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Experimental Study of Nutrient Runoff from Purple Soils in the Three Gorges Area

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ABSTRACT

The study was carried out both in the field and in the laboratory on the purple soil (Inceptisols) in Zigui of the Three Gorges Project Area, Hubei of central China. The rainfall simulator was used in the 11 runoff plots and a steel box of the simulated plot. Rainfall, runoff and soil loss values, organic matter content, total N, P, K, and available N, P and K in soil and eroded sediments were determined. The main objectives are to study the relationships between nutrients content and particle size distribution in sediment, and the effect of fertilization on concentrations of nutrients in flowing surface water. The results show that organic matter, total N, K and available N, P and K contents of eroded sediments are significantly higher than that of surface soils. Ratios of contents of the most nutrients and forms in sediments/soil are more than 1.00. Which could be set in sequence from high to low as available nutrients, total nitrogen and organic matter, total potassium, and total phosphorus. Nutrient content of sediment depends on the fine particle size content. Fertilization can rapidly increase the nutrient concentration in runoff, which varies with the methods of fertilization and forms and elements of the nutrients. The concentration of nutrients in runoff is mostly related to the nutrient content of the very shallow surface soil. Some of the results may be useful for modeling nutrient loss in steep cultivated land of mountain and hill areas.

INTRODUCTION

Soil erosion and runoff can easily result in a loss of soil and nutrients from slope cultivated land, which reduces the land's productivity and increases the nutrient inputs. Sediment and sediment-borne nutrients are two types of nonpoint source pollution, which can be carried from cropland by runoff, causing degradation of surface waters. Agricultural nonpoint sources (including cropland, rangeland, and pastureland) are thought to be major contributors both of conventional pollutants, such as sediment and dissolved solids, and of chemical pollutants, such as fertilizers. Various analyses indicate that nonpoint sources contribute as much as 99 percent of suspended solids, 83 percent of nitrogen, and 84 percent of phosphorus in U. S. waterways (Clark, 1987). It is estimated that the average loss of topsoil is more than 1 billion tons per year in China, which is equal to the remove of 8-15 tons/km^2 nitrogen, 15-40 tons/km^2 of phosphorus 200-300 tons/km^2 of potassium (Shuizhi and Deqi, 1982). The pollutant status investigation showed 80 percent of 532 rivers were polluted by nitrogen, and of the total 51 percent came from agricultural land (Wenshui, 1992).

The Three Gorges Project Area (TGPA) of the Changjiang River covers most of west Hubei and east Suchuan province, which are both located in central China, of which mountainous and hilly land makes up to 75 percent. Purple soil, a lithomorphic soil (Inceptisols) derived from purple shale, sandy shale or sandy rock, is a major soil type in the Area (SLC, 1991). Most purple soils where up to 78.7% was been cultivated were reclaimed as farmland and cultivated frequently in southern China. This is especially true in TGPA, and about quarter to half of this is distributed on steep slopes (>25º) (Zitong, 1993). With the natural population increase, emigration from the inundated area, the cultivation of steep slopes will rise considerably when the huge hydro-power-project is completed. Soil erosion, deficiency of organic matter and nitrogen, and low preservation capability of water and nutrients are the main problems of agriculture in slope land. Fertilization is one measure to maintain high agricultural production (Chongfa et al, 1996). Protecting soil productivity and controlling and minimizing the risk of nonpoint source pollution of surface waters are very important for the sustainable development of agriculture in this mountain area.

The main objectives of this study are to study the relationships between nutrient content and particle in sediment, and investigate the effect of fertilization on topsoil on concentrations of nutrients in flowing surface water.

MEASURES

The study was located at the Zigui Soil and Water Conservation Experimental Station, approximately 50km west of Yuchang city in Hubei province of central China. The area is dominated by purple soil on steep land derived from purplish red sandy shale of the Jurassic Period. Elevation is 184m at the foot of the hill and 1180m at the top of the hill. The average slope ranges from 27% (15º) to 81% (39º). On average, organic matter content varies from 8 to 20 g kg^{-1}, while total N, available N, total P, available P, total K and available K contents in the surface plow layer range from 0.3 to 0.6 g kg^{-1}, 30 to 50 mg kg^{-1}, 0.3 to 0.5 g kg^{-1}, 1 to 6 mg kg^{-1}, 15-20 g kg^{-1} and 60-100mg kg^{-1} respectively (Chongfa et al., 1996).

