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Runoff and Soil Erosion on Slope Cropland: A Review

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Abstract: Soil erosion has become a serious environmental problem worldwide, and slope land is the main source of soil erosion. As a primary cover of slope land, crops have an important influence on the occurrence and development of runoff and soil erosion on slope land. This paper reviews the current understanding of runoff and soil erosion on slope cropland. Crops mainly impact splash detachment, slope runoff, and sediment yield. In this review paper, the effects of crop growth and rainfall on the splash detachment rate and the spatial distribution of splash detachment are summarized. Crop growth has a significant impact on runoff and sediment yield. Rainfall intensity and slope gradient can influence the level of erosive energy that causes soil erosion. Furthermore, other factors such as antecedent soil water content, soil properties, soil surface physical crust, and soil surface roughness can affect soil anti-erodibility. The varying effects of different crops and with different influence mechanisms on runoff and soil erosion, as well as changes in their ability to influence erosion under different external conditions should all remain focal points of future research. The effect of crop vegetation on runoff and soil erosion on slope land is a very important factor in understanding large-scale soil erosion systems, and in-depth study of this topic is highly significant for both theory and practice.

Key words: runoff; soil erosion; crop growth; slope land; impacts

1 Introduction

Soil erosion refers to the process of soil being destroyed, eroded, transported, or deposited by external forces. Soil erosion greatly impacts the environment, and has long been an important concern. Soil erosion from slope farmland is the main source of soil and water losses from the slope (Gu, 2017). For agricultural soils, soil erosion leads to the redistribution of soil, the destruction of soil structure, a reduction in organic matter and nutrient content, and a decrease in water availability, thus making crops more sensitive to drought. Soil erosion also makes the plow layer thinner, causes a decline in soil fertility, limits crop cultivation, increases the cost of fertilizer inputs, and reduces productivity (Cihacek and Swan, 1994; Robbins *et al*., 1997; Fenton, 2012; Liu *et al*., 2012). Compared with the original forest or grassland, cropland has many characteristics conducive to the development of erosion. First, it is more difficult for the vegetation cover on slope cropland to achieve long-term stability, and the cover may change dramatically in any given year. Soil with little or no such coverage has no vegetation to minimize soil erosion during plowing, planting, and seeding. Second, the ability of slope cropland to intercept, delay, and store precipitation is less than that of forest or grassland. This is because slope cropland often has only one species and a simple vegetation structure, generally with no litter. Third, because slope cropland needs to be

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plowed regularly, achieving long-term stability of anti-erosion structures is difficult, and changes in slope micro topography from plowing can intensify erosion. In fact, excessive tillage, itself, in some cases represents a form of erosion (Roose, 1983; Mchunu *et al*., 2011; Felicia, 2014; Zhang and Tang, 1990; Wang *et al*., 2002; Wang *et al*., 2003). When the impacts of these factors occur in aggregate, soil erosion of slope cropland can be very significant. Comparing abundant runoff plots and watershed observations shows that slope cropland is the main source of soil and water loss on slopes, and that the amount of soil and water loss from slope cropland can be tens to hundreds of times greater than that from grassland (Tang, 2004). In Rwanda, cropland erosion was responsible for approximately 95% of the country's soil loss (Karamage *et al*., 2016). Since it is closely linked to major concerns such as agriculture livelihoods, food security, and the ecological environment, countries that suffer environmental degradation from soil and water loss pay close attention to the problem of soil erosion from slope cropland (Kimaro *et al*., 2008; Tamene and Le, 2015; Mwango *et al*., 2016) .

