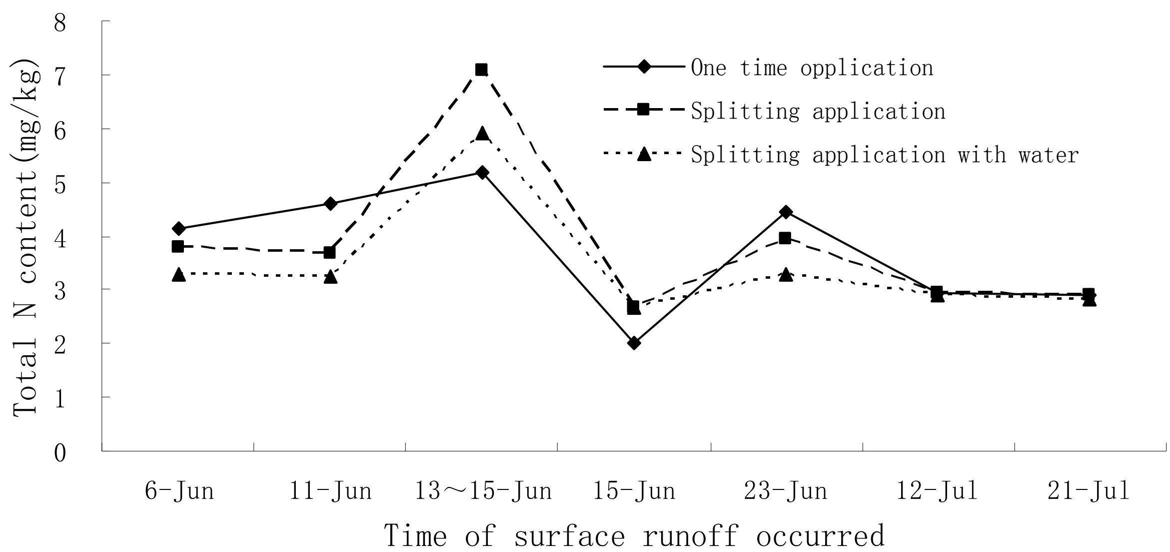

Fig. 3. Total N concentrations in surface runoff as affected by fertilizer placement and time

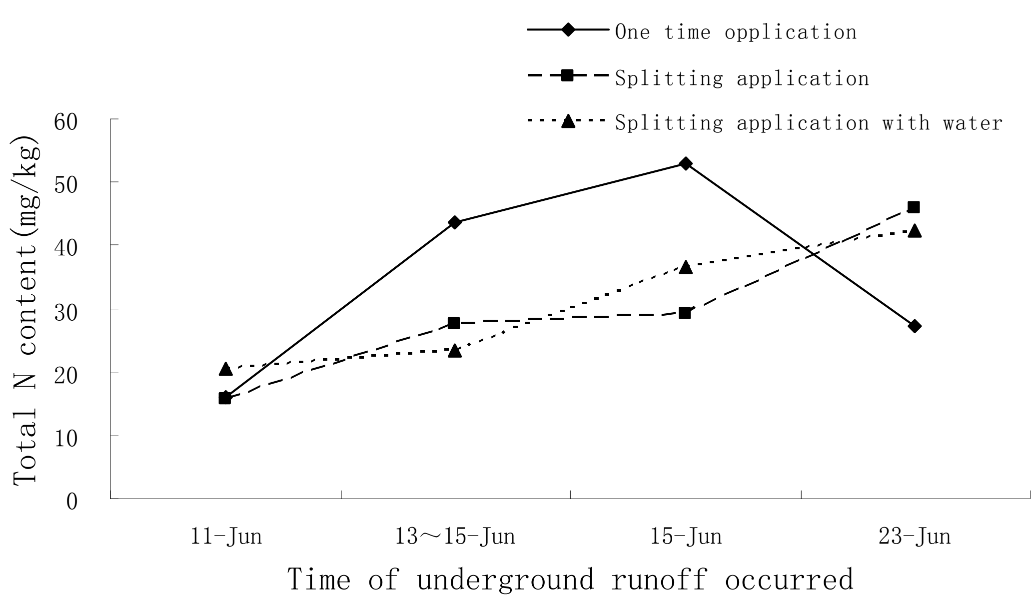

Fig. 4. Total N concentrations through leaching as affected by fertilizer placement and time

