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Trace Elements Loss Characteristics in Runoff Discharge from Tobacco-Growing Red Soil in Sichuan Province of China

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Abstract

Trace elements are found in small concentrations in soil, yet plants require them for physiological functions. The runoff process leads to soil fertility loss by shifting soil particles and elements, and deposits them to a different position. However, there is a lack of information about the amount of trace elements that flow in tobacco-growing red soil during the natural rainy seasons due to runoff. In this study, runoff discharge was collected from two different soil mulching conditions (straw and no straw) at 15˚, in Miyi county of Sichuan province, to evaluate the characteristics of trace elements in runoff discharge. The runoff discharge was filtered to separate water (runoff) from sediment. The concentrations of the elements were analyzed in samples obtained from 9 erosive rainfall events, with 3 replications for every sample. The considered trace elements were Zinc (Zn), Copper (Cu), and Molybdenum (Mo). In addition, the total amount of each element loss per unit area (total loss) was also calculated statistically. The results revealed different concentrations and total losses for the selected trace elements. The total loss in runoff ranged from 10.82 to 194.05 mg/ha, 0.62 to 18.91 mg/ha, and 0.32 to 2.37 mg/ha for Zn, Cu, and Mo, respectively. The total loss in sediment ranged from 54.65 to 12036.34 mg/ha, 44.74 to 5285.30 mg/ha, and 1.78 to 399.82 mg/ha for Zn, Cu, and Mo, respectively. Rainfall intensity, runoff depth, and sediment yield showed distinct positive correlations with the trace elements losses. The loss reduced with the addition of straw in the experimental area. Since each trace element showed distinct characteristics in the runoff and sediment, it is crucial to assess the loss of trace elements in runoff discharge from different agronomic practices. In turn, various sustainable practices of preventing soil fertility loss will be identified.

Keywords

Trace Elements, Runoff Discharge, Sediment, Red Soil, Tobacco Farming

1. Introduction

Trace elements are chemical elements found in relatively small concentrations in soil for different ecological functions, except Iron and Manganese that usually have high total contents [1]. Trace elements are essential in agriculture when playing a micronutrient role in various plant physiological functions and overall plant growth [2]. Zinc (Zn) plays a role in the prevention of drought effects by interacting with plant hormones and stimulation of antioxidants [3]. Copper (Cu) is recognized for many processes in a plant, like phosphorylation and iron mobilization within different tissues [4] [5]. Molybdenum (Mo) is mainly involved in nitrogen reduction and assimilation within different parts of a plant [6] [7]. In the nutrition of the tobacco crop, nitrogen and potassium are the major elements, required in higher amount than other chemical elements [8] [9] [10]. Despite the needs of nitrogen and potassium, other supportive micronutrients and agronomic performance are needed to make good quality tobacco as well as optimum quantity of tobacco production.

The main source of trace elements for plant use, is the soil environment [2]. One of the soil types currently used for cultivation is red soil, which is made of reddish clay minerals resulting from iron-rich sediments, or their iron and aluminum compounds may be developed in the soil as it weathers [11] [12]. Red soils are mainly distributed in the subtropical and tropical zone that include the south of China, and are generally reddish ferrosols within Sichuan province located in the southwest of China [13] [14]. The red soil places of Sichuan have become important production regions of forests and various crops in tropical and subtropical China [12]. Due to the hot climate, huge rainfall, and accelerated biological cycling within red soil places, they have a higher potential for food production in China [15]. However, the poor fertility is one of the main yield-limiting factors in the red soil regions [13]. According to the existing literature, careful management is needed to sustain cropping in red soil [15].

Interestingly, the red soil of China is in mountains and hills, places that make the agroecosystem very vulnerable to soil erosion [15] [16] [17]. It was previously emphasized that a sloping farmland is an important resource, and also a major source of soil and water loss in China [18]. In addition, the past results indicated that runoff generation of red soil slopes was influenced by both the slope angle and rainfall intensity [19]. The soil erosion can be regarded as a larger process, however our study focused on the runoff process, one of the specific major problems faced by farmers in mountainous areas. The slope runoff is the critical driving force of water erosion [20]. The expression of surface runoff refers to the portion of the water supply to the surface that is neither absorbed by the soil nor accumulates on its surface, but that runs downslope [21]. Runoff is usually rapidly produced, once rainfall intensity exceeds the usually low infiltration capacity of the soil [22]. Runoff typically begins as sheet flow but, as it accelerates and gains in erosive power, it eventually scours the soil surface to create channels [21].

Under higher rainfall intensity, the influence of slope gradient on runoff rate was significant, especially the moderate slope [19]. Although, past findings suggested that no-tillage practice could increase soil resistance to erosion and sustain soil productivity, the other study confirms that highly erosive rainstorms accelerate soil loss and the associated soil organic carbon loss [17] [23]. Laboratory based experiment have been conducted, where 12 artificial rainfall erosive events were simulated to investigate the coupling loss characteristics of surface flow-interflow-total nitrogen, nitrate nitrogen and ammonia nitrogen on weathered granite slopes [24]. Moreover, the previous study revealed that rainfall events of 30 mm or above were considered as those larger storms that were erosive enough to produce runoff [25].

In the previous time, runoff contributed to soil detachment and sediment yield from sloping land [26]. In fact, runoff brings about environmental effects such as water body pollution and eutrophication [27] [28]. The literature confirms that nutrients are easily transported as subsurface flow or runoff [29]. According to past studies, nutrients are mainly lost through runoff and sediment, but they are influenced by many factors such as rainfall characteristics, vegetation cover, soil properties, water flow type, and slope [11] [25] [30] [31].

