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Original Research Paper

Effects of Perennial Vegetation on Runoff and Erosion for Field Plots on Loess Plateau in China

Zhang Tiegang, Peng Li, Zhanbin Li* and Xiaoding Guo**
Key Lab of Northwest Water Resources and Environment Ecology of MOE, Xi'an University of Technology, Xi'an, Shaanxi, P R China 710048
***Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Education, Yangling, Shaanxi, P R China, 712100
****Department of Military Economy, Engineering University of CAPF, Xi'an Shaanxi, China, 710086

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ABSTRACT

Vegetation is one of effective methods for soil and water conservation. How to select suitable vegetation species is a key problem in the practice. In this study. through 7 years observations on the rainfall, vegetation cover, total runoff and sediment in the plots, results indicated that the benefit of the vegetative cover on runoff and sediment dominated on all plots. The accumulative sediment yield from bare plot was 7 times to that from *Astragalus absurgens* + *Caragana korshindkii* plots, also over 4 times to that from the *Medicago sativa*, *Medicago sativa* + *Caragana korshindkii* and *Astragalus absurgens* plots. Among all the vegetation types, *Caragana korshindkii* was the most efficient in reducing the runoff, and the combination of shrub and grass also had better effect in reducing the runoff. The accumulative runoff from bare plot was 2.57 times to that from the C. *korshindkii*, and over 2 times to that from *M. sativa*, *M. sativa* + *C. korshindkii*, *A. absurgens* + *C. korshindkii* and *Vicia amucena* + *C. korshindkii*. This study is of great importance for the selection of suitable species for vegetation reconstruction in arid and semi-arid areas.

INTRODUCTION

In arid environment, water erosion is the main soil degradation process. According to Renard (1980), in many arid environments, soil erosion is greater than might be expected considering the associated low rainfall. Sparsity of vegetation, steep topography, low infiltration capacity, and high-intensity thunderstorm were identified as causative factors. Runoff can be significant in degraded rangelands. Tromble (1974) reported that average runoff from creosote bush-infested rangelands was 20% of the precipitation received, with a maximum of 42% for the largest rainfall event. And erosion is closely related to soil productivity, because it selectively removes the organic matter and soil nutrients, reduce plant available water capacities, reduce the thickness of the arable layer rooting volume, and leads to a degradation of soil physical properties such as structural stability, infiltration, and bulk density (Peng Li 2002). Numerous studies (Zhu 2010, Peng 2011, Aref 2011) have verified that the growth and existence of the vegetation can change soil properties, improve soil anti-erodibility, intensify soil infiltration and water retention ability, protect soil aggregation from raindrop splash, decrease raindrop energy, prevent the formation of the surface crust, and decrease soil and water loss from surface runoff (Cresswell 1995). Most important of all, the existence of vegetation can disperse concentrated overland flow, decrease runoff erosivity by increasing resistance to runoff, impound runoff and sediment, allay and even prevent the formation of channel erosion (Meyer 1995). Some researchers (Carrol 2000, Gilly 2000, Cerda 1997) investigated the recover process on soil and spoil in mining areas, and the results indicated that the effect of vegetation on soil erosion was dominated across all soil types and sites. All these researches revealed the dynamic effect of vegetation cover on runoff and sediment, and provided scientific support for the evaluation of soil and water conservation efficiency of forest, shrub and grass (King 1995, Laflen 1981).

Recently, the use of crop residue to control erosion received more attention. The wind (Wooddruff 1965) and water (Wischmeier 1978) erosion equations have crop factors that recognize the influence of crop residues for controlling erosion. Gregory (1982) reported on the percent soil cover with six vegetative mulches, but he did not attempt to relate soil cover to wind erosion. In all cases, the first increment of cover gave the largest response, and there was minimal benefit of going over 100% cover except for water conservation. Residues were also recognized as a valuable tool for controlling water erosion (Meyer 1970, Laflen 1981). Soil losses due to water erosion on reclaimed rangeland site were reduced 51% with 72% surface cover (Hofmann 1983). The advantage of using ground cover in place of quantity of residue is the ease of measuring ground cover (Laflen 1981, Gregory 1982, Richards 1984). The data on soil erosion-crop residue cover were analysed using nonlinear-curve fitting techniques (Barr 1976). Especially with the development of soil erosion prediction model, such as USLE and WEPP, the effect of vegetation on soil has been received more attention, and numerical relations between vegetation cover and soil erosion were developed. But little attention was paid to the effect of perennial vegetation (grass and shrub) on soil and water loss.