P loss from the soil showed an opposite pattern from N that their peaks and troughs were just reversely matched. This can be attributed to the fact that as described above, N loss was mainly though runoffs, especially though leaching, while P loss was mainly through sediment loss. Thus, if a rain event can produce high surface runoff, the subsurface runoff or leaching water from this rain event must be low. Most of P loss was observed in the early to middle growing stages of corn but fluctuated sharply as rain intensity changed (Fig. 5). In the later stage, the loss of P from the soil leveled off as no heavy rains occurred during that period of time. Unlike the sediment P, the P in the leaching water was diminishing with advances of growing season, a reflection of freshly added fertilizer P is more vulnerable to leaching loss than after it reacts with the soil (Fig. 5, Fig. 6). For this reason, the one-time fertilizer application resulted in less P loss through leaching than the splitting application which repeatedly activated the soil P from acidification effect of nitrifying ammonium released from urea after its hydrolysis reaction in the soil (Bouldin and Sample, 1958, 1959). The average total P concentration was measured as 0.097 mg/kg in the surface runoff water and 0.031 mg/kg in the leachate, less than one-third of the P concentration in the surface runoff. This further substantiated that P is always cohered to or adsorbed by the soil particles so that it is virtually less mobile with leaching water or resistant to leaching loss compared to N and K.

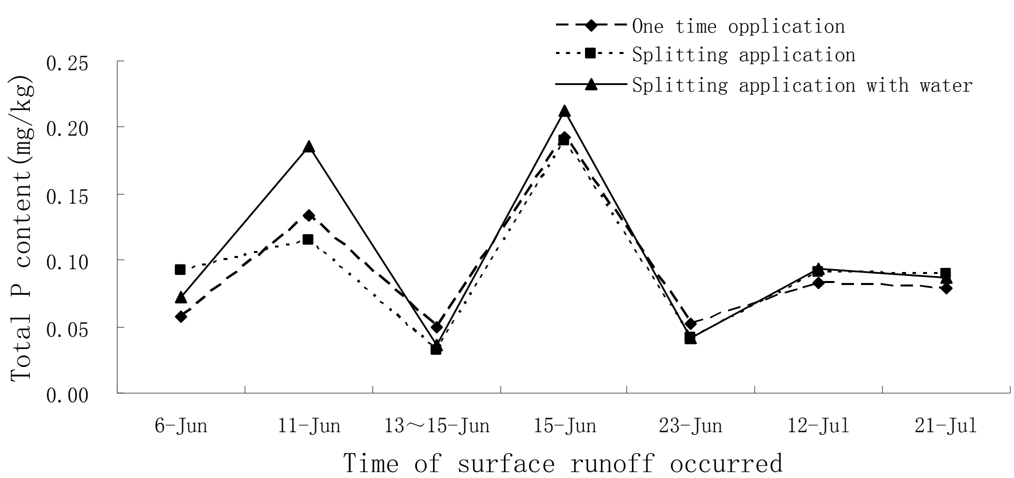

Fig. 5. Total P concentrations in surface runoff as affected by fertilizer placement and time