Different soil elements have been lost in the following different case studies. Potassium was lost via runoff and sediment flow in sugarcane, maize, black gram, and fallow land located on different slopes, in the cotton field of Red-yellow Latosol soil, and in the light red textured red soil planted with Sorghum [32] [33] [34]. On the other hand, total nutrients loss in stimulated rainfall of 64 mm/h and slope of 0.18 was significantly observed in soil erosion water, with a different loss estimated in different soil management systems [35]. Furthermore, the loss of trace elements has been a concern in the past studies on agricultural soils under different management and geographical location [36] [37] [38] [39] [40].

A previous study reported extensive concentration of trace elements in surface runoff at the karst catchment scale [41]. Zn was observed in surface runoff and leachate from an agricultural soil amended with poultry litter application [42]. Similarly, sediment Cu loss transport was observed under different tillage systems in long-term agricultural farmlands with field slope ranges of 7% - 13% [43]. However, there is no available study on soil trace elements runoff loss (Zn, Cu, and Mo) in the red soil of the tobacco planting field in Miyi county. The main objective of this study was to evaluate the characteristics of Zn, Cu, and Mo loss through runoff discharge in red soil under different factors, which was achieved through the following specific objectives: 1) to determine Zn, Cu, and Mo concentrations in runoff water and sediment, 2) to determine Zn, Cu, and Mo total amount in runoff water and sediment, and 3) To evaluate the characteristics of Zn, Cu, and Mo loss with runoff discharge in red soil under different factors.

2. Materials and Methods

2.1. Study Area Description

The study was conducted in the experimental field of tobacco-growing soil (27˚6'25''N, 102˚8'49''E) in Miyi County, Panzhihua city, located in Sichuan province of China (**Figure 1**). The region is under a subtropical climate with the hot-humid summer season; the average annual temperature is 19.2˚C, and the average annual rainfall is 1065 mm, with higher peaks from June to October [44]. The landform of Miyi county is generally dominated by mountains and hills, and its highest summit is above 3000 m of altitude (**Figure 1**). The soil is recognized as red soil, which is a result of the weathering of iron-rich sediments [15]. This red soil has a poor structure, which is easily eroded leading to runoff on steep slope and soil erosion in rainy season [15]. The in-situ experiment was conducted on field plots with slope gradient of up to 15˚, and the soil seasonally ploughed for annual crops cultivation. The soil concentration of Zn, Cu, and Mo for the 0 - 30 cm was 11.153 mg/kg, 9.225 mg/kg, and 0.412 mg/kg, respectively (determined by authors from soil collected before experiment start up). The region favors various outdoor farming activities by being frost-free for almost the whole year. The dominant cash crops in this region include tobacco (*Nicotiana tabacum L*), corn (*Zea mays L*), and different varieties of fruits. The downhill planting is the common conventional method used by farmers in the region to grow tobacco. Our study selected two different soil mulching conditions applied at 15˚, and a plastic film mulching at 0˚ of slope gradient, to study the loss characteristics of Zn, Cu, and Mo in runoff discharge observed during one season of tobacco cultivation period.

2.2. Runoff Plots Description and Experiment Setting

Plots were established following procedures previously described by Xu *et al.*, [45], but the control plots were reconstructed and set to 0˚ of slope gradient. In April 2021, the downhill rows were designed in every plot as it is the actual practice done by farmers in the study area. Then the straw mulching (straw) was applied to some plots, while others were kept free from straw mulching (no straw) (**Figure 2(a)**). Our study used a total of 9 plots arranged in randomized-block experimental design, where three replications were designed for each treatment.

