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Correlation of Mineral Element Loss in Contaminated Soil Based on Surface Runoff Principle

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The loss of mineral elements in agricultural land causes the problem of water eutrophication, resulting in the ecological unbalance of water environment. For this, this paper aims to study the loss of mineral elements in contaminated soil. To this end, based on the principle of surface runoff, this paper uses potassium sulfate-molybdenum antimony (MO-Sb) anti-spectrophotometry to test and analyse the phosphorus concentration in the collected water samples, and obtains the influence rule of soil slope and rainfall intensity on the surface runoff water and phosphorus concentration in seepage water at different soil depth. The results show that the total phosphorus (TP) concentration and solid phosphorus concentration in the surface runoff water are positively correlated with the soil slope, and the dissolved phosphorus concentration is negatively correlated with the soil slope; the TP concentration and liquid phosphorus concentration in the leakage water at the 20cm and 40cm-deep soil layers gradually decreases with the increase of soil slope; the TP concentration, dissolved phosphorus (DP) and particulate phosphorus concentration in surface runoff are positively correlated with rainfall intensity, and the TP concentration and DP concentration in the seepage water at 20cm and 40cm-deep soil layer increases with the increase of rainfall intensity.

1. Introduction

The use of pesticides and fertilizers in agricultural production has accelerated the crop growth or increased agricultural production (Simone et al., 2018; Mcdowell, 2012).

However, the crop itself has a utilization rate of less than 30% for nitrogen and phosphate fertilizers, and a large amount of organic chemical elements (such as nitrogen and phosphorus) remain in the soil and become contaminated soil (Cooperband, 2003; Le Ber et al., 2017; Mcdowell et al., 2016). The concentration of available phosphorus in the soil is low. However, the inflow of surface runoff into the water source after the rain can cause the loss of fertilizer, pesticides and nutrients in the farmland, and also lead to water eutrophication problem, seriously polluting the water environment (Lv et al., 2015). The loss of nitrogen and phosphorus fertilizers along the surface runoff in agricultural land is one of the key factors affecting eutrophication of water resources (Solomon and J, 2010; Ulén and Jakobsson, 2005).

The study found that the loss of mineral elements in the soil is not only related to the physical structure of the contaminated soil, but also affected by factors such as farmland slope, rainfall intensity and rainfall (Chang et al., 2002). Under the rainfall action, nutrients such as nitrogen and phosphorus in farmland contaminated soil can be lost with water by lateral transfer (running with surface runoff) or longitudinal transfer (rain leakage to deep soil) (Morra, 1991). However, the existence of soil slopes causes a large amount of nitrogen and phosphorus in the flow of water, which accelerates the loss of nutrients in contaminated soil and causes eutrophication of groundwater.

Therefore, based on the principle of surface runoff, this paper studies the loss of phosphorus in contaminated soil under the conditions of different soil slopes and rainfall intensity. This shall provide theoretical support and basis for the effect of soil slope and rainfall intensity on the loss of nutrient elements in agricultural contaminated soil during actual farmland operation.

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2. Experiments

2.1 Experimental materials

This paper tests the change of mineral elements in the planting soil, so as to analyse the loss of mineral elements in the contaminated soil. In the experiment, the Chinese cabbage planting soil in the botanical garden of a university was selected, by sampling the soils in layers and bagging it for later use. According to the method in the Chinese Standard *Technical Specifications for Soil Environmental Testing*, it was treated in the process of air-drying, 2mm sieve-screening, and static standing to be the experimental soil. For the experimental soil, the pH was 7.3, and the water content was 30.1%. During the planting stage of cabbage, the first fertilization (pig manure) was carried out to supplement the nutrients needed for the growth of cabbage in the soil before sowing. When about 4 leaves were grown in the cabbage, compound fertilizer was applied on the surface of the soil; when about 8 leaves grew in the cabbage, high-phosphorus fertilizer and nitrogen fertilizer were mixed and applied around the roots of the plants. The basic parameters of the various fertilizers applied are shown in Table 1.