Crops are the principal plants in the erosion system of slope farmland, the main cover on the soil surface, and thus the key factor affecting the development of slope farmland erosion. Crops directly benefit from erosion prevention. Crops cannot cover the surface at all times throughout the year; however, the erosive rainfall season generally coincides with the main growing period for numerous crops. During the growing season, surface coverage of crops decreases the rainfall and runoff scour. It is possible to effectively decrease soil and water loss from slope farmland by cover cropping (Ma, 2009). During the crop growth cycle, canopy cover changes dramatically, and most crop growing seasons occur over the summer and fall, a time of much rainfall in certain regions of the world. Further study of the effects of different growth stages of crops on soil erosion is necessary to clarify the inhibition mechanisms and degree of impact crops have on runoff and sediment yield from slopes, and also to provide a scientific basis for developing measures that prevent and soil erosion and control farmland water use.

2 Soil splash detachment under crop cover

Slope soil erosion includes two processes: raindrop splash and the scour and transport of slope runoff. In general, the destructive effect of raindrop splash on the soil structure makes it easier for slope runoff to scour the surface. Soil particles that have been dispersed by raindrops provide a rich source of material for the slope flow (Yao and Tang, 2001).

Raindrop splash detachment occurs when raindrops hit the soil directly and disperse soil particles, causing the particles to detach and migrate after rain hits the earth's surface. Splash detachment usually occurs early in slope runoff and is the initial stage of soil erosion on slopes (Zheng, 2008). Because of the impact of raindrops, soil particles separate from the soil layer, thus destroying the soil structure, increasing runoff turbulence, strengthening the scatter and capacity for surface runoff transport, and contributing to the occurrence and development of corrosion and erosion (Zhu, 1982). Splash detachment is an important part of the soil erosion process and a variety of study methods and observational tools have been employed to understand it (Zheng, 2008).

Splash energy is derived from a raindrop's kinetic energy. Splash detachment is thus closely related to the size, shape, terminal velocity, kinetic energy, and other physical characteristics of raindrops (Brodowski *et al*., 2009; Zheng, 2008). Raindrop size is the physical basis of soil splash detachment. As raindrops fall from high altitudes, they convert gravitational potential energy into kinetic energy, and thus have a certain speed and energy (Han *et al*., 2010). Raindrops of median diameter (D_{50}) can cause a strong splash, but the larger the diameter of the raindrop, the greater the raindrop energy and the greater the intensity of splash detachment (Guo, 1997). Raindrop diameter, energy, speed and other characteristics have been studied extensively in many parts of the world, and a number of calculation methods suitable to different conditions have been developed (Laws and Parsons, 1943; Jiang *et al*., 1983; Mou, 1983; Xu, 1983).

Extensive research has led to the establishment of a regional rainfall kinetic energy formula. However, a general natural rainfall formula for raindrop characteristics is still lacking. Factors such as geographic location and type of rain matter here, and the forms of the estimation formula and coefficient values differ (Zhang *et al*., 2002). If the product of rainfall kinetic energy and raindrop diameter is defined as rainfall erosion force, there is a strong correlation between this force and soil erosion. The rainfall erosion force reflects the potential ability of rainfall to erode (Gao and Bao, 2001).

The kinetic energy of rainfall is the main source of splash detachment power. To prevent or slow down erosion, the rainfall energy should be reduced. Vegetation has great potential to reduce rainfall kinetic energy (Zhang and Liang, 1996). There are three main ways to categorize rainfall that falls through a canopy: 1) In terms of "through raindrops" that fall through the canopy and hit the soil, 2) In terms of stem flow, 3) Or in terms of closure. Only the through raindrops can produce raindrop splash detachment (Liu *et al*., 1994; You *et al*., 2003). The effect of plants on rainfall is mainly reflected in the reduction of rainfall energy from stem flow and closure, followed by the influence of plants on energy reduction with through raindrops. However, the amount of kinetic energy with through raindrops depends on the height of the vegetation, and the higher the vegetation, the larger the splash. Therefore, vegetation height is the most important factor determining the amount of splash detachment (You *et al*., 2003; Han *et al*., 2010).