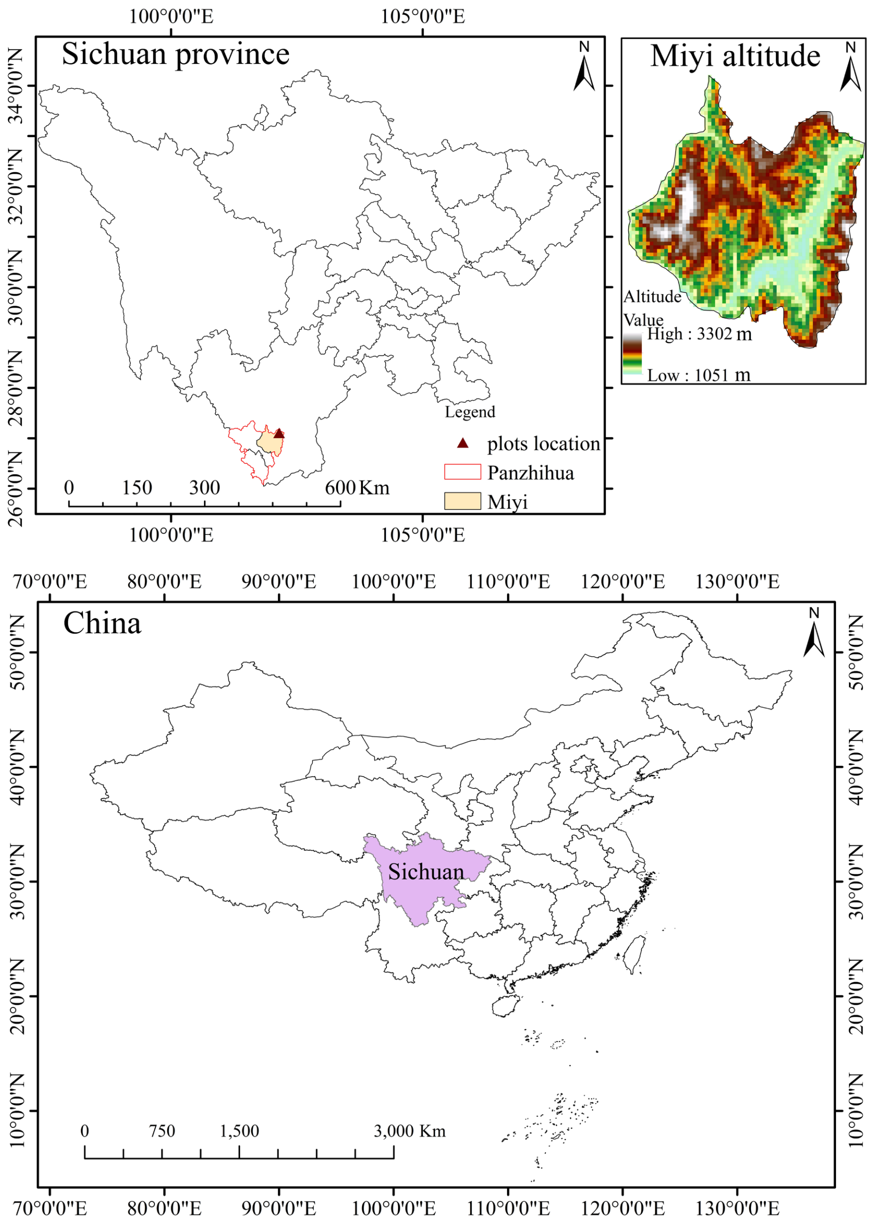

Figure 1. Geographical position of the study area. It shows the position of Sichuan province in China, the experimental location, and the altitude of Miyi county. The red small triangle represents the position of the runoff plots at 1700 m of altitude. The red boundary is for Panzhihua city. The maps were created using ArcMap version 10.5 software (https://desktop.arcgis.com/). The shapefiles and the altitude mask were accessed via https://mapcruzin.com/.

Additionally, different soil fertilizers were evenly applied in the plots prior to seedling transplanting. The fertilizers were organic manure of sheep, Calcium superphosphate, and NPK, which are commonly used by tobacco farmers in the study area to support the growth of the tobacco plants. It was followed by water supply to enhance the initial soil water necessary for seedling survival. The seedlings were then transplanted with 60 cm between two neighboring tobacco

(a)

(b)

Figure 2. Mulching practices on plots of downhill planting system. The mulching practices that were done on sloping land of 15˚ of slope gradient, and the seedlings that transplanted in downhill system; (a) displays the straw used in our experiment and (b) shows the view of the plots after seedlings transplanting.

seedlings, and plots were ultimately covered with a plastic film to maintain the soil moisture for growth of the seedlings (**Figure 2(b)**).

2.3. Runoff Plots Description and Experiment Setting

The field sample collection of rainfall, runoff, and sediment characteristics was carried out according to the techniques previously described Xu *et al.*, [45]. In the laboratory, runoff water was filtered with 0.45 μm PTFE membrane, while sediment samples were dried overnight in an oven-dryer machine at 105˚C. The sediment samples were digested using acids (65% HNO_3, 70% $HClO_4$, and HF), and the target micronutrients in runoff and sediment were analyzed using inductive coupled plasma-mass spectrometry [46] [47].

2.4. Erosive Rainfall and Runoff Discharge Characteristics

During 7 months (April to October) of the field experimental time, the first erosive rainfall was observed in July. Our experiment selected 9 erosive rainfall events of different intensities to study the loss of Zn, Cu, and Mo with runoff discharged caused by these different rainfall characteristics. The details of rainfall, runoff, and sediment were as follow.

The range of runoff depth from plots mulched by straw was from 0.65 mm exhibited by 1.27 mm/h to 4.85 mm exhibited by 10.54 mm/h; plots without straw mulching showed runoff that ranged from 3.54 mm to 12.98 mm exhibited by 1.59 mm/h and 6.04 mm/h respectively (Table 1). In addition, the range of sediment yield under straw mulching was from 4.52 kg/ha influenced by 1.27 mm/h to 111.79 kg/ha caused by 10.54 mm/h; plots without straw mulching showed sediment yield that ranged from 60.69 kg/ha to 478.61 kg/ha exhibited by 1.27 mm/h and 10.54 mm/h respectively (Table 1). At the control plots, there were no runoff generation in all rainfall events.

2.5. Statistical Analysis

The observed concentration of Zn, Cu, and Mo, with total volume of observed runoff, and the sediment yield, were used to calculate the total amount of these trace elements (total loss) flowed in the runoff discharge of each erosive rainfall event. The following formula was used:

Table 1. Runoff depth and sediment yield under different rainfall in the study area.

Rain intensity (mm/h)	Date (month/Day/year)	Runoff depth (mm)		sediment yield (kg/ha)	
		no straw	straw	no straw	straw
1.06	08/13/2021	4.18	1.74	137.78	45.18
1.27	08/23/2021	3.61	0.65	60.69	4.52
1.35	08/29/2021	3.73	0.65	84.37	14.53
1.59	08/18/2021	3.54	0.83	99.76	12.42
2.10	08/20/2021	4.70	0.75	174.84	15.38
4.65	07/03/2021	5.90	2.00	244.26	97.30
5.48	07/28/2021	12.60	4.25	127.26	48.03
6.04	08/27/2021	12.98	3.00	148.56	25.80
10.54	07/07/2021	12.23	4.85	478.61	111.79

Note: Runoff samples and sediment samples were obtained by filtering the runoff discharge collected after every erosive rainfall event. Filtered water is referred to as runoff, and suspended soil is referred to as sediment.

$$\text{Total loss}\left(\frac{\text{mg}}{\text{ha}}\right) = \frac{\text{concentration of the element}\left(\frac{\mu\text{g}}{\text{L}}\right)\times\text{run off volume}\left(\text{L}\right)\times 1000}{0.0008\ \text{ha}}$$

where, "mg" is milligram, "ha" is hectare, "L" is liter, and "0.0008 ha" is the plot area.

Data were subjected to descriptive statistics, analysis of variance (ANOVA), and correlation analysis using IBM SPSS statistics. The maximum, minimum, and average values of concentration and total loss were described for the whole experimental area. The trend of concentration of elements according to changes in rainfall intensities was performed for both runoff and sediment. This study compared the total loss of elements under different rainfall intensities and different mulching conditions, we used ANOVA with Duncan's test to know the significance of the mean difference between element loss in runoff discharge. Using Pearson's correlation, different factors (rainfall, runoff, and sediment) and total loss of elements have been analyzed to check whether they are related to each other. Then graphs were plotted using Origin software.