The objective of this study were to (a) verify quantitative relationship between ground cover and soil erosion, and (b) determine the accumulative effect of perennial grass on soil erosion.

MATERIALS AND METHODS

Location and experiment layout: The experiment site was located on the slopes at An'sai Ecological Station of the Soil and Water Conservation Institution (ISWC) of China Academy of Sciences (CAS), 18km southwest to Ansai city. Local climate is semi-arid, warm-temperate and windy. Mean annual temperature is 9.3°C, and mean annual rainfall is 541.2mm. Rainfall is not uniformly distributed throughout the year; with July, August and September being the wettest months. Annual as well as monthly totals of precipitation exhibit a high variability.

The slope gradient was uniformly 20%. Leguminous grasses and shrubs were planted on the bounded plots with the size of 5m × 40m, vertical projection areas 169.6m^2, and single plot was left bare as a comparison with the vegetation treatment. The field study was terminated after 7 years when the rill erosion occurred on the plots. Rain gauges were placed near the experiment location to record the rainfall and its intensity. Soils type is Ustorthents, its fertility is low and the organic matter content usually is below 1%.

Rainfall and its intensity were recorded by auto-recorded pluviometers (type) laid near the plots when runoff occurred on runoff plots. In 1986 year, due to personnel matters to the people who are responsible for the observation, no observations were carried out to runoff, sediment, and vegetation cover, and consequently no data.

Pastures and shrubs: Five species of grasses and shrubs and their combination were planted on the plots according to the Table 1: *Vicia amucena* Fish., *Medicago sativa* L., *Astragalus* absurgens, *Onobrychis viciifolia* Scop and *Caragana korshindkii* Kon. To the mixture vegetation, the grass and shrub were planted at 5-m intervals across the plots. During the experiments, bait was placed near the plots to prevent damages from field mouse; and weeds have been holed up to avoid its negative effect on the shrubs and grass. To get as closely effect to the nature as possible, no fertilizer was applied to the plots during the experiment.

Table 1: The species and their combination for the experiment layout.

nudation
Caragana korshindkii Kon
Onobrychis viciifolia Scop + *Caragana korshindkii* Kon
Onobrychis viciifolia Scop
Astragalus absurgens + *Caragana korshindkii* Kon
Astragalus absurgens
Medicago sativa L + *Caragana korshindkii* Kon
Medicago sativa L
Vicia amucena Fish + *Caragana korshindkii* Kon
Vicia amucena Fish

Runoff and sediment: Total runoff was measured by using a splitting bucket to determine its volume. Sediment content was determined by sampling from the bucket after weighing and drying. After that, related data to runoff and sediment were transformed to runoff depth and soil erosion modulus respectively according to each definition.

Vegetation cover: Quantitative estimates of cover components can be made with point frame quadrats (Levey 1933). The point frame technique provided statistically reliable quantitative estimates of vegetation and cover on reclaimed land grazed at several intensities in previous studies. The number of the needle that can not fall down when the instrument was covered on the vegetation was thought to be the vegetation coverage. In this study, vegetation cover was measured with vertical point frames of 20 sliding pins spaced about 5cm apart. The first contact with live, litter or bare soil was recorded as first hit. The pin travel then was continued downward and a similar contact at ground level was recorded as a surface hit. Coverage measurement was taken after runoff event occurred on the runoff plots, each with 10 repeats at the same place of the previous studies.

RESULTS

Rainfall and intensity: According to the records of rainfall on the rain gauge, rainfall events when runoff occurred on the vegetative plots are shown in Table 2 and Fig. 1. The results indicated that rainfall in the study area is characterized by a large amount of small event fewer than 30mm. During the 6 years, of 19 rainfall events recorded during the study period, only 3 were larger than the average of 35.94mm, and accounted for 42% of the total; to the rainfall intensity, only 16 were larger than the average of 10.29mm/h, and accounted for 15.8% of the total.