Table 1: Parameters of fertilizers

Types of fertilizers	Base fertilizer	Compound fertilizer	Phosphate fertilizer	Nitrogenous fertilizer
Component	Pig manure	N (27%); P_2O_5 (16%); K_2O (7%)	P_2O_5 (16%)	N (46%)
Consumption (g)	155	30	21	5

2.2 Experimental design

In order to study the effects of rainfall intensity and soil slope on the loss of mineral elements in contaminated soil, the “rainwater spray system and farmland planting system” were established in the cabbage planting area to simulate the rainfall and land slope in the actual environment. In addition, rectangular flowerpots with length, width and height of 90cm, 30cm and 50cm were used as production containers for cabbage, and 25 cabbages were evenly distributed in each pot, with the thickness of the soil layer in the pot of 40cm. In the experiment, a gauze-covered cylindrical container (10cm high and 5cm in diameter) was inserted into the soil near the lower edge of the flowerpot to simulate the influence of surface runoff. Also, a drainage hole and a collection basin were respectively provided at the pot wall and the pot bottom about 20cm from the surface of the soil layer for collecting the leakage water of the soil at a depth of 20 cm and 40cm. The slope was simulated by raising one side of the flower pot.

To simulate the rainfall intensity in the actual environment, four rainfall intensities of 30mm/h, 60mm/h, 90mm/h and 120mm/h were set by the rain spray system, and each rainfall lasted 1h.

2.3 Experimental scheme

Using the control variable method, the parameters set in the experiment were rainfall intensity and soil slope, specifically expressed as: with the soil slope of 10°, the rainfall intensity is 30mm/h, 60mm/h, 90mm/h and 120mm/h respectively; with the rainfall intensity of 90mm/h, the soil slope is set to be 5°, 10°, 15° and 20°. Finally, the surface runoff and the amount of phosphorus loss in the 20cm and 40cm deep leakage soil for each set of experiments was tested. Table 2 lists the fertilization, rainfall characteristics and sampling frequency during the experiment. On the 16th day, the rainfall and sampling were conducted firstly, then followed by fertilization.

Table 2: Fertilization, simulated rainfall and sampling frequency

A	B	C	D	A	B	C	D	A	B	C	D
1	Y			11		Y	Y	21		Y	Y
2		Y	Y	12				22			
3				13				23			
4		Y	Y	14				24			
5				15				25			
6		Y	Y	16	Y	Y	Y	26		Y	Y
7				17		Y	Y	27			
8	Y			18				28			
9				19		Y	Y	29			
10				20				30		Y	Y

Note: A-Days; B- Apply fertilizer; C- Simulated rainfall; D- Water sampling.

Based on the above scheme, the collected water samples were taken back to the laboratory, shaken, and placed in a beaker. Then its supernatant was used for determining the TP and DP concentration by potassium sulfate-Mo-Sb spectrophotometry method.

3. Influence of soil slope on phosphorus loss in contaminated soil

3.1 Influence of soil slope on phosphorus loss in surface runoff water

In the experiment, the rainfall intensity was set to be 90mm/h, and the soil slopes were 5°, 10°, 15° and 20°, respectively. The change curve of the TP concentration with the experimental days was obtained by measuring the phosphorus concentration in surface runoff water (Figure 1). It can be seen that the TP concentration in surface runoff water increases gradually with the increase of soil slope, and the difference of TP concentration is smaller when the soil slope is 5° and 10°, indicating the influence of slope change on TP concentration is not significant; when the slope of the soil reaches 10° or more, the slope has a great influence on the TP concentration in surface runoff water.

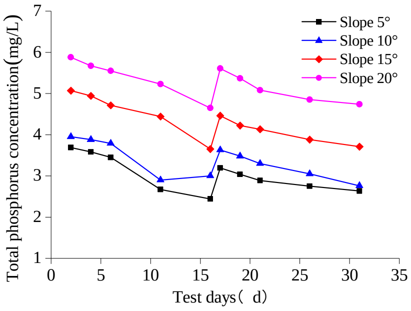

Figure 1: Changes of phosphorus concentration in surface runoff under different slopes

Under different soil slopes, the changes of free-state phosphorus concentration and particulate phosphorus concentration in surface runoff water with experimental days are shown in Figure 2 and 3, respectively. It can be seen from Figure 2 that as the soil slope increases, the concentration of DP in the surface runoff water gradually decreases. This is because with the small slope of the soil layer, the soil pressure is large, and the contact time of the rainwater with the soil in the runoff is relatively longer, so that more phosphorus in the soil is dissolved in the runoff water. Thus, the concentration of DP in the surface runoff water is negatively correlated with the soil slope. It can be seen from Figure 3 that as the soil slope increases, the flow velocity of the runoff water increases and it is easy to form a fine groove in the soil, so that the particulate phosphorus adhered to the soil layer is lost with the water flow. It indicates that the concentration of particulate phosphorus in the surface runoff water gradually increases with the increase in soil slope.