3. Results

The results revealed distinct Cu, Mo, and Zn concentrations in the runoff discharge. Some trace elements were dissolved in runoff water, while others were associated with sediment in runoff discharge. Zn content was higher than other trace elements contents in runoff and sediment. Moreover, Mo was lower than other trace elements concentrations and total losses in all conditions. On the other hand, the plots of 0˚ did not generate any runoff discharge implying that the results in this section are for plots on 15˚ of slope gradient.

3.1. Concentrations of Trace Elements in Runoff and Sediment

For plots without straw mulching, average Cu, Zn, and Mo in runoff water were 0.28 μg/L, 3.05 μg/L, and 0.04 μg/L, respectively (**Table 2**). At the same time, under straw mulching, average Cu, Zn, and Mo were 0.54 μg/L, 3.10 μg/L, and 0.06 μg/L, respectively (**Table 2**). On the other hand, average concentrations in sediment from no straw mulching were 9.45 mg/kg, 12.38 mg/kg, and 0.43 mg/kg for Cu, Zn, and Mo, respectively; while under straw mulching, there were 9.85 mg/kg, 13.20 mg/kg, and 0.49 mg/kg for Cu, Zn, and Mo respectively (**Table 2**).

3.2. Total Loss of Trace Elements in Runoff and Sediment

The average total losses of Cu, Zn, and Mo in runoff water from plots without straw mulching were 18.91 mg/ha, 194.05 mg/ha, and 2.37 mg/ha, respectively (**Table 3**); and were 14.12 mg/ha, 56.20 mg/ha, and 1.23 mg/ha under straw mulching for Cu, Zn, and Mo respectively (**Table 3**). The average total loss in sediment was 1632.68 mg/ha, 2446.72 mg/ha, and 85.27 mg/ha without straw

Table 2. Ranges and mean of trace elements concentrations in runoff water and sediment.

Element	no straw			with straw		
	min	max	average	min	max	average
	Concentration in runoff					
Cu (μg/L)	0.05	0.61	0.28	0.08	1.63	0.54
Zn (μg/L)	2.11	6.59	3.05	1.66	11.39	3.10
Mo (μg/L)	0.02	0.11	0.04	0.03	0.16	0.06
	Concentration in sediment					
Cu (mg/kg)	7.79	11.7	9.45	7.92	11.67	9.85
Zn (mg/kg)	9.07	22.9	12.38	9.53	22.29	13.2
Mo (mg/kg)	0.32	0.76	0.43	0.32	1.93	0.49

Note: Table 2 represents the maximum (max), minimum (min), and mean (average) concentration of selected trace elements (Zn, Cu, and Mo) in runoff and sediment within the experimental area. Runoff samples and sediment samples were obtained by filtering the runoff discharge collected after every erosive rainfall event.

Table 3. Ranges and mean of trace elements total loss in runoff water and sediment.

Element	no straw			with straw		
	min	max	average	min	max	average
	Total loss in runoff					
Cu (mg/ha)	3.42	48.6	18.91	0.62	69.27	14.12
Zn (mg/ha)	81.03	392.04	194.05	10.82	137.13	56.2
Mo (mg/ha)	0.62	4.52	2.37	0.32	2.83	1.23
	Total loss in sediment					
Cu (mg/ha)	341.26	5285.3	1632.68	44.74	1258.5	402.8
Zn (mg/ha)	432.36	12036.34	2446.72	54.65	2453.7	596.9
Mo (mg/ha)	14.94	399.82	85.27	1.78	72.42	18.83

Note: Table 3 represents the maximum (max), minimum (min), and mean (average) loss of selected trace elements (Zn, Cu, and Mo) in runoff and sediment within the experimental area. Runoff samples and sediment samples were obtained by filtering the runoff discharge collected after every erosive rainfall event.

application for Cu, Zn, and Mo, respectively (**Table 3**); then 402.80 mg/ha, 596.90 mg/ha, and 18.83 mg/ha under straw mulching for Cu, Zn, and Mo respectively (**Table 3**).

The average concentrations of trace elements were higher in runoff and sediment from straw mulched plots than plots without straw mulching (**Table 2**). In contrast, the average total losses of trace elements were distinctively lower in runoff and sediment from mulched plots than plots without straw mulching (Table 3). That contrast between concentrations and total losses is due to the amount of runoff discharge and the quantity of sediment yield, which were obviously higher in no straw conditions.

3.3. The Loss Characteristics in Runoff Discharge from Different Mulching and Rainfall

3.3.1. The Changes in Trace Elements Concentration in Runoff Discharge

The trends of average concentrations of Cu, Mo, and Zn were not smooth according to the increase of rainfall intensity (Figure 3). Generally, the average Zn concentration in runoff water decreased from lower to higher rainfall intensities, with maximum values at 1.35 mm/h (6.074 μg/L for no straw mulching and 8.248 μg/L for straw mulching) (Figure 3). Contrastingly, Zn concentration in sediment increased from lower rainfall intensities to higher rainfall intensities, with minimum values at 1.06 mm/h (9.466 mg/kg for no straw mulching and 10.343 mg/kg for straw mulching) and maximum values at 10.54 mm/h (20.221 mg/kg for no straw mulching, and 18.488 mg/kg for straw mulching) (Figure 3).

Furthermore, the trends of average Cu showed that its concentrations in runoff from both mulched and non-mulched soils were less than one μg/L, with the exception of the highest concentration in runoff from mulched plots (1.579 μg/L) caused by 5.48 mm/h (Figure 3). On the other hand, the concentration of Cu in sediment was generally increased according to the increase in rainfall intensity because all the values observed at higher rainfall intensities are greater than the values observed at the lowest rainfall intensity (1.06 mm/h) (Figure 3). The lowest Cu concentration in sediment from no straw mulching practices was 7.870 μg/L exhibited by 1.06 mm/h, and the highest was 11.180 μg/L caused by 6.04 mm/h (Figure 3). At the same time, the lowest Cu concentration in sediment from straw mulched plots was 8.408 μg/L, caused by 1.06 mm/h, and the highest was 10.833 μg/L, exhibited by 1.27 mm/h (Figure 3).