Fifteen of the 18 rainfall events were happened in July, August and September. Maximum rainfall was 79.2mm and 68 mm, and peak intensities recorded were 81.78mm/h. The occurrence of rainfall events of high magnitude and low

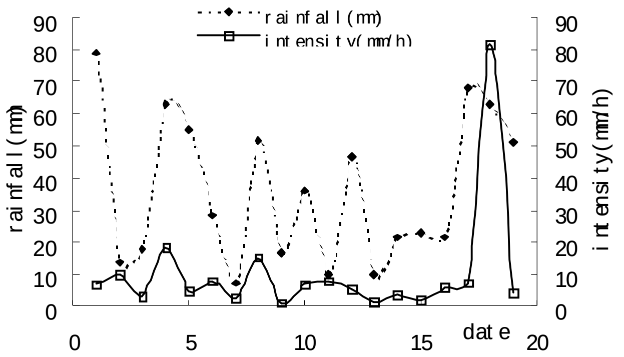

Fig. 1. Rainfall and its intensity when runoff occurred on the plots.

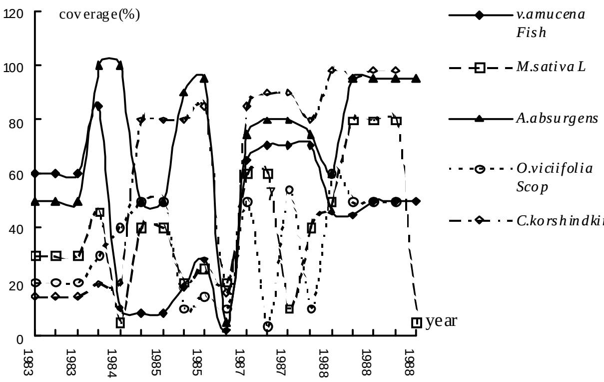

Fig. 2: The coverage patterns of different vegetation types.

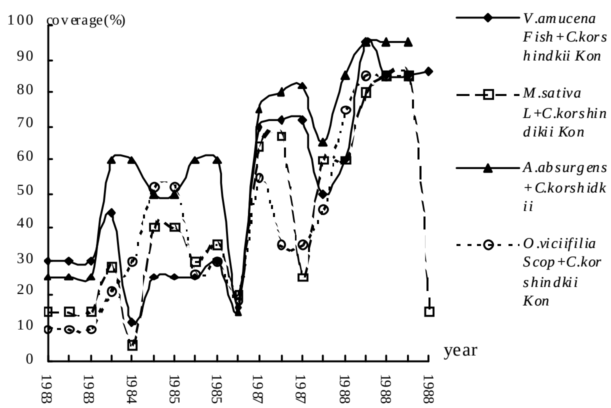

Fig. 3: The coverage patterns of different vegetation combinations.

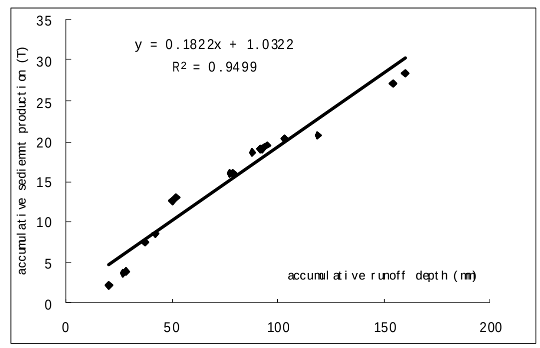

Fig. 4: Relation between accumulative runoff depth and accumulative sediment yield on bare plot.

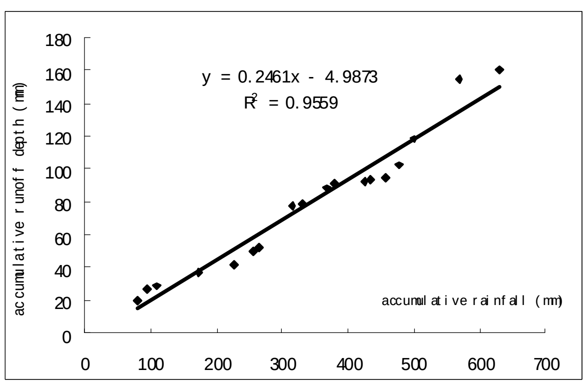

Fig. 5: Relation between accumulative rainfall and accumulative runoff depth on bare plot.