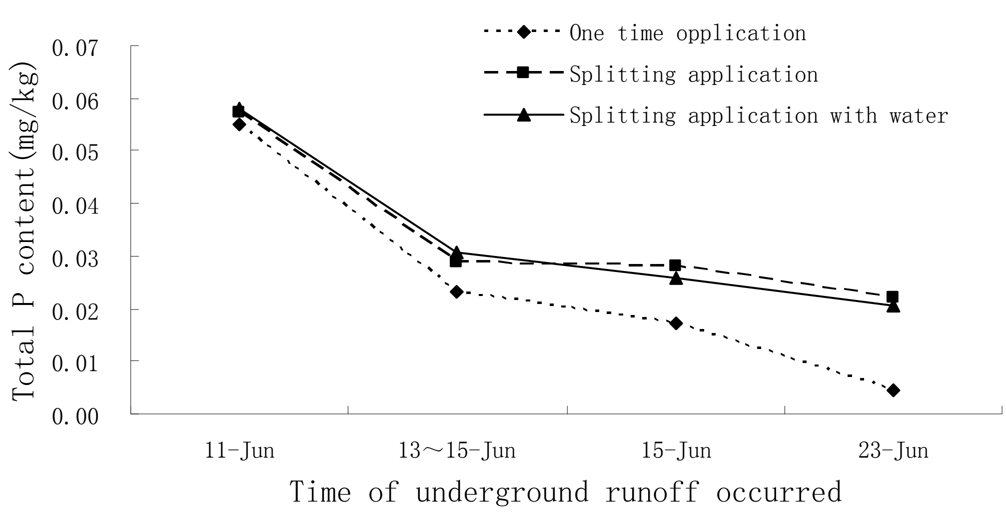

Fig. 6. Total P concentrations through leaching as affected by fertilizer placement and time

The patterns of K loss from the soil were similar to P loss through leaching water, that is, the amount of K removal with surface runoff or leaching water deceased over time (Fig.7-8). The mean concentration of K was measured as 14.9 mg/kg in the first surface runoff water and 6.8 mg/kg in the first leaching water. Thereafter, the K concentrations in the surface and subsurface runoff waters were dropped dramatically no matter what the rain intensities or the types of fertilizer placement were, reflecting that this soil was capable to adsorb K against leaching loss. In June 23, a weak K loss peak occurred, probably due to release of K from the soil K minerals weathering after one-week dry period.

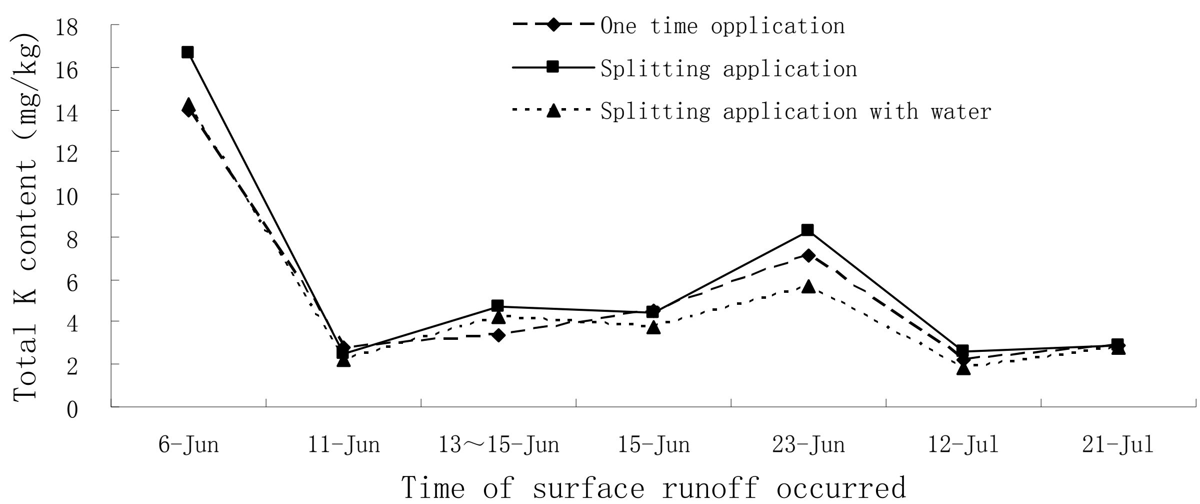

Fig. 7. Total K concentrations in surface runoff as affected by fertilizer placement and time

