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Effects of straw covering methods on runoff and soil erosion in summer maize field on the Loess Plateau of China

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ABSTRACT

The objective of this paper is to clarify the impacts of straw covering method on runoff and soil erosion in summer maize field on the Loess Plateau of China. A field experiment was conducted (2012–2014) in the artificial raining hall of the State Key Laboratory, with three soils and five straw covering methods. Three soils were Heilu soil (Calcisols), Huangmian soil (Fluvisols) and Lou soil (Anthrosols). Five straw covering methods were CK – no straw mulching and no stubble standing on the surface of the plot; T30 – 30 cm of winter wheat (WW) stubble standing above ground; M30 – 30 cm of WW stubble was harvest and mulched on the surface of the plot; M10T20 – 20 cm of WW stubble standing and 10 cm WW straw mulching on the surface of the plot; M20T10 – 10 cm of WW stubble standing and 20 cm of WW straw mulching on the surface of the plot. The results showed that (1) straw covering method not only impacted ITRP (initial time of runoff producing), but also affected runoff volume in summer maize field on the Loess Plateau of China. M10T20 was the best to postpone ITRP and to reduce runoff volume in summer maize field. (2) Different covering methods produced different sediment yield in summer maize field. M30 was the best to reduce soil erosion in summer maize field on the Loess Plateau of China. (3) When one covering method was used to reduce runoff or soil erosion, bulk density and soil mechanical composition (silt content, clay content and sand content) should be considered seriously.

Keywords: straw mulching; stubble standing; *Triticum aestivum* L.; arid and semi-arid areas

Soil erosion is widespread and affects adversely all natural and human-managed ecosystems, especially in arid and semi-arid areas (Liu et al. 2014). The Loess Plateau, located in the northwestern areas of China, is one of the most severe soil erosion areas in the world. More than 60% of land on the Loess Plateau has been eroded, with an average annual soil loss of 2000–2500 t/km^2 (Zheng et al. 2005). Significant amounts of nutrients associated with surface soil have been lost during soil erosion in the Chinese Loess Plateau. It has been estimated that each ton of lost soil contains 0.8–1.5 kg of ammonia, 1.5 kg of total phosphorus and 20 kg of total potassium (Liu et al. 2012). Furthermore, the Loess Plateau is the main source area for sediment discharging into the Yellow River (Sui et al. 2014). Between 1990 and 2000, approximately 90% of the sediment in the Yellow River (1.6 billion tons per year) came from the Loess Plateau (Xu and Yan 2005). Ecosystem degradation on the Loess Plateau and elevation of the riverbed at the lower Yellow River are the most serious consequences of intensive soil erosion (Zheng et al. 2005). In fact, the highest erosion rate is usually found on agricultural land where

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the vegetation cover is low. Research conducted in Spain confirmed that sediments coming from agricultural land are higher than that from grass land, forest land and scrub land (Garcia-Estringana et al. 2013). This is why soil erosion control strategies are widely applied on agricultural land worldwide.

Among the available mechanical and agronomic practices, straw cover is one of the most important practices known as the 'first line defense measures' against soil erosion. Malvar (2013) reported 45% lower runoff in mulching plots than in no mulching plots. Döring et al. (2005) reported that soil erosion was reduced by 97% in a rain simulation experiment on a potato field of 8% slope with 20% crop cover. Soil loss was greatest (1606 g/m^2) in no mulching treatment, and 31, 42 and 26 g/m^2 in treatments with chopped straw at 1.25, 2.5 and 5 t/ha, respectively. Many field and laboratory experiments investigated the impacts of straw covering on soil erosion by water in a large range of environmental conditions on the Loess Plateau. Most authors agreed that covering soil surface with straw was a very effective practice to control soil erosion (Tasumi and Kimura 2013). However few papers reported different impacts of different covering methods on soil erosion in summer maize field on the Loess Plateau of China.

The objective of this investigation was (1) to study the effect of different straw covering methods on runoff and soil erosion for different soils in summer maize field on the Loess Plateau of China. (2) To provide some advices for farmers to conserve rainfall and reduce soil erosion in arid and semi-arid regions.