The study was carried out both in the field and in the laboratory. 1) In the field, a total of 11 runoff plots, each 2m wide by 10m long were established on a 46.6% (25º) slope land in the field with two crops (soybean--wheat) each year. Each plot was hydrologically isolated on the surface. After summer and autumn harvests in April and November, two

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simulated rainfall experiments were conducted every year.

Table 1. Total and available nutrient in eroded sediments and surface soil.

	Organic Matter g kg^{-1}	Nitrogen		Phosphorus		Potassium	
		Total g kg^{-1}	Available mg kg^{-1}	Total g kg^{-1}	Available mg kg^{-1}	Total g kg^{-1}	Available mg kg^{-1}
Sediment	16.90**	1.22**	78**	0.47	9.9**	28.95**	249**
Soil	11.88	0.84	47	0.45	6.5	24.75	138
Ratio	1.42	1.44	1.67	1.05	1.52	1.17	1.82

**significant at the 0.01 probability level as determined by t-distribution test.

Table 2. Correlation matrix between nutrients contents and Particle size composition of eroded sediments in the natural runoff (n=26, $r_{0.05}$=0.388, $r_{0.01}$=0.496).

Size diameter(mm)	Organic Matter	Nitrogen Total	Nitrogen Available	Phosphorus Total	Phosphorus Available	Potassium Total	Potassium Available
2-0.2(Sg.)[a]	-0.721**	-0.656**	-0.687**	-0.456**	-0.560**	-0.827**	-0.693**
2-0.2(Ag.)[b]	-0.710**	-0.693**	-0.711**	-0.573**	-0.719**	-0.825**	-0.579**
0.2-0.02(Sg.)	-0.725**	-0.714**	-0.722**	-0.589**	-0.735**	-0.887**	-0.767**
0.2-0.02(Ag.)	-0.728**	-0.706**	-0.670**	-0.495*	-0.586**	-0.799**	-0.729
0.02-0.002(Sg.)	0.138	-0.086	-0.051	0.250	-0.132	0.249	-0.174
0.02-0.002(Ag.)	0.732**	0.596**	0.650**	0.662**	0.558**	0.827**	0.614**
<0.002(Sg.)	0.599**	0.683**	0.705**	0.465*	0.783**	0.748**	0.802**
<0.002(Ag.)	0.283	0.461*	0.363	0.044	0.474*	0.367	0.539

[a]Single grain (dispersed by 0.5mol L^{-1} NaOH), [b]micro-aggregate (dispersed by water).
*Significant at the α<0.05 level, ** Significant at α<0.01 level.