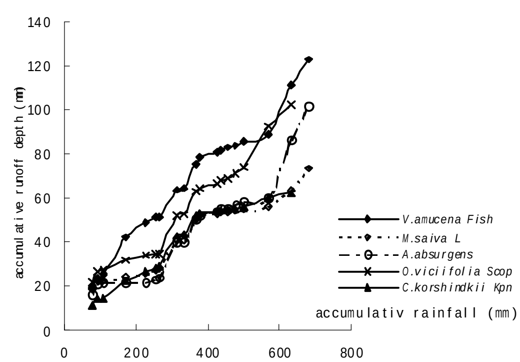

Fig. 6: Relation between accumulative rainfall and accumulative runoff depth on vegetation plots.

intensity and events of high intensity and low magnitude may in part explain the low correlation between rainfall amount and runoff. Slatyer & Mabbut (1964) regarded rainfall amount and intensity as the most significant factors affecting runoff in arid areas. However, they noted that rainfall intensity might be more important than the total rainfall amount in producing runoff, as in the present case.

Vegetation cover pattern: During the vegetation development process, the vegetation cover showed different trends with types (Fig. 2). In the initial stages, because of the retarded growth of shrubs, the coverage of *C. korshindkii* Kon was as low as 15%. But the coverage of the pastures such as *V. amucena* Fish and *A. absurgens* reached almost 60%, which indicated that the herbaceous species could provide

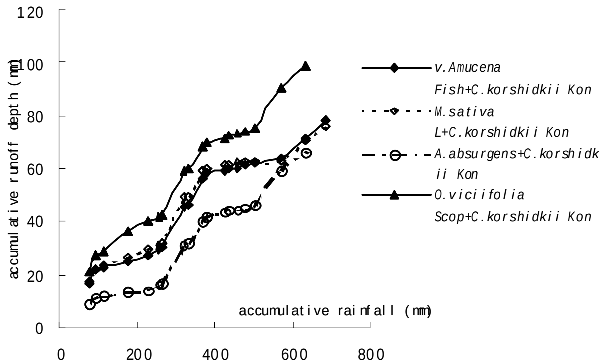

Fig. 7: Relation between accumulative rainfall and accumulative runoff depth on vegetation plots.

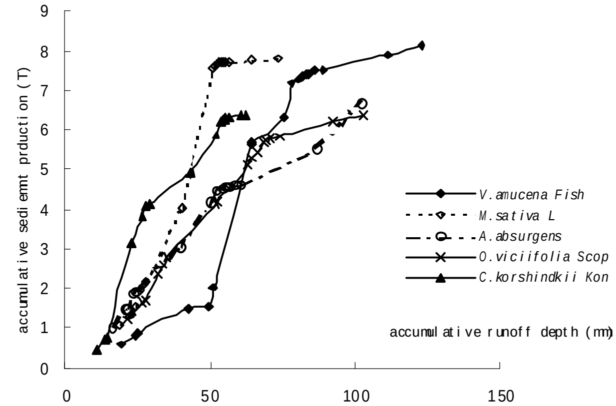

Fig. 8: Relation between accumulative runoff depth and accumulative sediment yield on vegetation plots.

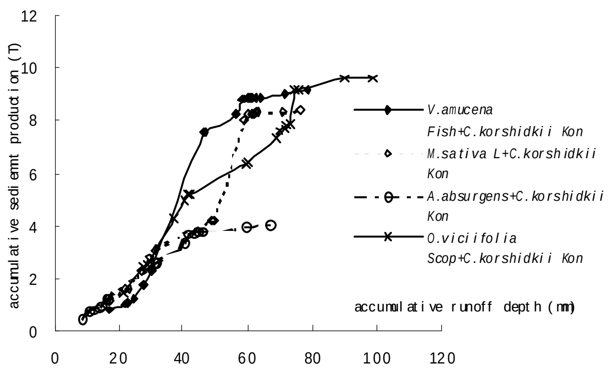

Fig. 9: Relation between accumulative runoff depth and accumulative sediment yield on vegetation plots.

better protection to the soil surface in shorter time.

As all the water needed during the vegetation growth was from the rainfall, the drought-resistance ability of the species determined the species coverage pattern. To the herbaceous species, its drought-resistance ability was lower than that of shrub; they were more easily affected by the aridity of the year. Thus, with the vegetation development, the coverage of *C. korshindkii* Kon showed a steady increase and surpassed the other herbaceous species in the following years, and its variation range was also smaller.

To the types of grass combination with shrub (Fig. 3), it was clear that the coverage of all the types showed a steady increase, among which the coverage increase of *A. absurgens + C. korshindkii* Kon and *V. amucena* Fish + *C. korshindkii* Kon were the biggest. Because of the lower drought-resistance ability, coverage changes of *M. sativa* L + *C. korshindkii* Kon was great, and its coverage reached lower level when the rainfall was small.