Because the growth environment of crops is special and managed by humans, the influence of crops on splash detachment is different than that of trees or grass. Crop splash erosion under the crown increases with the height of the crop canopy above ground (Sreenivas *et al*., 1948). At the same time, it also decreases with an increase in crop canopy coverage. The relationship between rainfall kinetic energy reduction and splash erosion reduction is relatively complex (Morgan, 1982). Morgan (1982) notes that rainfall kinetic energy reduction by crops and the closure of crop canopies has no connection. The influence of the canopy on rainfall is determined by the amount of rain that falls through the canopy, the raindrops size, and the change of energy created. Morgan (1982) also notes that the impact of the crop canopy on erosion is not only a factor of changes in rainfall characteristics, but is also influenced by other factors such as crop cover, crust, and rainfall intensity, etc. As kale, sugar beets, and potatoes grow, crop interception increases and the amount of through rainfall decreases, but the amount of water on leaf margins rises, meaning that the amount of splash erosion under the crop crowns decreases (Finney, 1984). The amount of splash erosion in areas like this increases because the median raindrop diameter and the rainfall kinetic energy increase. Corn and soy crops have been found to have opposite results on splash detachment (Morgan, 1985). Splash erosion under the crown increases with an increase in corn canopy coverage. When corn coverage reaches 90%, the amount of corn crown splash erosion is 1.5–2.0 times that of splash erosion on bare land. The amount of erosion under a soybean canopy decreases with an increase in soybean coverage, and when the coverage reaches 90%, erosion is only 20%–60% that of erosion on bare land. In the case of corn, canopy growth increases splash erosion. The most likely reason is the interaction between the size of raindrops and the fall height from the corn canopy. In other words, a high degree of rain falling through a corn canopy can increase the kinetic energy of the raindrops (Morgan, 1985). Within and below the canopy of the plant, no splash will be generated when the rain falls from a height of less than 0.3 m. As the fall height of the large raindrops in the canopy increases, the erosion capacity of the canopy gradually increases. Especially as fall heights approach 2 m, the erosion capacity of large raindrops increases rapidly (Moss and Green, 1987). Morgan (1985) found that splash erosion intensity can be significantly different in different areas of crop crowns. This illustrates that the amount of splash erosion under crop crowns is unevenly distributed (Ma, 2009). The spatial distribution of through rain is an important factor influencing splash erosion, because the splash detachment amount can increase if distribution under the crown is concentrated at certain points (Armstrong, 1987; Armstrong and Mitchell, 1988). It has been found that the potential splash erosion rate under a soybean crown is 5%–30% that of bare land splash erosion under uniform rainfall. From these studies, it can be seen that the effects of crop canopy on rainfall erosion are complex, and that different crops have widely different impacts on splash erosion due to different morphological structure characteristics and more.

3 Runoff and sediment yield from slope land

The rainfall kinetic energy is much greater than the potential energy of the surface runoff on a slope. This means that raindrops have a greater ability than runoff to separate soil particles. In fact, surface runoff causes 85% of surface soil loss, whereas raindrops only cause 15% (Fu *et al*., 2001). The process of runoff scouring on slope land was first studied long ago. In 1917, Miller and others used plots to observe soil erosion caused by crop rotation. Subsequently, Bennet and others established a soil erosion test station and promoted Miller's observational method (Zheng, 2008). A large number of studies have shown that runoff and sediment yield involve complex processes, affected by a variety of factors such as rainfall, soil, soil moisture, and soil crust factors, as well as factors related to underlying conditions (Fu *et al*., 2001).

3.1 Effects of crop vegetation

Studies have shown that runoff from bare land is determined mainly by rainfall intensity and soil infiltration rate. Conversely, vegetation affects the amount of infiltration and flow rate by changing the state of the underlying surface, thus reducing the sediment capacity of surface runoff and water and soil loss from the slope (Qin *et al*., 2005;Wu, 2005). The effect of crops on soil erosion is reflected in the interception of rainfall by the above-ground plants. Crops reduce the impact of raindrops on the surface of earth by trapping rainfall, thus reducing soil erosion. The effect of crops intercepting rainfall is mainly influenced by the height and density of the ground crops. When raindrops fall on crops, the energy of the raindrops is dispersed and the drops cannot hit the surface directly. Some of the rain is trapped by the crops and some evaporates into the atmosphere, while the remaining raindrops move down due to gravity or flow down along the stalks. Because of the accumulation effect that occurs to raindrops on crop leaves, these raindrops have diameters roughly two times as great as those of natural raindrops as they fall (Brandt, 1989). Surface crops also have a redistributive effect on the spatial distribution of natural rainfall (Mosley, 1982).