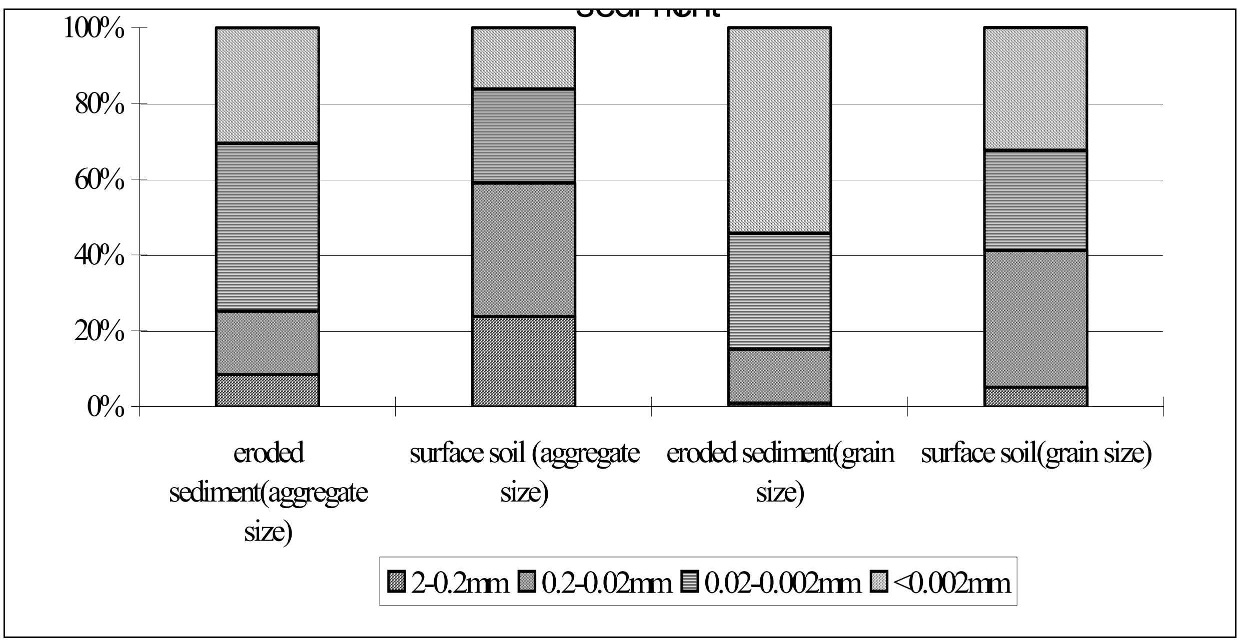

Figure 1. Size distribution of surface soil and eroded sediment.

Total 6x11 rainfalls were implemented from 1994 to 1996. 2) In the laboratory, a steel box 0.5m wide by 2m long by 0.3m deep was used as plot, filled with surface soil passed through a 2mm sieve with a bulk density of 1.3 g cm^{-1}. Two measures of fertilization, whole layer fertilization and surface dressing, were used in 5 replicates. The application rates for NPK were 13.2, 5.5, and 9.6 g m^{-2} for surface dressing and 22, 22, and 25 g m^{-2} respectively for whole layer respectively, which simulated the usual fertilization rates in the field.

The rainfall simulator was used in the research of a series of downward spraying nozzles, the details of which have been described in previous publication (Luke, 1986). The kinetic energy generated is approximately 90% equivalent of natural rainstorms. The rainfall intensity was controlled at two levels, 1 and 1.5 mm min^{-1}, which were designed as a once a year and a ten-year events, respectively. The duration was 1 h.

Rainfall, runoff production, and soil loss values were measured at all natural runoff events, of which 26 runoff events have enough sediments to be collected for determining nutrients contents and particular size composition from 1994 to 1996. With the aid of rainfall simulation, runoff sediment concentrations were measured every three minutes during rainfall, while sediment and running water samples were collected every six minutes. Particles size distributions of sediment and surface soil from its eroded site were determined. Organic matter content, total N, P, K, and available N, P and K were also determined.

RESULTS AND DISCUSSION

Comparison of nutrient contents in eroded sediments and surface soil

Total and available N, P, K contents of eroded sediments and surface soil averaged from 1994 and 1996 are presented in Table 1. All surface soil samples were collected from the plot in the field from which the sediment comes. The data show that organic matter, total N, K and available N, P and K contents of eroded sediments are significantly higher than that of surface soils, while total P contents of both are almost the same. The ratio of nutrient contents of the eroded sediment to surface soil can be considered as an index of nutrient enrichment, called "enrichment degree". In the purple soils, the enriched degrees are more than 1.00 for most nutrient elements and forms. The ratio could be set in sequence from high to low, which would be available nutrients, total N and organic matter, total K, and total P.

Table 2 is a correlation matrix between particle size composition and nutrient contents of the eroded sediment. Organic matter, total P, K and available N are significantly related with the clay content (grain size less than 0.002mm) and the 0.02~0.002mm micro-aggregate content. In addition, the total N, available P and K are also significantly related with the content of the smallest sized micro- aggregate (smaller than 0.002mm).