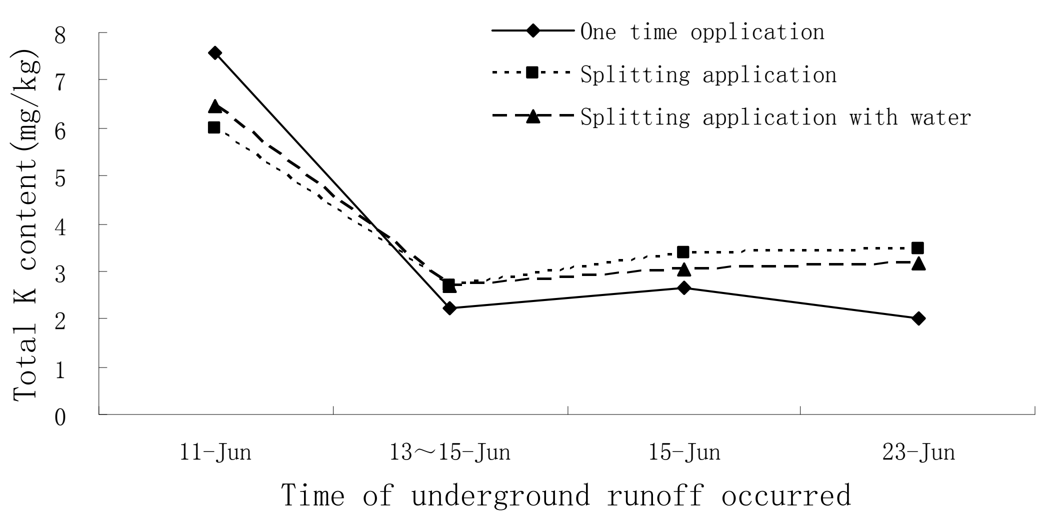

Fig. 8. Total K concentrations through leaching as affected by fertilizer placement and time

3.5 Effect of surface mulch on soil, water and nutrient losses from purplish soil

In order to examine the effect of surface mulch on soil erosion and nutrient losses, the experiment was carried out with paired design with no mulch vs surface mulch using wheat straw or plastic film, the mostly commonly used two mulch materials in the region, under the same cultivation practices. There were four types of cultivation practices employed, including down slope ridge, contour ridge, flat (no ridge) and strip cultivation (a soil erosion reducing technique). Compared to the no mulch plots, surface runoff was significantly reduced by 73.9%-86.2% in the plots mulched with straw and considerably reduced by 16.8%-19.8% in the plots mulched with plastic film (Fig. 8). Since the volume of surface runoff water and subsurface leachate from the soil induced by rainfalls were in a reverse relationship of ups and downs, the straw mulch treatments increased subsurface leachate by 15.4%-156.4%, while the plastic mulch treatments reduced subsurface leachate by 38.3%-65.5%. Even though, the total runoff water from the three straw mulch treatments was the lowest among all the treatments. Different combinations of surface mulch with cultivation practices significantly affected the soil erosion (Table 7). Compared to no mulch treatments, the straw mulch was extremely effective in reducing soil erosion.

Treatment	Surface runoff (mm)	Subsurface runoff (mm)	Total runoff (mm)	Surface runoff/Total (%)	Sediment (t/ha)
Down slope ridge	247.0	54.1	301.0	82.0	25.4
Flat	263.7	62.9	326.6	81.2	22.3
Contour ridge	195.4	96.4	291.8	68.3	4.3
Contour strips	197.4	33.8	231.2	85.4	9.2
Down slope + straw	64.5	138.7	203.2	31.7	0.5
Flat + straw	56.4	52.7	109.1	48.7	0.8
Contour ridge + straw	26.9	111.3	138.2	19.9	0.1
Down slope + plastic film	205.4	33.4	238.8	86.4	10.8
Contour ridge + plastic film	156.7	71.7	228.4	67.9	2.2

Table 7. Soil erosion and water losses as affected by cultivation practices and mulch materials

The sediment eroded from the three treatments ranged from 0.1 to 0.8 t/ha or 2.3% to 3.6% of its corresponding counterpart treatments without mulch. When the down slope cultivation that is usually considered as the most vulnerable practice was covered with straw, the soil erosion was reduced from 25.4 to 0.5 t/ha, making the vulnerable practice anti-erosion. When covered with plastic film, the soil erosion from this plot was cut down by 14.6 t/ha (57%). Contour ridge cultivation turned out to be the best in reducing soil erosion among all the no mulch treatments. After covered with plastic film, soil erosion further reduced by 2.1 t/ha (49%).

The results suggest that contour cultivation was the best in controlling soil erosion and strip cultivation was excellent in reducing water loss when there was no mulch material on the soil surface. Straw mulch could be considered as the best practice for soil and water conservation on sloping lands, which was able to convert the vulnerable down sloping cultivation to a conservative practice.