The variations of average Mo concentration in runoff water were less than 0.1 μg/L, except for the highest concentration (0.134 μg/L) from mulched plots caused by the rainfall of 1.06 mm/h (Figure 3). The lowest value of average Mo concentration was 0.024 μg/L from no straw practice and 0.044 μg/L from mulched plots, all caused by rainfall of 2.1 mm/h. Generally, Mo concentration in runoff water was increased by applying straw to the soil. However, there was an exception exhibited by a rainfall intensity of 1.27 mm/h, Mo content from no straw mulching was 0.075 μg/L, and Mo content from straw mulched plots was 0.063 μg/L. Furthermore, the trend of Mo concentration in sediment showed the average values were lower than 1 mg/kg, with the exception of 1.206 mg/kg observed under mulched plots due to rainfall of 1.59 mm/h (Figure 3). The lowest value of average Mo concentration in sediment was 0.331 mg/kg from no straw practice at 1.06 mm/h. Whereas the lowest Mo content in sediment from mulched plots was 0.322 mg/kg, which was exhibited by 4.65 mm/h.

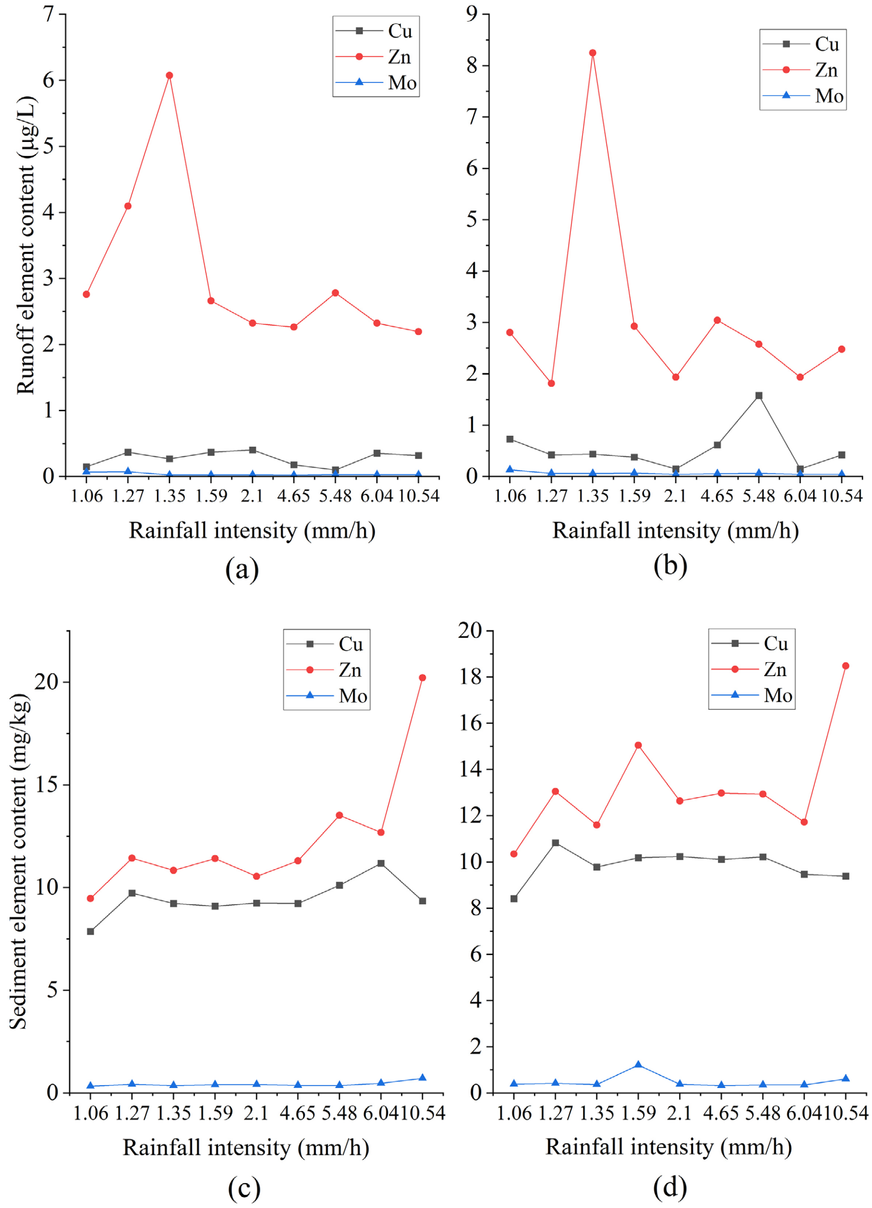

Figure 3. Variations of trace elements concentrations in runoff and sediment with rainfall intensity. Runoff samples and sediment samples were obtained by filtering the runoff discharge collected after every erosive rainfall event. (a) represents the variations of Zn, Cu, and Mo concentration in runoff from plots without straw mulching. (b) shows the variations of Zn, Cu, and Mo concentration in runoff from straw mulched plots. (c) represents the variations of Zn, Cu, and Mo concentration in sediment from plots without straw mulching. (d) represents the variations of Zn, Cu, and Mo concentration in runoff from straw mulched plots.

3.3.2. The Changes in the Total Loss of Trace Elements in Runoff Discharge

There were significant differences as a result of the effects of rainfall intensities on trace elements loss in runoff water from plots without soil mulching ($p < 0.001$ for Zn, $p = 0.004$ for Cu, and $p = 0.029$ for Mo). Simultaneously, some losses in sediment from plots without soil mulching were significantly different

($p = 0.001$ for Zn and Cu, and $p < 0.001$ for Mo).