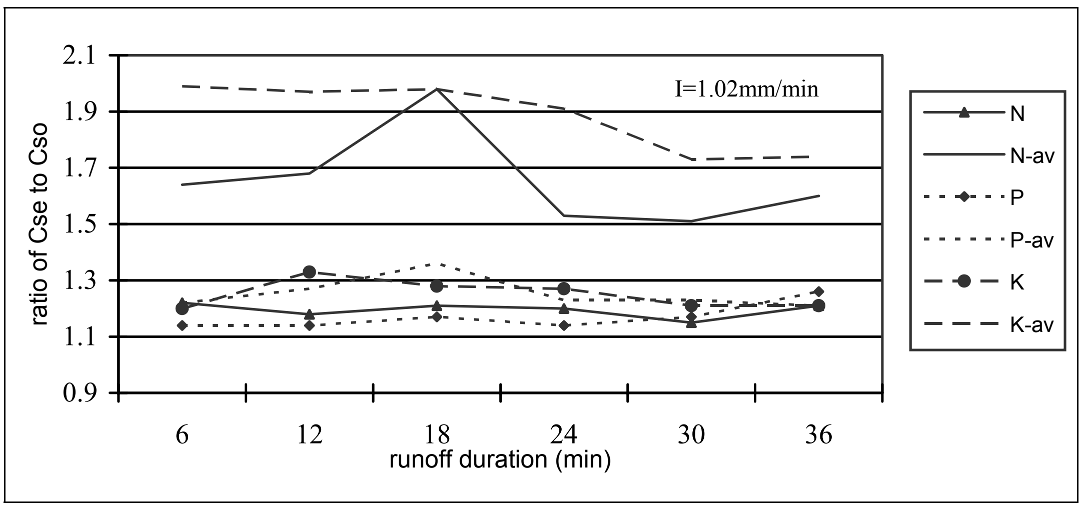

Figure 2a. Ratios of nutrient content in sediment to soil in different time duration of runoff

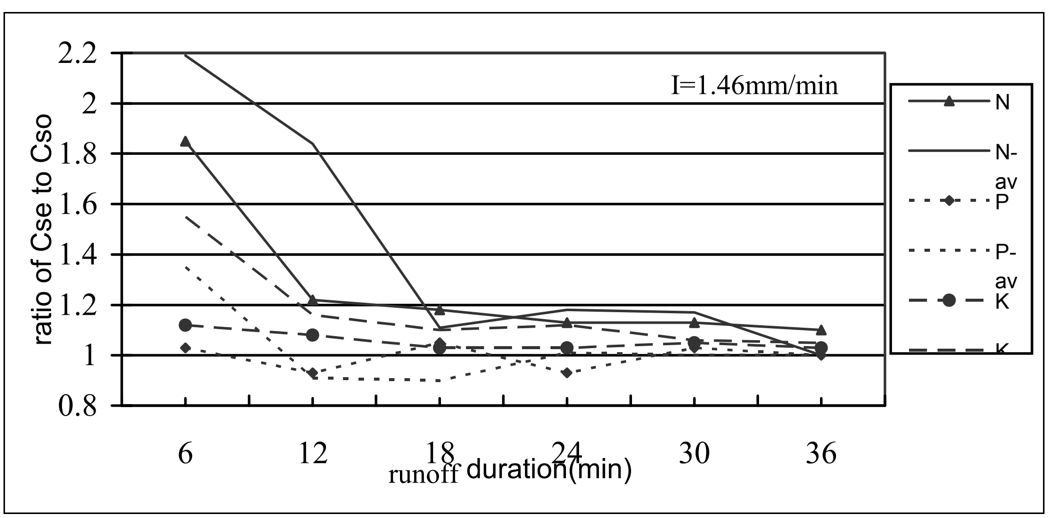

Figure 2b. Ratios of nutrient content in sediment to soil in different duration of runoff.

As can be see from Fig. 1, coarse (2-0.2 mm) and fine coarse (0.2-0.02) particle sizes in sediment were lower, and the fine size (less than 0.02 mm) was higher than in the surface soil from which it comes. The nutrient contents of eroded sediment are influenced by the sediments particle size distribution.

In previous reports, nutrient loss of watershed was estimated by using the sediment yield of the river multiplied the nutrient content of the surface soils (Shuizhi and Deqi, 1982, Zitong, 1993). Results indicated that nutrients in sediment are mainly loaded by fine particle size. The reason may be that the nutrient contents were higher in eroded sediment than the surface soil, due to particle size distribution in sediments, which had more fine particle size than the surface soils from which it comes. We can use the ratio of nutrient in eroded sediment to that in surface soil, or the enrichment degree, to calculate the nutrient loss into river.

Effects of rainfall intensity on enriched degree of nutrients in sediment

The ratio of nutrient content in surface soil to that of sediments may change during runoff. The process of the change showed in Fig. 2. When the rainfall intensity reaches that of a ten-year event, the ratio of total nitrogen content, available N, P, K is considerably higher at the beginning (0-6min) of the runoff. Then they gradually decreased from 6 to 18 minutes, and fluctuated around 1.00 after 18minutes. However, when the rainfall intensity is at about 1.0mm/min, the ratios of nutrients contents in surface soil to sediment did not change greatly during rainfall, all of which are more then 1.00, roughly the same as the enriched degree. We could also set a sequence for available nutrients, total N, K, and P from high to low.