MATERIAL AND METHODS

Study area. The Loess Plateau, including the study site, was a transitional zone between the southeastern humid monsoon climate and the northwestern continental dry climate. Its annual precipitation ranged from 200–750 mm, with the annual mean temperature of 8.6–13.58°C, and the frost-free period of 185–210 days (Xiao et al. 2013). The historical record of maximum annual precipitation was 722 mm in 1967, and the minimum record was 246 mm in 1982. Generally speaking, 40% of rainfall events occurred during the period from June to September, 80% of rainstorm took place in July, August and September, with the rainfall intensity of 0.5–1.5 mm/min.

The soil in the top 1.2 m was loess soil (a term derived from the Chinese soil taxonomy), and the mean bulk density of the 0–60 cm topsoil zone was near to 1.35 g/cm^3 before experiment.

Field experiment. The experiment was carried out, from 2012–2014, in the artificial rainfall hall of the State Key Laboratory of Dry Land Agriculture at Yangling, Shaanxi province, China. Artificial rainfall system was used to simulate the rainfall during experimental period. The spray nozzle of artificial rainfall system was set at the height of 16 m beside plot, and its raindrop landing speed was near (90%) to the nature rainfall. Rainfall intensity was set to 1.2 mm/min, with the duration of 60 min, according to the range of

Table 1. Treatments of the experiment in this study

	CK	T30	M30	M10T20	M20T10
A	Ck A	T30 A	M30 A	M10T20 A	M20T10 A
B	Ck B	T30 B	M30 B	M10T20 B	M20T10 B
C	Ck C	T30 C	M30 C	M10T20 C	M20T10 C

A – Heilu soil (Calcisols); B – Huangmian soil (Fluvisols); C – Lou soil (Anthrosols); CK – no straw mulching and no stubble standing on the surface of the plot; T30 – 30 cm of winter wheat (WW) stubble standing above ground; M30 – 30 cm of WW stubble was harvest and mulched on the surface of the plot; M10T20 – 20 cm of WW stubble standing and 10 cm WW straw mulching on the surface of the plot; M20T10 – 10 cm of WW stubble standing and 20 cm of WW straw mulching on the surface of the plot

Table 2. Detailed information of soil selected for the experiment

Chinese soil taxonomy	Soil taxonomy	Bulk density (g/cm^3)	Organic content (%)	Soil profile character	Mechanical composition (%)		
					< 0.001	0.001–0.05	0.05–1
					(mm)		
Heilu soil	Calcisols	1.23–1.26	1.3	Ap-Aca-Ab-Bca-C	23.2	70.1	6.7
Huangmian soil	Fluvisols	1.31–1.36	0.9	Ap-C	13.9	45.4	40.7
Lou soil	Anthrosols	1.26–1.31	1.5	Ap-Aca-Ab-Bt-Bca	25.7	69.4	4.9

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Table 3. Straw covering methods used in this study

	Straw amount	Stubble	Mulch
	(t/ha)		
CK	–	–	–
T30	3.2	30 (3.2)	–
M30	3.2	–	30 (3.2)
M10T20	3.2	20 (2.1)	10 (1.1)
M20T10	3.2	10 (1.1)	20 (2.1)

CK – no straw mulching and no stubble standing on the surface of the plot; T30 – 30 cm of winter wheat (WW) stubble standing above ground; M30 – 30 cm of WW stubble was harvest and mulched on the surface of the plot; M10T20 – 20 cm of WW stubble standing and 10 cm WW straw mulching on the surface of the plot; M20T10 – 10 cm of WW stubble standing and 20 cm of WW straw mulching on the surface of the plot

rainstorm intensity in the study area and the ability of the rainfall simulator.

45 steel tanks (2 m × 3 m × 0.5 m) were used in the experiment for 15 treatments (Table 1) with 3 replicates. Each steel tank was set with some equipment at its bottom to collect runoff and sediment. After soil was loaded into steel tanks, layer by layer, winter wheat (*Triticum aestivum* L.) and summer maize (*Zea mays* L.) were planted in the steel tanks. Heilu soil, Huangmian soil and Lou soil (Table 2) were put into steel tank, with the soil water content of 10.2–12.1, 11.3–12.4 and 12.1–13.6%, respectively, and the bulk density of 1.23–1.26, 1.31–1.36 and 1.26–1.31 g/cm^3, respectively. Though the slope of this tank can be adjusted from 0–45°, it was set at 15° in this study, according to the normal slope in the hilly region on the Loess Plateau.