Because crops have a short growth cycle and are subject to considerable human intervention, the effects of crop vegetation on slope runoff and sediment yield are quite different than those of forest or grassland. Studies have shown that the runoff from farmland is much greater than that from forest or grassland, with sediment yields 2–4 times that of woodland, and 4–7 times that of natural slope. Sediment yields from farmland runoff also have a large range of vari-

variations. Therefore, the erosion resistance of farmland is poor (Li *et al*., 2006). However, compared with bare land, forage crops, banana plantations, and tree crops can reduce erosion and the C factor of most seasonal food crops ranges from 0.2 to 0.8 (Roose, 1986). Corn and wheat are more likely to intercept rainfall than bare land, and thereby reduce runoff (Song *et al*., 2000). Sediment yields are less when land cover conditions are better. In terms of crop types, runoff and sediment yield from corn is less than that from wheat stubble. Wheat has less runoff loss than sorghum and *Helianthus annulus*, while a wheat-sunflower rotation can reduce the risk of soil erosion (Loch *et al*., 2000). Wheat fields can reduce slope runoff by about 22%, while the ratio of bare land to wheat field erosion modulus was as much as 25 times greater (Sun *et al*., 2005). Compared with bare land, the annual runoff and sediment yield from corn fields decease an average of 19% and 30%, respectively, while the annual runoff and sediment yield from alfalfa fields decease an average of 76% and 86%, respectively (Wang *et al*., 2011), which may indicate that the anti-erosion ability of crops is relatively weaker than other vegetation canopy. A WEPP model simulation showed that planting soybean and peanuts can reduce erosion by 29.6% and 27.7%, respectively, on steeply sloped land (Singh *et al*., 2011). In addition, crop stubble also has a preventative effect on soil erosion, and an increase in crop stubble results in lowered runoff and sediment yield from a slope (Kenimer *et al*., 1986). The effect of crops on runoff and sediment yield has been studied extensively, but previous research has not been effectively combined with the formation cause of the effect of crops on runoff and sediment yield.

3.2 Effects of rainfall intensity

Rainfall erosivity, the term used to represent the erosive force of rainfall and the consequent runoff, involves the detachment of topsoil particles by the kinetic energy of falling raindrops, and the transport of soil particles by means of surface runoff (Vrieling *et al*., 2014). Studies have shown that the main rainfall factor affecting runoff and splash amount is rainfall intensity. The intensity of soil erosion depends on the rainfall intensity when other conditions are constant (Yao and Tang, 2001; Zhu, 1982). A large number of observational studies have found that the effect of rainfall intensity on slope flow is very direct. The essential reason for runoff is that the rainfall intensity is greater than the infiltration rate. The greater the rainfall intensity, the greater the speed of slope runoff, the stronger the surface flushing action, and the greater the slope sediment yield (Ekern, 1954; Zhu, 1982; Watson and Laflen, 1986; Song *et al*., 2000; Truman *et al*., 2011). The higher the intensity of the rainfall, the sooner slope runoff starts to flow. However, slope infiltration increases significantly when the rainfall intensity increases to a certain critical value (Liu and Tang, 1990). If rainfall intensity continues to increase, runoff will increase and infiltration will begin to decrease again. Runoff from gentle slopes increases with a moderate rainfall intensity increase in China's Loess Plateau, but the correlation is low (Wu and Zhao, 2000). Rainfall intensity is the main factor impacting the sediment yields of hilly lands (Song *et al*., 2000). Slope soil erosion and rainfall intensity exhibit a power function relation, and the corresponding parameters are determined from splash erosion and slope surface erosion (Wan *et al*., 2001). However, rainfall intensity has a closer relationship to slope runoff and erosion modulus. The influence of rainfall intensity on slope runoff and sediment yield is more significant than the influence of terrain factors, e.g., slope (Sun *et al*., 2005). The effect of rainfall intensity on runoff and sediment yield of slopes is greater than the effect of factors such as slope, slope length, and others, based on data for erosion from a bare slope (Wang *et al*., 2005). Munodawafa (2014) found that runoff and soil losses were a function of rainfall intensity and the number of years of cultivation of the land, and they differed depending on the kind of ground cover. Indoor simulations of rainfall suggest that rainfall intensity is the main factor in determining slope runoff, but that the impact of intensity on sediment yield is weak (Lu *et al*., 2011). An increase in rainfall intensity not only drops more water resulting in more material being transported because of strong splash erosion caused by stronger rainfall kinetic energy, but can also increase slope runoff turbulence. Previous studies have found that slope sediment yields decrease by an average of 63.45%, to a maximum of 83.9%, when raindrop impact is eliminated. Thus, the effect of rainfall intensity on runoff and sediment yield is complicated (Wu, 1999).