The comparison of grain size distribution between surface soil and sediment collected from different durations of runoff at two levels of rainfall intensity is showed in Fig. 3. The fine-particle size content of surface soil is much lower than that of sediments in the low intensity rainfall, which results in a high nutrient content in the sediment. Because the rainfall intensity is at the level of one-year event, the ratios of nutrient contents were about that of enriched degree of natural runoff. In conditions of heavy rainfall intensity, the particle size distributions of sediments are almost as surface soil except those that come from the beginning of runoff. It is most possible that the heavy rainfall intensity can generate more energy and amass more runoff, so that the coarse particles or fragments can be removed.

The results indicated that nutrient contents depend on the fine particle size content in sediment. Although heavy storms may cause huge volumes of sediment to be eroded, the nutrient is not higher than in soil.

Effect of fertilization on the concentration of nutrient in runoff

Normally, the concentration of nutrients is not high enough to be determined in runoff that amassed from purple soil (Chongfa et al., 1996). However, nutrient loss in soluble form is inevitable, especially at first storm events when fertilization practices, such as top dressing, broadcasting, foliage dressing, hole application etc, are conducted, which may cause contents of nutrient to be excessively high in some parts temporarily. Two treatments, whole layer and surface dressing fertilization, were used in the paper.

Surface Dressing Fertilization: Concentration of soluble and exchangeable N and K is extremely high at the beginning, being 37.5mg/L and 64.3mg/L, and 100 and 12 times higher than at the end of the runoff, respectively. From 3 to 21 minutes of runoff, Concentrations of N and K sharply decreased to 4.1mg/L and 12.3mg/L, being 10% and 20% of the beginning concentration. After that, both gently decreased. Concentrations of soluble and exchangeable P decreased gradually from the beginning to end (Tab.3).

Whole Layer Fertilization: Although the application rate is higher than Surface dressing fertilization, Concentrations of N and P and K are greatly lower. During the runoff, Concentrations of N and K decreased slightly, while P did not change. It is clear that fertilization can rapidly increase nutrient concentration in runoff. After fertilization, the nitrogen is easily lost in the first storm since the concentration sharply decreases in the runoff, while phosphorus in runoff decreases slowly. This may be because of the behavior of their movement in the soil.

Effective depth interacted by rain and runoff in soil

Nutrients at near the soil surface can be transferred to overland flow by the mixing of rainwater with soil solution. The mixing is accelerated by the kinetic energy of rainfall and runoff, but also depends on the soil properties and other conditions (Ahuja, 1986). To examine the depth of interaction between rainfall, overland flow and soil, the available nutrient contents and depth of soil in the soil boxes were measured at the end of a 60 minutes rain event after precipitation of up to 60 mm. From top to the bottom of the boxes, the soil layer was divided into 8 thin layers (each ranging from tan 1 to 3 cm). Compared to that of the original soil collected before the rain, available N, P, K of 0-1cm topsoil decreased over 9% after rain (Fig. 4), and below the depth of 2cm, N, and P contents were only cut down 3% of the total, which do not significantly differ from the original soil samples. However, the change of K contents is not similar to N and P. It showed that the amount of K released decreased exponentially with depth, which is possibly due to different transfer rates.

The nutrient losses occur mostly in the shallow surface, which differs soil properties and elements and the forms of nutrients. Also the movement varies with nutrient elements, which normally echoes the enriched degree.

CONCLUSIONS

Organic matter, total N, K and available N, P and K contents of eroded sediments are significantly higher than those of surface soils. In the purple soils, the enrichment degree are more than 1.00 for all nutrient elements and forms. The ratio could be set in sequence from high to low. This sequence is available nutrients, total nitrogen and organic matter, total potassium, and total phosphorus. We may use the ratio to calculate nutrient loss of watershed into rivers. One of reasons is that the sediment contains more fine particles than topsoil does. The content of silt (diameter of particle size 0.02-0.002mm), clay (less than 0.002mm) and micro-aggregates (diameter of aggregate less 0.002mm) are higher in sediments than in topsoil. Nutrient contents depend on the fine particle size content in sediment.