The lowest average loss of each element in runoff was 94.20 mg/ha, 6.28 mg/ha, and 0.88 mg/ha for Zn, Cu, and Mo, respectively; whereas the lowest average loss of each element in sediment was 690.61 mg/ha, 590.63 mg/ha, and 25.89 mg/ha for Zn, Cu, and Mo, respectively. The rainfall of 1.59 mm/h resulted in the lowest amount of Zn loss in the runoff, 1.06 mm/h resulted in the lowest amount of Cu runoff loss, and 1.35 mm/h resulted in the lowest amount of Mo runoff loss.

In addition, the highest average loss of each element in runoff was 350.40 mg/ha, 45.96 mg/ha, and 3.86 mg/ha for Zn, Cu, and Mo, respectively; while the highest average loss of each element in sediment was 9804.07 mg/ha, 4508.10 mg/ha, and 346.85 mg/ha for Zn, Cu, and Mo, respectively. The rainfall of 6.04 mm/h resulted in the highest Cu loss in the runoff, whereas 5.58 mm/h resulted in the highest Zn and Mo loss.

The changes in trace element loss in runoff from straw mulched plots as a function of rainfall intensities, showed some significant mean differences ($p = 0.001$ for Zn, $p < 0.001$ for Cu and Mo). At the same time, some sediment losses in straw mulched plots were significantly different in samples resulted from different rainfall intensities ($p = 0.002$ for Zn, $p < 0.001$ for Cu and Mo).

As a result of straw mulching practices in our study, the lowest average loss of each element in runoff was 11.81 mg/ha, 1.12 mg/ha, and 0.33 mg/ha for Zn, Cu, and Mo, respectively; while in sediment was 58.16 mg/ha, 48.37 mg/ha, and 1.85 mg/ha for Zn, Cu, and Mo respectively. The rainfall of 1.27 mm/h showed the lowest Zn loss in the runoff, and 2.10 mm/h showed the lowest Cu and Mo runoff loss.

In straw mulching conditions, the highest average loss of each element in runoff water was 120.30 mg/ha, 67.10 mg/ha, and 2.78 mg/ha for Zn, Cu, and Mo, respectively; while in sediment was 2060.42 mg/ha, 1049.79 mg/ha, and 68.28 mg/ha for Zn, Cu, and Mo respectively. The rainfall of 10.54 mm/h showed the highest Zn loss in the runoff, while 5.58 mm/h showed the highest Cu and Mo loss in runoff.

Each lowest loss in sediment was caused by a rainfall event of 1.27 mm/h, while each highest loss in sediment was caused by a rainfall event of 10.54 mm/h (Appendix). The details of significantly different losses exhibited by different rainfall events are presented in Appendix.

In all rainfall conditions, loss of Zn and Mo were higher in runoff and sediment from plots without straw mulching (**Figure 4**). The Cu loss was also higher in sediment from plots without straw mulching; the exception was observed for Cu loss in runoff (**Figure 4**). The exceptions at 1.06 mm/h, 4.65 mm/h, and 5.48 mm/h were due to the higher concentration of Cu observed in runoff from straw mulched plots.

To further analysis, the runoff and sediment losses of Zn, Cu, and Mo were positively correlated with rainfall intensity and runoff depth in our experiment. With the exception of Cu, other correlations were significant (**Table 4**).