Treatment	Runoff N			Sediment N		Total loss
	Surface	Subsurface	Subtotal	Subtotal	Available	
Down slope	12.4	17.5	29.9	22.8	1.6	52.7
Flat	16.1	23.2	39.3	19.0	1.5	58.3
Contour ridge	9.2	29.9	39.1	3.7	0.3	42.8
Contour strips	14.7	11.1	25.8	7.3	0.5	33.1
Down slope + straw	3.4	42.2	45.6	0.4	0.0	46.0
Flat + straw	3.6	16.2	19.7	0.6	0.0	20.3
Contour ridge + straw	1.7	25.5	27.2	0.1	0.0	27.3
Down slope + plastic film	11.9	8.0	19.9	9.1	0.6	29.0
Contour ridge +plastic film	8.4	16.9	25.3	1.9	0.1	27.2
Average	9.0	21.2	30.2	7.2	0.5	37.4

Table 8. Amounts (kg/ha) of N lost as affected by cultivation practices and mulch materials

As stated above, since N is lost mainly through runoff rather than with sediment, particularly through subsurface runoff or leaching process, any practice that can reduce runoff is able to reduce N loss (Table 8). Thus, the contour strip cultivation had the lowest total runoff and N loss (25.8 kg/ha of runoff N) as well among the no mulch treatments in which the runoff N ranged from 25.8-39.3 kg/ha; the flat cultivation + straw and the down slope cultivation + plastic film treatments were able to reduce N loss to its minimal levels (19.7-19.9 kg/ha of runoff N) and followed by the two treatments of contour ridge cultivation + mulching with straw and film (25.3-27.2 kg/ha of runoff N).

Treatments	Runoff P			Sediment P		Total loss
	Surface	Subsurface	Subtotal	Subtotal	Avail.	
Down slope ridge	0.96	0.14	1.09	26.22	0.23	27.31
Flat	0.97	0.14	1.10	22.01	0.21	23.11
Contour ridge	0.61	0.31	0.92	4.70	0.04	5.62
Contour strips	0.56	0.09	0.65	9.49	0.08	10.14
Down slope + straw	0.22	0.36	0.58	0.52	0.00	1.10
Flat + straw	0.20	0.14	0.34	0.83	0.01	1.17
Contour ridge + straw	0.05	0.31	0.36	0.12	0.00	0.48
Down slope + plastic film	0.77	0.06	0.83	10.97	0.10	11.80
Contour ridge + plastic film	0.61	0.18	0.79	2.34	0.02	3.13
Average	0.55	0.19	0.74	8.58	0.08	9.32

Table 9. Amounts (kg/ha) of P lost as affected by cultivation practices and mulch materials

The overall P losses from the soil induced by rainfalls were relatively small with an average of 9.32 kg/ha (Table 9). Since P loss is mainly through sediment accounting for 24.0%-96.0% of total P loss (an average 92.1%), any farming practices that increase or decrease soil erosion will lead to an increase or a decrease in P loss. Therefore, the down slope cultivation and flat cultivation had the highest sediment yield and P loss, and the three straw mulch treatments produced little sediment and P loss only ranging from 0.12 to 0.83 kg/ha, or 2.5% to 3.8% of the no straw mulch counterparts. Besides, the treatment of down slope ridge cultivation + plastic film was also effective in controlling P loss and followed by the ones with straw mulch.

Amounts of K loss as affected by cultivation practices varied greatly, spanning from the low of 5.6 kg/ha to the high of 558.5 kg/ha, with much greater highs than those of N or P (Table 10). This provided a sharp contrast for the treatment effect in control of K loss. At the low extremes, the contour ridge + straw behaved excellent with a minor loss of K by 5.6 kg/ha in total, accounting for about 5.8% of K lost from the contour ridge treatment and only 1% from the down slope ridge treatment, and followed by the treatments of down slope ridge + straw and flat cultivation + straw.

Treatments	Runoff P			Sediment P		Total loss
	Surface	Subsurface	subtotal	subtotal	Available	
Down slope ridge	7.5	1.0	8.5	550	4.4	558.5
Flat	6.7	1.1	7.9	455.8	3.7	463.6
Contour ridge	5.7	1.5	7.2	88.6	0.7	95.8
Contour strips	7.4	0.5	7.9	185.9	1.4	193.8
Down slope + straw	2.8	3.6	6.4	9.6	0.1	16.0
Flat + straw	2.3	0.9	3.3	16.2	0.1	19.5
Contour ridge + straw	1.9	1.3	3.2	2.3	0.0	5.6
Down slope + plastic film	6.6	0.5	7.1	238.2	1.8	245.3
Contour ridge + plastic film	5.4	0.7	6.2	45.8	0.4	51.9
Average	5.2	1.2	6.4	176.9	1.4	183.3