3.3 Effects of slope gradient

Slope is the factor that determines how powerful runoff is, and the runoff dynamic on a slope surface is determined by the slope gradient (Yao and Tang, 2001). Many studies have shown that slope surface runoff and soil loss increase as slope increases within a certain range (Foster and Martin, 1969; Chen, 1985; Shi, 1991; Liu and Jiang, 1994; Geng *et al*., 2010). Analysis of a large amount of data from rainfall simulations has shown that slope soil erosion is proportional to slope angle (Zingg, 1940). But the relationship between slope and slope surface erosion is more complicated than this suggests. There is a quadratic polynomial relationship between soil erosion and slope, which has been used by the USLE in later research (Smith and Wischmeier, 1957). Erosion occurs when the slope of farmland is greater than 2°, and when rainfall intensity is getting greater (Zhu, 1982). The amount of erosion from a slope increases with increases in slope, but the relationship lacks regularity. When the slope is less than 18°, changes in slope soil erosion are quite gradual with an almost straight line relationship existing between changes in slope and soil erosion (Morgan, 1985). When the slope is between 18° and 25°, the change of slope soil erosion becomes more pronounced, and the relationship between changes in slope and soil erosion becomes exponential. When the slope is greater than 25°, the slope soil erosion decreases rather than increases as the slope becomes greater. As this suggests, the relationship between slope and surface erosion on slopes is complicated. Based on observational data, many scholars have concluded that the relationship between the two is an index or quadratic polynomial, and the forms are different because runoff from different plots has been studied and different observational methods have been used (Wang *et al*., 2004; Chen *et al*., 2010). The impact of slope on runoff depth can be described by parabolic equation, and the equation is highly correlated when the rainfall intensity is light, but the correlation becomes weak when the rainfall is heavy (Wang *et al*., 2005). While runoff is affected by slope and rainfall intensity, the effect of rainfall intensity can overtake that of slope. Runoff increases slowly with rainfall when the degree of slope is low (Lin *et al*., 2009). When the slope is steep, runoff increases rapidly with rainfall. As a slope becomes increasingly steep, the effect of rainfall on slope runoff and sediment yield becomes increasingly significant. In general, the erosion rate increases with an increase in slope. The reason is that the runoff velocity on a steep slope is relatively high, thus reducing the time the runoff is on the slope surface and amount of infiltration. With infiltration reduced, there is more runoff and the amount of erosion increases (Yao and Tang, 2001). The relationship between runoff and erosion from different slope surfaces and degrees of slopes remains roughly the same when the slope is planted with crops. On slopes of less than 8%, a certain level of coverage by a crop (in this case, *Hordeum vulgare*) can greatly reduce soil erosion caused mainly by rainfall factors, but when the slope is greater than 16%, erosion is high because of scour (Woodruff, 2004). For slope farmland, the greater the slope, the greater the runoff assuming coverage and rainfall conditions remain constant, but the situation for sediment yield is not obvious (Song *et al*., 2000). Runoff from a cornfield decreased from 29.2% to 12.2% when the slope of bare land fell from 15º to 5º, and erosion also decreased from 59% to 22% (Wang *et al*., 2011). Runoff from an alfalfa field decreased from 78.5% to 75% as the slope fell from 15º to 5º, but erosion increased from 79.2% to 93.2%. With an intercropping of corn and alfalfa, runoff decreased from 71.8% to 59.1% when the slope decreased, and sediment yield increased from 74% to 89.5%. The effect of slope on the erosion of farmland planted with crops is affected by the crop species and the planting method, which results in a complex relationship between slope and erosion.