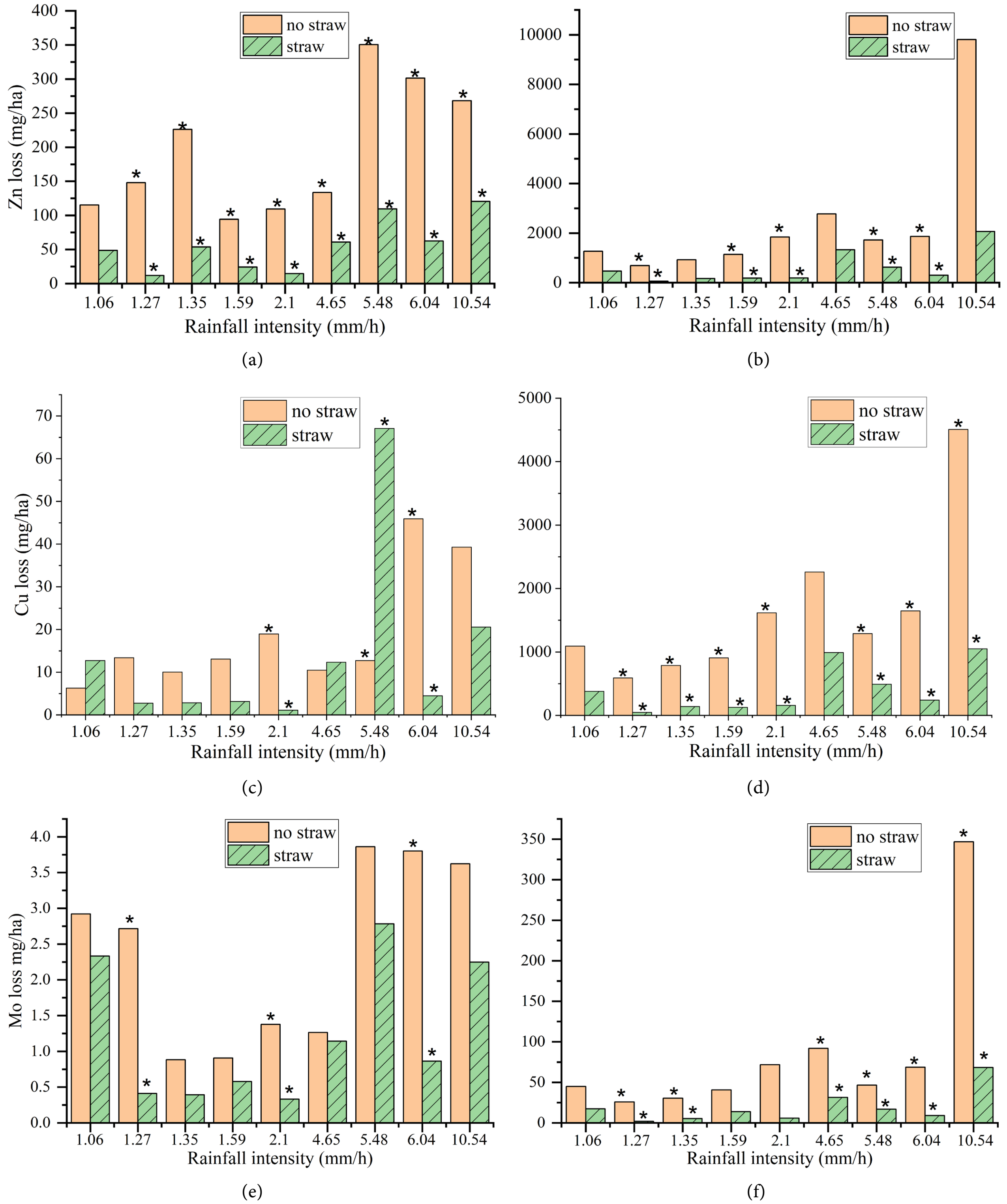

Figure 4. Comparison of Zn, Cu, and Mo loss in runoff and sediment from different soil mulching. Runoff samples and sediment samples were obtained by filtering the runoff discharge collected after every erosive rainfall event. (a) shows Zn total loss in runoff while (b) represents Zn total loss in sediment; (c) is the representation of Cu total loss in runoff and (d) is the representation of Zn total loss in sediment; (e) represents Mo total loss in runoff whereas (f) represents Mo total loss in sediment. The star sign (*) shows that the difference between loss from straw mulching is significantly different to loss from no straw mulching in the same rainfall intensity, at $p < 0.05$.

Table 4. Correlations of different factors and total loss of elements in the study area.

Factors	Straw mulching			no straw mulching		
	Zn	Cu	Mo	Zn	Cu	Mo
			Runoff loss (mg/ha)			
Rainfall intensity	0.799**	0.400	0.497*	0.632**	0.686**	0.528*
Runoff depth	0.895**	0.690**	0.769**	0.848**	0.681**	0.703**
			Sediment loss (mg/ha)			
Rainfall intensity	0.782**	0.734**	0.807**	0.830**	0.844**	0.832**
Runoff depth	0.682**	0.670**	0.705**	0.508*	0.536*	0.496*
Sediment yield	0.950**	0.996**	0.897**	0.952**	0.989**	0.956**

** Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level. Runoff samples and sediment samples were obtained by filtering the runoff discharge collected after every erosive rainfall event.

4. Discussion

The difference in concentration of the trace elements (Zn, Cu, and Mo) in runoff and sediment was more likely influenced by their concentration in the considered red soil region. Prior to the experimental runoff plots preparation, the soil samples taken showed that Zn was the highest, while Mo was the lowest in the red soil of the study area. Therefore, it is obvious that to link the observed runoff and sediment concentration to the actual soil concentration is crucial.

A past study observed different concentrations of Cu and Zn in three different runoff events, which is in line with the results of our study that showed different concentrations of these elements when distinct runoff events were observed [48]. Considering the Mo content in runoff observed in the previous study, our study findings showed lower Mo content that may be due to the difference in the actual soil Mo concentration in each study [39].

The observed concentrations of trace elements in our study were normal as many are in range of their concentration values in surface water around China, in rivers of the Chinese loess plateau region, and in the whole Yangtze source region whose water quality indexes met the surface water environmental quality standard in China [49] [50] [51].

As the three trace elements showed different values of their concentration in runoff water, other previous studies also showed different order of concentration of the element in different cases of the environment. The difference of order of concentrations (Cu > Zn > Mo) for trace elements dissolved in surface water of the source region of the Yangtze River, and a higher concentration of Cu than Zn in a wetland were previously revealed by different studies [49] [52]. In contrast, in the other past findings, a greater runoff Zn than runoff Cu was found in both surface and groundwater in a recent review about China, and was predicted in runoff from agricultural watersheds of Nebraska [37] [50]. Although, different findings showed difference in the order of trace element concentrations within identical conditions, our study showed Zn > Cu > Mo as the order of trace elements loss in the study area.

The variations of concentrations of these three selected trace elements showed different trends according to the increase in rainfall intensity. One of the factors that may be the reason of those different variability, is the difference in number of charges of each element in natural environment. Zn has +2, Cu can have both +1 and +2, while Mo can have positive various charges between +2 and +6 [4] [53] [54]. From the view of these charges, Mo is more likely to be disturbed by various factors that may be present in any natural environment resulting in its non-uniform changes in runoff discharge within our study.

The smoothness of the concentration changes with rainfall intensity was not possible because this study was based on natural rainfall events, the changes in rainfall characteristics were irrespective to the order of their intensities. Indeed, the erosive rainfall events change the soil environmental conditions, where transfer of trace elements between soil phases are considered as the main processes controlling their behavior in soil [2]. In line with the highest values of average Zn concentration in runoff observed in our study, it was previously observed that runoff trace element concentrations in months with less rainfall were higher than in June, July, and August of higher rainfall [55].

According to the comparison between straw mulching and no straw mulching, many rainfall events of different intensities showed significant difference between their mean values. The mean differences in straw mulching were more significant than in no straw mulching conditions. Moreover, various cases revealed a significantly lower loss in straw mulched plots than in plots without straw mulching. The decrease in total loss due to the application of straw mulching shows that using this agronomic practice in the study area may be one of the best methods to minimize the negative impacts of soil fertility loss in red soil of the study area.