Heavy storms can cause huge volumes of sediment, but nutrient content is not higher than the surface soil from which it comes. Fertilization can rapidly increase nutrient concentration in runoff, which varies with the methods of fertilization, as well as the forms and nutrient elements. The concentration of nutrients in runoff is mostly related to nutrient contents of the very shallow surface soil. The effective depth varies with nutrient form, which closely matches the enriched degree in purple soil.

Sloped land is commonly used for cultivation in the Three Gorges area of the upper-middle Yangtze River watershed, southwest China, due to the high-density population and the immigrants from the flooded area. However, slope cultivation easily causes soil erosion and nutrient losses. The results were useful for modeling nutrient loss in steep cultivated land of mountain and hill areas. More detail work is to control agricultural non-point and reduce the input of fertilization.

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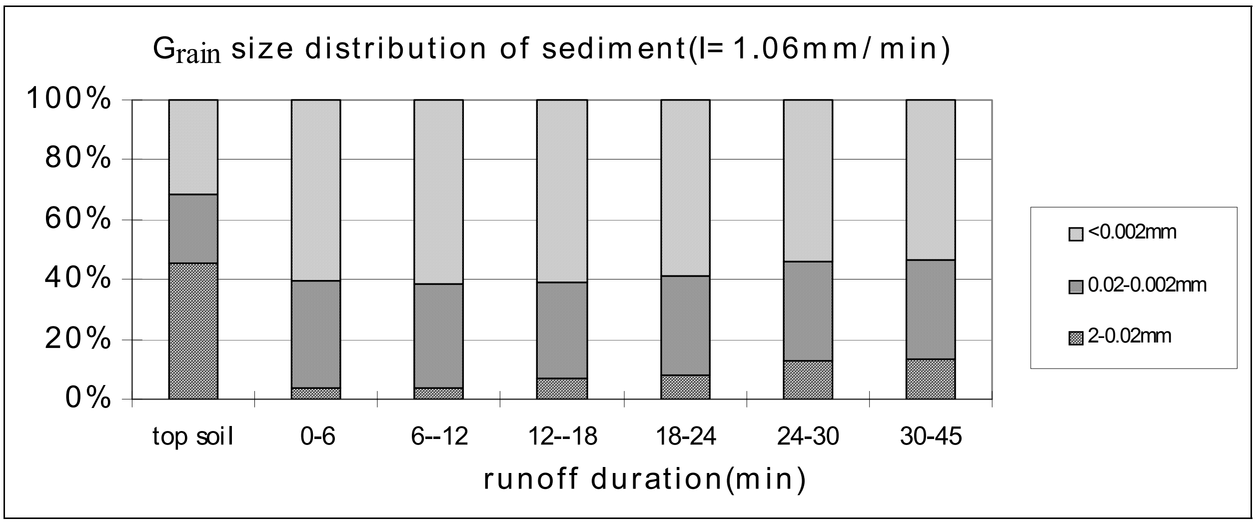