Rainfall during the growing season is very important to the vegetation growth. Less rain will accelerate grass degradation. Generally, the coverage of herbaceous species was more easily affected by rainfall than the shrubs, and was also related to its drought-resistance ability. According to the observations, in 1988yr, coverage on *Onobrychis viciifolia* Scop plot degraded, and its cover dropped to lower level. This indicated that the exotic artificial vegetation needs proper management to avoid vegetation degradation.

Impacts of vegetation types on runoff and soil loss: From Figs. 4 and 5, linear relationship existed between accumulative runoff depth, and sediment and accumulative rainfall on the bare plot, which indicated that larger rainfall tended to result higher runoff, and consequently higher sediment yield. The accumulative curve of the runoff and sediment reflected the accumulative changes of soil and water loss under the accumulative rainfall. As all the water used by the vegetation came from the rainfall, the decrease of runoff meant the increase of infiltration and soil water content. Thus, the decrease of runoff under crop cover had particular ecological meaning in arid agriculture. Compared to the bare plot, the benefit of the vegetative cover on soil erosion dominated across all plots despite of different vegetation types (Figs. 6 and 7). All vegetation types are effectively in reducing sediment yield, whose accumulative sediment yields were only 1/7 to 1/3 to that from bare plot. The accumulative sediment yield from vegetative plots also increased quickly during the initial years after planting, but stabilized after 4 or 5 years after planting, which indicated only light soil erosion happened on vegetative plots. This result is in accordance with former studies that the growth of vegetation will remarkably decrease soil erodibility, bind soil particles together with fine root, and increase water stable aggregate content (Zhu Bingbing 2010). The accumulative sediment yield from bare plot was 7 times to that from *A. absurgens* + *C. korshindkii* Kon plots, also over 4 times to that from the *M. sativa*, *M. sativa* L + *C. korshindkii* Kon and *A. absurgens* plots. Among all the vegetation types, *C. korshindkii* Kon is effectively in reducing runoff; while to

Table 2: Equations of accumulative runoff an sediment under different vegetation cover.

Species	Runoff		Sediment yield	
	Equation	Correlation Coefficient	Equation	Correlation Coefficient
Bare plot	y = 7430x + 7790.6	R^2 = 0.9375	y = 1389.5x + 2109.9	R^2 = 0.9384
Vicia amucena Fish	y = 4882.6x + 18579	R^2 = 0.9414	y = 488.74x + 99.526	R^2 = 0.8715
Onobrychis viciifolia Scop	y = 4275.7x + 14213	R^2 = 0.9453	y = 323.51x + 1074.2	R^2 = 0.9461
Astragalus absurgens	y = 3911.3x + 6131.1	R^2 = 0.8801	y = 285.77x + 567.59	R^2 = 0.9198
Medicago sativa L	y = 2819.2x + 14674	R^2 = 0.9388	y = 477.16x + 308.7	R^2 = 0.8446
Caragana korshindkii Kon	y = 3178.6x + 10663	R^2 = 0.9220	y = 355.51x + 1231.7	R^2 = 0.8183
Astragalus absurgens + *Caragana korshindkii* Kon	y = 3245.5x + 1823.9	R^2 = 0.9394	y = 249.89x + 120.97	R^2 = 0.8968
Medicago sativa L + *Caragana korshindkii* Kon	y = 3214.4x + 16333	R^2 = 0.9217	y = 488.43x + 715.45	R^2 = 0.8538
Vicia amucena Fish + *Caragana korshindkii* Kon	y = 3298x + 14283	R^2 = 0.9410	y = 571.53x + 274.71	R^2 = 0.8054
Onobrychis viciifolia Scop + *Caragana korshindkii* Kon	y = 4100.9x + 19502	R^2 = 0.9536	y = 464.54x + 1943.3	R^2 = 0.9506

vegetation combinations, *A. absurgens* + *C. korshindkii* Kon was most efficient in reducing the sediment.