5. Conclusion

The evaluation of trace elements characteristics in runoff discharge from different soil mulching techniques found the following conclusions: the general order of the concentrations and the total losses of trace elements in both runoff water and sediment in the experimental area was Zn > Cu > Mo; this was attributed to their actual soil concentrations in the red soil of the study area. The straw mulching decreased the runoff discharge and the sediment yield, which resulted in lower total loss of Zn and Mo from straw mulched plots than their total loss from plots without straw mulching. Cu had the exception in runoff water due to rainfall events of 1.06 mm/h, 4.65 mm/h, and 5.48 mm/h that showed higher total loss from straw mulched plots than their total loss from plots without straw mulching. In addition, the analysis revealed positive correlations between factors (Rainfall intensity, runoff depth, and sediment yield) with total loss of elements in both runoff and sediment. At the same time, the sediment resulted in a higher loss of trace elements than runoff loss of trace elements. Therefore, the selected trace elements showed different characteristics in runoff discharge. Indeed, the considered factors contributed to the observed concentrations and total loss of trace elements in our study.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

Table A1. The comparison of total loss of elements in runoff and sediment from different rainfall intensities.

Factor Rain intensity (mm/h)	Straw mulching		No straw mulching	
	Runoff loss	Sediment loss	Runoff loss	Sediment loss
	Zn (mg/ha)			
1.06	48.74 ± 3.71[bc]	465.67 ± 24.17[c]	115.17 ± 24.39[d]	1266.80 ± 1180.08[b]
1.27	11.81 ± 1.40[c]	58.16 ± 4.95[c]	147.98 ± 24.85[d]	690.61 ± 48.24 [b]
1.35	53.61 ± 28.86[b]	167.56 ± 10.38[c]	226.25 ± 27.34[c]	922.22 ± 262.37[b]
1.59	24.15 ± 5.15[bc]	183.02 ± 8.43[c]	94.20 ± 18.63[d]	1137.25 ± 85.02[b]
2.10	14.51 ± 1.08[c]	194.37 ± 16.72[c]	109.21 ± 14.18[d]	1838.94 ± 111.02[b]
4.65	60.90 ± 18.77[b]	1323.06 ± 787.23[b]	133.52 ± 4.34[d]	2770.96 ± 514.79[b]
5.48	109.45 ± 20.19[a]	620.89 ± 20.06[bc]	350.40 ± 58.89[a]	1723.79 ± 216.01[b]
6.04	62.32 ± 2.50[b]	298.98 ± 24.11[c]	301.48 ± 39.15[ab]	1865.87 ± 260.87[b]
10.54	120.30 ± 23.80[a]	2060.42 ± 556.19[a]	268.25 ± 12.65[bc]	9804.07 ± 3156.91[a]
	Cu (mg/ha)			
1.06	12.71 ± 1.16[bc]	378.89 ± 8.80[bc]	6.28 ± 4.04[b]	1092.33 ± 1062.18[bc]
1.27	2.75 ± 0.33[cd]	48.37 ± 5.14[d]	13.40 ± 12.29[b]	590.63 ± 84.11[c]
1.35	2.86 ± 0.15[cd]	141.27 ± 9.59[cd]	10.05 ± 3.31[b]	785.65 ± 230.55[c]
1.59	3.14 ± 3.57[cd]	126.77 ± 27.17[cd]	13.09 ± 1.82[b]	905.56 ± 57.09[c]
2.10	1.12 ± 0.53[d]	157.49 ± 14.22[cd]	18.95 ± 1.32[b]	1615.99 ± 166.92[bc]
4.65	12.33 ± 11.13[bc]	990.10 ± 379.62[a]	10.48 ± 6.55[b]	2259.57 ± 371.05[b]
5.48	67.10 ± 3.07[a]	490.89 ± 8.28[b]	12.71 ± 8.93[b]	1287.93 ± 81.34[bc]
6.04	4.47 ± 2.11[cd]	241.94 ± 24.73[bcd]	45.96 ± 3.55[a]	1648.33 ± 269.59[bc]
10.54	20.58 ± 3.45[b]	1049.79 ± 47.47[a]	39.30 ± 13.15[a]	4508.10 ± 1099.13[a]
	Mo (mg/ha)			
1.06	2.33 ± 0.58[a]	17.28 ± 3.47[c]	2.92 ± 2.26[ab]	44.80 ± 42.23[b]
1.27	0.41 ± 0.03[b]	1.85 ± 0.10[d]	2.72 ± 0.25[ab]	25.89 ± 4.44[b]
1.35	0.39 ± 0.003[b]	5.27 ± 0.08[cd]	0.88 ± 0.38[b]	30.44 ± 8.49[b]
1.59	0.58 ± 0.22[b]	13.81 ± 10.00[cd]	0.91 ± 0.16[b]	40.55 ± 2.23[b]
2.10	0.33 ± 0.01[b]	5.82 ± 0.17[cd]	1.38 ± 0.12[b]	71.74 ± 9.98[b]
4.65	1.14 ±0.33[b]	31.41 ± 11.2[b]	1.26 ± 0.20[b]	91.84 ± 4.67[b]
5.48	2.78 ± 0.07[a]	16.79 ± 0.59[c]	3.86 ± 0.78[a]	46.57 ± 3.69[b]
6.04	0.86 ± 0.13[b]	9.00 ± 1.34[cd]	3.80 ± 0.34[a]	68.71 ± 4.31[b]
10.54	2.25 ± 0.71[a]	68.28 ± 5.86[a]	3.62 ± 1.12[a]	346.85 ± 74.92[a]

Note: Appendix represents mean ± standard deviation of the amount of Zn, Cu, and Mo, resulted from the runoff and sediment caused by different rainfall events, on plots of different mulching in red soil of Miyi county. Runoff samples and sediment samples were obtained by filtering the runoff discharge collected after every erosive rainfall event. The values of one element in different rain intensities (along one column) that do not have any similar small letter, are significantly different according to Duncan's test.