3.4 Effects of antecedent soil moisture content

Antecedent soil moisture is one of the important factors impacting runoff and sediment yield from slopes. Research on antecedent soil moisture content has focused on soil water infiltration and migration. There are few studies about the impact of antecedent soil moisture content on erosion. When rainfall conditions are constant, the higher the antecedent soil moisture content, the greater the amount of erosion (Cai *et al*., 1998). A statistical analysis of observational data reveals that the initial time required to produce runoff decreases as soil moisture content increases. The higher the soil moisture content in the early stages, the higher the non-stable production rate, and the earlier the stable production flow time. There exists a power function relationship between antecedent soil moisture content and the time that production flow begins. Antecedent soil moisture has a positive linear correlation with the runoff coefficient, average yield flow rate, runoff depth, and a logarithmic function with sediment transport (Jia *et al*., 1987). The higher the antecedent soil moisture content, the faster the slope flow rate, the lower the average infiltration rate, and the shorter the duration of the stable infiltration rate (Song *et al*., 2006). By observing different soils, the effect of antecedent soil moisture content on the start time, infiltration, and slope flow has been determined to be insignificant. However, the effect on the start time of slope surface runoff in sand loess was significant (Hui *et al*., 2008). However, the slope runoff yield did not stabilize within 60 minutes when the antecedent soil moisture content was low (Zhang *et al*., 2010). When planting crops, the influence of antecedent soil moisture content on slope runoff and sediment yield overlaps with other factors. The correlation coefficient from a single factor analysis is not very high. Thus, when exploring the interrelationship between antecedent soil moisture content and other factors, it is important to understand the effects of other factors on antecedent soil moisture content.

3.5 Effects of soil surface roughness

Surface roughness is an index used to describe the randomness or irregularity of surface terrain at a certain scale. Different farming methods, soil types, crop types, physical parameters of rainfall, and sediment transport processes accounts for the formation of and changes to surface roughness. The surface roughness of cropland is the result of land management and soil erosion. Surface roughness consists of the rise and fall and the sags and crests of the land surface of cropland, and these affect surface runoff and erosion processes (Burwell and Larson, 1969). Surface roughness exerts an effect on erosion mainly by increasing runoff resistance and changing runoff velocity, thus affecting sediment loading capacity and changing the soil erosion yield (Burwell and Larson, 1969; Zheng Zicheng 2007). Surface roughness can increase infiltration and reduce soil erosion on slopes (Johnson *et al*., 1979). Compared with a smooth surface, a rough surface can reduce the runoff volume by 77% and can reduce soil loss by 89%. The influence of surface roughness on soil erosion is not only related to the duration of rainfall, but is also closely associated with slope;