Winter wheat straw was covered by different methods as followed (Table 3), step by step. First winter wheat was harvested by hand and 30 cm (above ground) of winter wheat stubble was left on the ground for all treatments. Second for CK, all winter wheat stubble above ground was cut and was removed outside the plot; no winter wheat straw was left in the plot. For T30, all winter wheat stubble was still stand on soil. For M30, all winter wheat stubble was cut down and was mulched on the surface of soil. For M10T20 treatment, 10 cm of winter wheat stubble (from the top of winter wheat stubble) was cut down to mulch on the surface of soil, and another 20 cm of stubble still stood on soil; M20T10, 20 cm of winter wheat stubble (from the top of winter wheat stubble) was cut down to mulch on the surface of soil, and another 10 cm of stubble was left to stand on soil.

Summer maize was planted on 6 July, with the row spacing of 45 cm and the plant spacing of 22.5 cm, and was harvested at the end of September. The fertilizer was applied at the recommended rate of 40 kg/ha N and 20 kg/ha P.

Samples and measurements. Sediment and runoff were collected each 3 min after the runoff produced. The runoff volume was measured by measuring cylinder method, and the sediment was measured by oven-dry and weighting method.

The initial time of runoff producing (ITRP) was calculated by Equation 1:

$$ITPR = T1 - T0 \quad (1)$$

Where: T1 – time that runoff start produced; T0 – time that the rainfall start.

The total runoff volume (RV_T), and total sediment yield (SY_T) was calculated by Equations 2 and 3, respectively:

$$RV_T = \sum_{i=1}^{N} RV_I \quad (2)$$

$$SY_T = \sum_{i=1}^{N} SY_I \quad (3)$$

Where: RV_I – runoff volume that measured at the Ith times; SY_I – sediment yield that measured at the Ith times.

RESULTS

Effect of straw covering method on ITRP in summer maize field. Though straw mulching and stubble standing both postponed ITRP, different straw covering methods got different value of ITRP. Compared with CK, average value of ITRP for T30, M30, M10T20 and M20T10 increased by 141, 182, 220 and 148%, respectively. M10T20 got the highest ITRP value of 958, 384 and 406 s on Heilu soil, Huangmian soil and Lou soil, respectively.

The effectiveness of straw covering method on ITRP was affected by the mechanical composition of different soil, especially bulk density, clay content, silt content and sand content. The average ITRP value of M10T20 was the highest among all straw covering methods; while the value of ITRP on Heilu soil (958 s) was significantly higher than on Huangmian soil (384 s) and Lou soil (406 s). Similar results were also found for CK, T30, M30 and M20T20 (Figure 1a).

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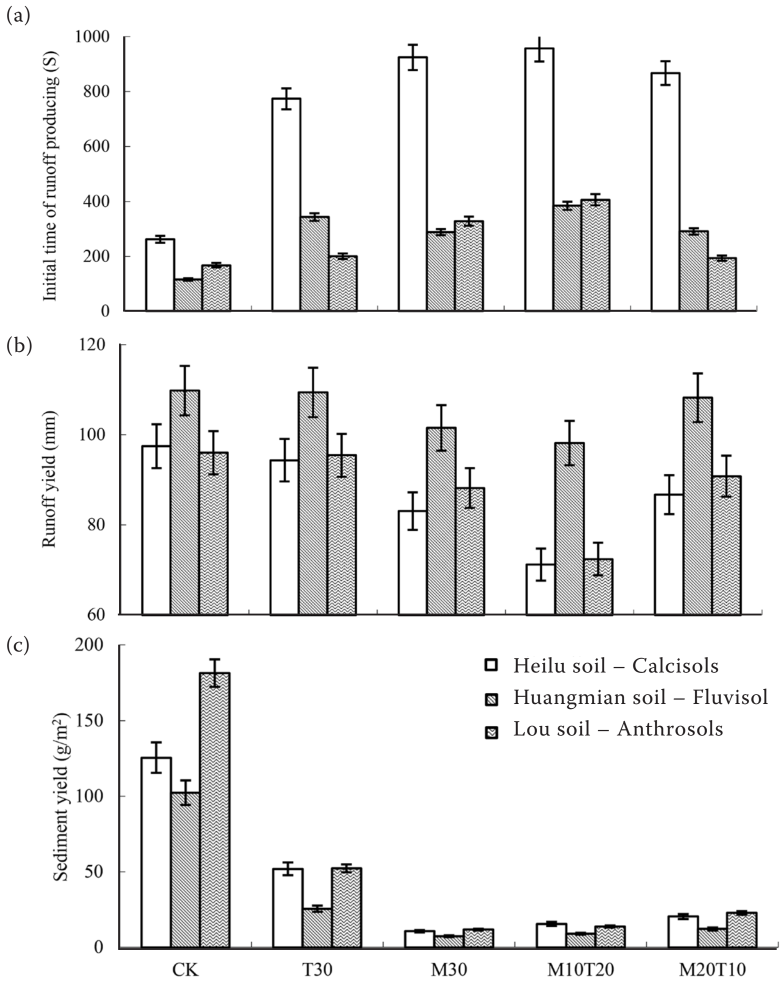