Figure 3a: Grain size distribution of sediment in different duration of runoff

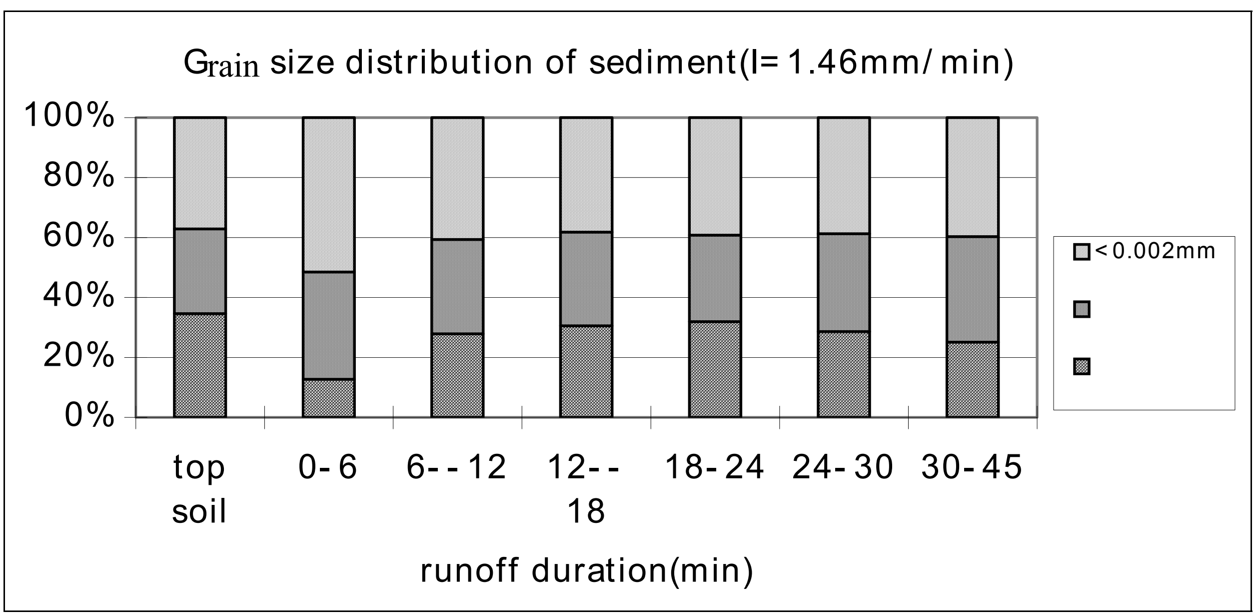

Figure 3b: Grain size distribution of sediment in different duration of runoff

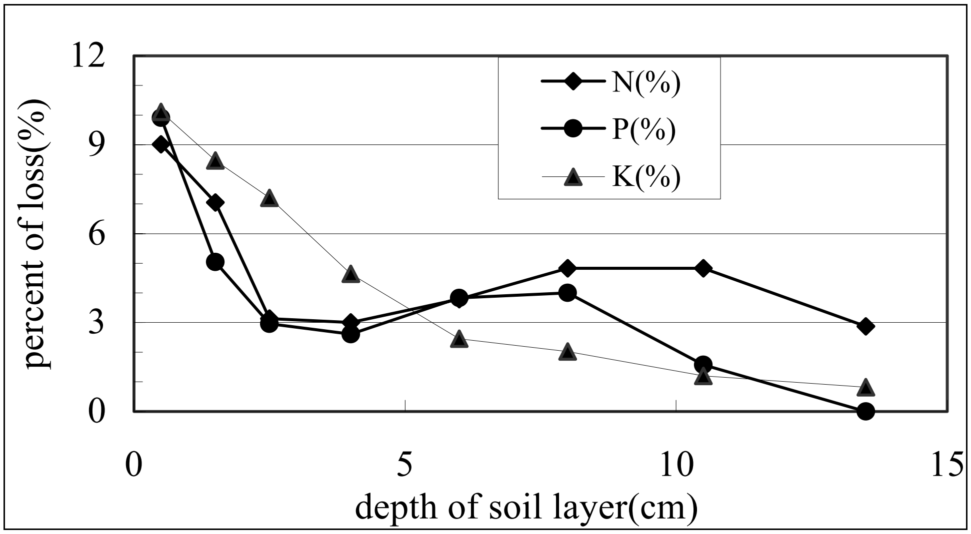

Figure 4. The percent of available nutrient loss with soil depth after 60 minutes or rain.

Table.3: Concentration of nutrients in runoff of different duration from soil with treatment of whole layer and surface dressing fertilization

Duration of runoff (min)	Concentration of nutrients in runoff from surface dressing (mg/L)			Concentration of nutrients in runoff from whole layer (mg/L)		
	N	P	K	N	P	K
0--3	37.5	52.5	64.3	1.68	4.09	9.74
3--6	32.4	48.8	42.1	1.75	3.43	7.19
6--9	23.1	50.2	29.6	1.58	3.08	7.19
9--15	13.1	47.1	20.4	1.40	2.03	3.83
15--21	4.1	29.5	12.3	1.40	1.90	3.16
21--27	4.6	27.1	9.8	1.08	1.84	3.55
27--33	0.5	15.7	7.4	1.40	1.75	2.86
33--39	0.4	14.1	6.8	1.41	1.62	2.71
39--45	0.4	11.9	5.6	1.47	1.65	2.73
45--54	0.3	9.9	5.3	1.47	1.68	2.27

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