surface roughness in the loess areas creates critical conditions. A rough surface can temporarily store relatively more water in its cavities than a smooth surface, thus increasing the resistance to downward flowing surface runoff. Additionally, surface roughness can increase the amount of sediment interception and hinder the movement of sediment in runoff, thus significantly reducing soil erosion (Cogo *et al*., 1983; Engman, 1986; Sadeghian and Mitchell, 1990). Many studies have shown that an increase in surface roughness can effectively improve the infiltration of slope surfaces and reduce surface runoff and soil loss (Engman, 1986; Johnson *et al*., 1979; Cogo *et al*., 1983; Onstad, 1984; Lawrence, 2015; Bissonnais *et al*., 2005; Lampurlanés and Cantero-Martínez, 2006). However, it should be noted that some researchers believe that surface roughness can increase the potential for erosion of a slope surface, compared with a smooth surface (Burwell and Larson, 1969; Wang and Wei, 1995). Perhaps the different viewpoints are due to different experimental conditions and different research subjects (Zheng Zicheng 2007). Observations of erosion on slope land indicate that average sediment discharge is positively correlated with surface roughness and rill runoff, suggesting that the degree of erosion on bare slope land does not lessen due to an increase in surface roughness. Moreover, the influence of surface roughness on soil erosion resistance might outweigh the influence of erosive force (Wang and Wei, 1995). Also of note, human management can change the surface roughness beneath a crop canopy. In fact, the influence of surface roughness on runoff and sediment yield remains an area requiring further research, as there have been few studies performed to date.

3.6 Effects of soil properties and soil surface physical crust

Soil is the object of erosion and soil, itself, is the intrinsic factor that influences erosion; soil properties are close related to the process of soil erosion. In the case of constant external forces, the degree of soil erosion depends on soil properties, such as soil particle composition, aggregates, etc. Soil particle composition is one of the key factors affecting soil erosion resistance. As early as 1969, Wischmeier and Mannering (1969) pointed out that most soil erosion of farmland in the United States occurred in areas with sandy and silty soil. Study of the Loess Plateau region in China also indicates that coarse silt (0.05–0.01 mm) and sand (> 0.05 mm) are the leading determinants of soil erosion resistance (Liu, 1997). In recent years, scholars have begun to analyze the relationship between soil properties and soil erosion by studying changes to soil particles before and after rainfall. The study of yellow soil in hilly loess areas shows that fine particles are more easily carried away by water (Zhang *et al*., 2000).

Soil aggregate is the basic unit of soil structure, and stability of the aggregate determines the stability of soil surface structure. It is generally believed that sandy soil aggregate is prone to dispersion and corrosion, while soil with high clay content and high organic matter content characteristically has strong adhesive force, stable aggregate and strong resistance to corrosion (Barthès and Roose, 2002; Bissonnais *et al*., 1995). Guo and Wang (1992) determined the resistance to erosion of forestland, farmland and loess plateau grassland soils, and found that the content of water stable aggregates was the best indicator of a soil's resistance to erosion. Li *et al*. (2005) also showed that soil with high water stability did not easily form soil crust and had good infiltration performance; runoff and erosion of such soil was limited.

As a result of the action of water, soil crust is a relatively dense plate-like structure formed on the soil surface. The surface crust of slope land is formed by rainfall and characteristically has a smooth surface and a close texture and is prone to cracking (Fan, 2001). Much research has focused on the development mechanisms, formation processes, and influencing factors of topsoil crust. Findings indicate that crust can reduce infiltration, increase surface runoff, affect the erosion process, and cut down crop biomass and yields (Watt and Valentin, 1991; Farres, 1978; Moore and Singer, 1990; Tang *et al*., 2004; Cheng *et al*., 2007; Wu and Fan, 2002; Wu and Fan, 2005; Pu *et al*., 2007). The surface is more likely to form runoff and is more prone to erosion when the topsoil is crusted (Cai *et al*., 1998). In situations where all else was similar, the runoff coefficient, the cumulative runoff yield, the erosion modulus, and the cumulative sediment yield of a crusted slope were all several to tens of times greater than those for a non-crusted slope. When crust compactness increased in the early stage, the influence of crust on runoff and sediment yield was greater. The runoff yield of crusted slopes increased, thus changing the dynamics of the runoff. For example, runoff shear stress increased and this increased the slope sediment yield (Tang *et al*., 2004). Observations of topsoil crust on different slope gradients reveals that an increase in slope gradient decreases the rate topsoil crust contributes to runoff and sediment, and the increases the rate slope contributes (Cheng *et al*., 2007). The increase in erosion force on a slope was much larger than that of anti-erosion force after the crust was produced, leading to an increase in sediment.