Figure 1. (a) Initial time of runoff producing; (b) total runoff volume and (c) sediment yield of different straw covering methods for different soils in summer maize field on the Loess Plateau of China. CK – no straw mulching and no stubble standing on the surface of the plot; T30 – 30 cm of winter wheat stubble standing above ground; M30 – 30 cm of winter wheat stubble was harvest and mulched on the surface of the plot; M10T20 – 20 cm of winter wheat stubble standing and 10 cm winter wheat straw mulching on the surface of the plot; M20T10 – 10 cm of winter wheat stubble standing and 20 cm of winter wheat straw mulching on the surface of the plot

Effect of straw covering method on runoff volume in summer maize field. Both straw mulching and stubble standing can reduce total runoff volume. Compared with that of CK, the total runoff volume of T30, M30, M10T20 and M20T10 decreased by 1, 10, 20 and 60 mm, respectively. M10T20 was the best method to reduce runoff volume in summer maize field on the Loess Plateau of China, with the mean total runoff volume of 71.2, 98.2 and 72.4 mm on Heilu soil, Huangmian soil and Lou soil, respectively.

Besides straw covering method, soil mechanical composition and bulk density were other important factors to affect the runoff volume in summer maize field on the Loess Plateau (Figure 1b). Mean value of total runoff volume for Heilu soil, Huangmiang soil and Lou soil was 86.5, 105.4 and 88.6 mm, respectively. Heilu soil and Lou soil was better than Huangmian soil to conserve soil water on the Loess Plateau of China.

Compared with stubble standing, straw mulching was better to reduce the runoff volume, and if mixed with stubble standing method, it will be better. Compared with T30, total runoff volume of M30 reduced it by 11, 7 and 7% on Heilu soil, Huangmian soil and Lou soil, respectively. M10T20 reduced it by 25, 10 and 24%, respectively, and M20T10 reduced it by 8, 1 and 4%, respectively. Statistical data showed that the difference of runoff volume between M30 and M20T10 was not significant ($P > 0.05$), while between M30 and M10T20 it was significant at P

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< 0.01, and between M20T10 and M10T20 it was significant at $P < 0.05$.

Effect of straw covering method on sediment yield in summer maize field. Both straw mulching and stubble standing can reduce soil erosion significantly (Figure 1c). Compared with that of CK, sediment yield of T30, M30, M10T20 and M20T10 decreased by 93, 126, 123 and 118 g/m^2, respectively. Compared with CK, T30 reduced sediment yield by 58, 75 and 71% on Heilu soil, Huangmian soil and Lou soil, respectively; M30 reduced it by 91, 93 and 92%; M10T20 reduced it by 87, 91 and 87%; M20T10 decreased it by 84, 88 and 87%, respectively.

Using the same amout of wheat straw, straw mulching method (M30) was the best to reduce soil erosion, then it was mixing method (M10T20 and M20T10), stubble standing method (T30) was the least effective method (Figure 3). On the same soil, M10T20 and M20T10 both produced more sediment yield than M30, while less than T30. Compared with M30, M10T20 increased sediment yield by 46, 23 and 17% on Heilu soil, Huangmian soil and Lou soil, respectively. M20T10 increased it by 92, 67 and 94%, respectively. Compared with T30, M10T20 decreased sediment yield by 70, 64 and 73% on Heilu soil, Huangmian soil and Lou soil, respectively. M20T10 decreased 60, 52 and 56%, respectively.