Table 10. Amounts (kg/ha) of K loss as affected by cultivation practices and mulch materials

4. Conclusion

A comprehensive study was conducted to investigate effects of different rain intensities, fertilizer rates and placement, cultivation practices, mulch materials and its interaction with cultivation practices on amounts of soil erosion, pathways and amounts of nutrient losses during corn growing season from a purple soil on a sloping land in the Sichuan basin. Amounts of surface runoff and sediment eroded from the soil were increased with an increase in rain intensity while the subsurface runoff was inversely proportionate to rain intensity. Effects of straw mulch on reducing soil and water losses were superior to use of plastic film. Straw mulch significantly reduced surface runoff by 73.9% - 86.2% in spite of increased subsurface runoff by 15.4% - 156.4%, resulting in reduction of total runoff by 32.5% - 66.6% and soil erosion by 96.4% - 98.1%. Though use of plastic film alleviated the subsurface runoff and total runoff to some extent, the difference was not significant compared to the traditional cultivation. Amount of N lost from the soil was measured as 37.4 kg/ha, of which N loss through subsurface runoff accounted for 70.1%. The straw mulch decreased total N loss by 12.8% - 65.1% despite some increase in N loss through subsurface runoff. Amount of P lost from the soil was relatively small (9.32 kg/ha) but it was mainly removed out of the field with the sediment, accounting for 92.1% of total P loss. Amount of K lost from the soil reached 183.3 kg/ha of which the loss through the sediment accounted for 96.5%. Mulching soil surface with either straw or plastic film effectively controlled P and K loss. Compared to the traditional, down slope ridge cultivation, the contour ridge cultivation produced higher corn yields while it lowered losses of soil, water and nutrients. The integration of flat cultivation and straw mulch can be a better practice as it does realize straw recycling, improve crop yields and reduce losses of soil, water and plant nutrients.

It was further revealed that the quantity of P lost from the sloping farmland was mainly through the sediment and influenced by rain intensity. Thus, to control P loss, soil erosion must be minimized first. Contour ridge cultivation proved to be highly effective in control of both soil erosion and P loss. Loss of soil N was mainly through runoff, especially through subsurface runoff during a small rain. Thus, minimizing runoff is the best way to control N loss from soil. The conventional contour cultivation tended to increase both subsurface runoff and N loss. In order to control N and P losses in the purple soil area, the integrated agronomic methods such as cultivation practices against soil erosion and water loss, soil depth improvement and organic matter enrichment can be adopted. The high N rate or one-time basal application susceptible to N loss should be always avoided and balanced fertilization that counteracted N loss should be promoted wherever possible. The total amounts of P and K lost from the farmer practice were the worst, indicating the crucial role of proper application methods in reducing P and K losses in the purple soil area.

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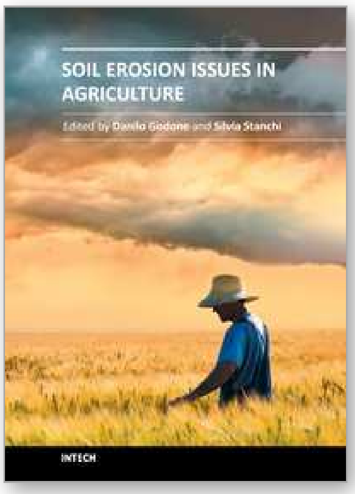

Soil Erosion Issues in Agriculture
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The book deals with several aspects of soil erosion, focusing on its connection with the agricultural world. Chaptersâ€™ topics are various, ranging from irrigation practices to soil nutrient, land use changes or tillage methodologies. The book is subdivided into fourteen chapters, sorted in four sections, grouping different facets of the topic: introductive case studies, erosion management in vineyards, soil erosion issue in dry environments, and erosion control practices. Certainly, due to the extent of the subject, the book is not a comprehensive collection of soil erosion studies, but it aims to supply a sound set of scientific works, concerning the topic. It analyzes different facets of the issue, with various methodologies, and offers a wide series of case studies, solutions, practices, or suggestions to properly face soil erosion and, moreover, may provide new ideas and starting points for future researches.

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