Although researchers have reached a consensus about the impact of crust on runoff, there is still disagreement about whether soil crust promotes sediment yield. Planchon *et al*. (1987) found that severely crusted surfaces could limit erosion upslope, but lead to more serious erosion downslope. Compared to slopes without crusts, the initial runoff time and runoff peak of a slope with crust occurred sooner, and the runoff yield increased, whereas the sediment yield was lower on the slope with crust (Wu and Fan, 2005). Quaternary red clay and granite soil did not easily form crusts. If the surface has heavy crust, it can reduce runoff amount and sediment yield (Hui *et al*., 2008). However, loess crust reduces the increase in infiltration and runoff and has little effect on slope anti-erosion, but the effect of the crust gradually disappears with rainfall (Pu *et al*., 2009). The increase of runoff from yellow soil was higher than the increase of purple soil because of topsoil crust, but the topsoil crust of both soils tended to suppress sediment yields (Chen *et al*., 2011). It can be seen that topsoil crusts are a special kind of underlying surface that has a profound effect on runoff and sediment yield processes. There is, however, still controversy about the impact of crusts on the sedimentation process. This may be due to differences in the way studies have considered soil, rainfall, topography, and other factors, as these relate to soil crust. This topic requires further study.

4 Conclusions

Crops are a special form of vegetation, and the effect of crops on soil erosion from slope land is a concern of great importance. However, many studies of soil erosion from slope land have focused on bare slopes, while studies of the mechanisms of crop influences on soil erosion from slope land are relatively rare. The occurrence and development of soil erosion in cropland are the result of the combined effects of various factors. Crop cultivation influences the various factors that impact the erosion process, and changes in crop cultivation bring great change to erosion processes on slope land. Various factors combined with crop vegetation exert an influence on soil erosion from slope land. Additionally, based on an analysis of soil erosion mechanisms on cropland, this research has clarified the effects of the main factors on soil erosion of cropland, and the interaction of the various factors that influence erosion has been discussed. Future research on the processes and mechanisms of soil erosion from slope cropland will help to predict soil erosion problems and aid in the management of agricultural production.

Agricultural in Africa is largely rain-fed agriculture, and the rainfall is concentrated in rainy seasons. The main type of cultivated land in Africa is slope land, so extensive cultivation on slope land will lead to more and more soil and water loss. Unfortunately, land degradation caused by soil erosion seriously threatens food security in Africa. Future studies of slope land erosion in Africa can focus on the appropriate crop species to plant, the form of planting, planting density, the development of rain-fed agriculture patterns and annual rainfall distribution.

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坡耕地径流与土壤侵蚀研究进展

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摘 要: 土壤侵蚀一直是重要的全球性环境问题之一，而坡耕地的土壤侵蚀是坡地水土流失的主要源头。作为坡耕地的主要覆盖方式，作物对坡耕地径流和土壤侵蚀的发生和发展都产生了重要的影响。本文主要回顾了目前坡耕地径流和土壤侵蚀的影响因素，以及作物生长、降雨溅蚀及其空间分布等问题。作物主要影响了坡耕地雨滴溅蚀、坡面径流和侵蚀产沙，并且径流和土壤侵蚀还受降雨强度、坡度、土壤前期含水量、土壤表层物理结皮及土壤糙率等因素影响。不同作物对径流和土壤侵蚀的作用和影响机制，以及它们在不同外部条件下影响侵蚀的能力的变化，都将成为未来研究的重点。作物植被对坡地土壤侵蚀的影响是了解大规模土壤侵蚀系统的一个重要因素，对这一课题的深入研究对坡耕地径流和土壤侵蚀研究的理论和实践都具有重要意义。

关键词: 径流；土壤侵蚀；作物；坡耕地；影响