DISCUSSION

Covering soil surface with mulch increased the soil infiltration rate during a rainfall event (Fehmi and Kong 2012), therefore ITRP of T30, M30, M10T20 and M20T10 was postponed compared with that of CK. Lots of studies had investigated the effects of straw mulching on soil erosion by water, most of them reported a linear correlation between runoff volume and mulching percentage (Robichaud et al. 2013a). Results of this paper showed that straw covering method postponed the ITRP significantly. Compared with CK, average ITRP value of T30, M30, M10T20 and M20T10 increased by 257, 332, 401 and 269 s, respectively. M10T20 was the best method to postpone runoff production in summer maize field on the Loess Plateau of China.

Previous research indicated that the presence of straw mulching on soil affected soil properties, hydrologic and hydraulic characteristics of runoff (Robichaud et al. 2013b). Due to an increase of viscous forces from the physical interference of mulch cover with runoff, mulch cover caused an increase in runoff flow depth and hydraulic roughness and a decrease in flow velocity. Results of this study showed that straw covering methods affected runoff velocity and volume. On the same soil with the same straw covering amount, runoff velocity and runoff volume was different significantly. With the same straw amount, M10T20 was the best to reduce runoff velocity, then was M30 and M20T10, T30 was the worst. Which method is better to reduce runoff velocity was also influenced by soil mechanical composition and rainfall period. On Heilu soil, velocity of M20T10 was the slowest at the beginning of rainfall period, while it was the fastest at the end of period. On Lou soil, velocity of M30 was the slowest at the beginning of rainfall period, while it was the second fastest at the ending period.

Straw mulches spread upon soil surface protected soil from the effects of raindrops (Fehmi and Kong 2012); therefore, compared with CK, sediment production of T30, M30, M10T20 and M20T10 it decreased significantly (Figure 3). Many studies indicated that mulch covering is an important factor in controlling soil detachment and transport by splash and runoff (Alliaume et al. 2014). Results of this paper showed that with the same straw amount, M30 was the best to reduce soil erosion, then it was M10T20 and M20T10, T30 was the worst. This result explained why straw mulching and stubble standing are often used to protect soil surface and to reduce soil erosion during the critical period of plant establishment on the Loess Plateau of China. On the other hand, a previous study indicated that soil mechanical composition was another important factor to affect sediment yield during rainfall (Tasumi and Kimura 2013). Thus, applying the same straw cover method with the same straw amount on different soils (Heilu soil, Huangmian soil and Lou soil) produced different sediment yield (Figure 3).

Soil texture and structure impact the infiltration and retention of rainfall and play an important role in postponing runoff and soil-losing (Noy-Meir 1975). Compared with Huangmian soil and Lou soil, bulk density of Heilu soil was lower; Heilu soil was had higher; therefore more water was infiltrated at the beginning of rainfall period; while, after the runoff produced, more soil would be eroded by runoff. Results of this paper showed that (1) ITRP was the longest on Heilu soil, with the value of 262, 774, 925, 958 and 868 s for CK, T30, M30, M10T20 and M20T10, respectively. (2)

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Compared with other two soils, runoff volume was the largest on Huangmian soil, with the runoff volume of 110, 109, 101, 98 and 108 mm for CK, T30, M30, M10T20 and M20T10, respectively. (3) Sediment yield was the lowest on Huangmian soil, compared with other two soils, with the sediment yield of 102, 25, 7, 9 and 12 g/cm^3 for CK, T30, M30, M10T20 and M20T10, respectively.

In conclusion, straw covering method not only impacted the ITRP, but also affect the runoff volume in summer maize field on the Loess Plateau of China. Compared with other straw covering methods, M10T20 (straw mulching connected with stubble standing) was the best to postpone ITRP and to reduce runoff volume in summer maize field. However, when using this method to reduce runoff, the impacts of soil bulk density and mechanical composition (content of silt, clay and sand in soil) should be considered.

Different covering methods produced different sediment yield in summer maize field. With the same straw amount, M30 was the best to reduce soil erosion in summer maize field on the Loess Plateau of China. Of course, when it was used in summer maize field, the impacts of soil mechanical composition (content of silt, clay and sand in soil) should be considered seriously.

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