As to the runoff, there also existed linear relation between accumulative rainfall and accumulative runoff depth on bare plots, which indicated that larger rainfall tend to result larger runoff. Compared to bare plot, all the vegetation types were efficiently in reducing runoff, whose accumulative runoff depth was 1/3 to 3/4 to that from bare plot, but were not as remarkable as their effect on the sediment yield. Among all the vegetation types, C. *korshindkii* was the most efficient in reducing the runoff, also the *M. sativa*, *M. sativa* L + *C. korshindkii* Kon, *A. absurgens* +*C. korshindkii* Kon and *V. amucena* Fish + *C. korshindkii* Kon also had better effect in reducing the runoff. The accumulative runoff from bare plot was 2.57 times to that from the C. *korshindkii*, and over 2 times to that from *M. sativa*, *M. sativa* L + *C. korshindkii* Kon, *A. absurgens* + *C. korshindkii* Kon and *V. amucena* Fish + *C. korshindkii* Kon.

Temporal changes of soil and water loss under different vegetation types: Generally, bigger runoff induced larger sediment yield. But the amount of surface soil erosion was also related to the soil structure, organic matter content, aggregation condition and porosity etc., which tended to be more complex when vegetation existed.

From the Figs. 8 and 9, it was clear that all vegetation types were effective in reducing the surface soil and water loss. During the initial stages of the development, the effect of shrubs on runoff and sediment yield was not as remarkable as grass, and the quick growth of the grass could afford better coverage to soil surface and resulted in less sediment yield than the shrub. With the vegetation development, the coverage of all vegetation types increased, and their protection to the soil surface increased too, which resulted in the similar trend of soil loss under different vegetation cover in 4 and 5 yr after planting. The effect of vegetation on runoff seemed a little simple. Better linear relations existed between the accumulative rainfall and the accumulative runoff depth on all plots (Table 2). The reason was that the vegetation growth will improve soil physical and chemical properties, such as soil organic matter content, soil water stable aggregate content, soil infiltration ability, and soil porosity, which have great effect on soil infiltration ability.

DISCUSSION

In Guobin Liu's research (Guobin Liu 1997), the decrease of soil loss in the initial years of the vegetation restoration was the result of the vegetation coverage only. Later with the vegetation development, the number of the roots in the soil increased, and it was effective in reducing the sediment yield because of its improvement and amelioration to the soil physical and chemical properties. Thus, with the development of the vegetation and its succession, the effect of the vegetation in reducing the runoff and sediment would be more remarkable.

In this paper, the analysis of the temporal changes of the runoff and sediment indicated that during the initial stages of the vegetation development, the quick growth of the herbaceous species afforded better coverage to soil surface and resulted in less sediment yield than the *C. korshindkii* Kon. With the vegetation development, the coverage of all vegetation types increased, and their protection to the soil surface increased too, which resulted in the consistent decrease of soil loss under different vegetation cover in 4 and 5 yr after planting.

In this study, the *V. amucena* Fish, *A. absurgens* and *O. viciifolia* Scop had no similar response in the years when there was less rain; it indicated that there existed a kind of threshold for the vegetation functions. Vegetation physiological characters, root vigour, stem flexibility, leaf area index and so on, have potential effect on the runoff and sediment transportation. Thus, further studies are needed to study the relations between vegetation physiological conditions and soil and water loss, which is of great importance for the selections of suitable species for vegetation reconstruction in arid and semi-arid areas.

CONCLUSIONS

Based on this research, following conclusions can be drawn: During the vegetation development process, the vegetation cover showed different trends with types. In the initial stages, grass species, such as *V. amucena* Fish and *A. absurgens* could provided better coverage, while in later time, shrub species have grown better. Coverage of grass combination with shrub showed a steady increase and surpassed the other herbaceous species in the following years.

Compared to the bare plot, the benefit of the vegetative cover on soil erosion and runoff dominated across all plots. The accumulative sediment yield from bare plot was 7 times to that from *A. absurgens* + *C. korshindkii* Kon plots, also over 4 times to that from the *M. sativa, M. sativa* L + *C. korshindkii* Kon and *A. absurgens* plots. Among all the vegetation types, *C. korshindkii* Kon is effective in reducing runoff; while to vegetation combinations, *A. absurgens* + *C. korshindkii* Kon was most efficient in reducing the sediment.

As to the runoff, all the vegetation types were efficient in reducing runoff, whose accumulative runoff depth was 1/3 to 3/4 to that from bare plot. Among all the vegetation types, C. *korshindkii* was the most efficient in reducing the runoff, also the *M. sativa, M. sativa* L + *C. korshindkii* Kon, *A. absurgens* + *C. korshindkii* Kon and *V. amucena* Fish + *C. korshindkii* Kon also had better effect in reducing the runoff.

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