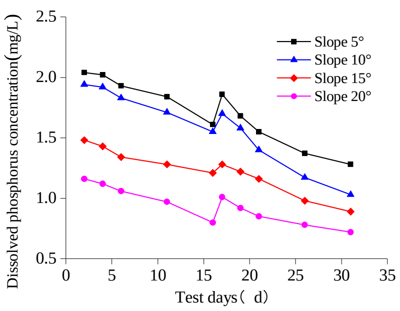

Figure 2: Changes of dissolved phosphorus concentration in surface runoff under different slopes

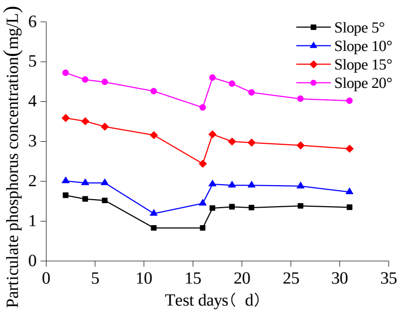

Figure 3: Changes of particulate phosphorus concentration in surface runoff under different slopes

3.2 Influence of soil slope on phosphorus loss in seepage water

Figure 4 and 5 show the trend of the TP concentration in the leakage water at the 20cm and 40cm soil depth with the test days under different soil slope conditions. It can be seen that the concentration of TP in the seepage water at the depth of 20cm and 40cm soil layer decreases with the increase of soil slope. In the leakage water at the 20cm deep soil layer, the TP concentration increases first and then decreases, and after fertilization, it starts to increase and then decreases. In the seepage water at the 40cm deep soil layer, the concentration of the TP doesn't change significantly with the test days, indicating that the soil has a strong role of phosphorus fixation, making the TP amount infiltrated to the pot bottom be relatively small.

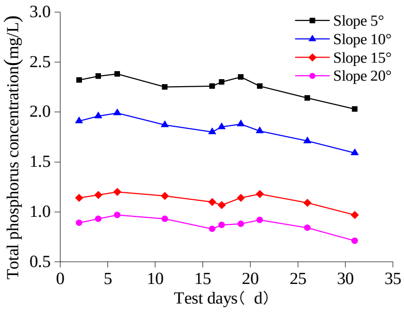

Figure 4: Changes of phosphorus concentration in 20cm soil depth under different slopes

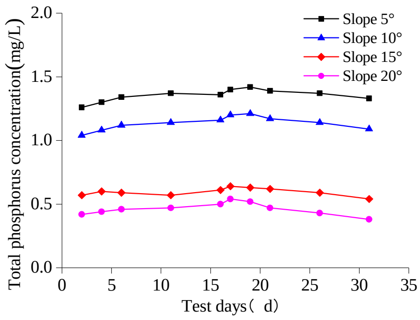

Figure 5: Changes of phosphorus concentration in 40cm soil depth under different slopes

Figure 6 and 7 show the change trend of liquid phosphorus concentration in the leakage water at the depth of 20cm and 40cm soil layer with test days under different soil slope conditions. It can be seen from the results that the concentration of liquid phosphorus in the seepage water at the depth of 20cm and 40cm is negatively correlated with the soil slope. In the leakage water at the depth of 20cm soil, the concentration of DP firstly increases with the the experimental time, and then decreases rapidly after the fertilization for a certain period of time. In the leakage water at the depth of 40cm soil, similar to that at the 20cm deep soil, the DP concentration shows the trend of increasing first, decreasing slowly and then stabilizing.

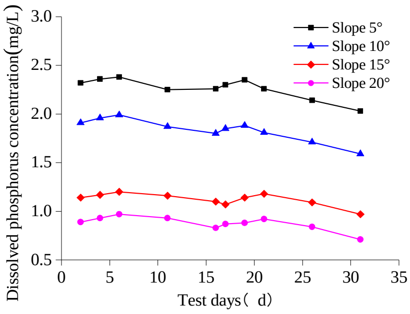

Figure 6: Changes of dissolved phosphorus concentration in 20cm soil depth under different slopes

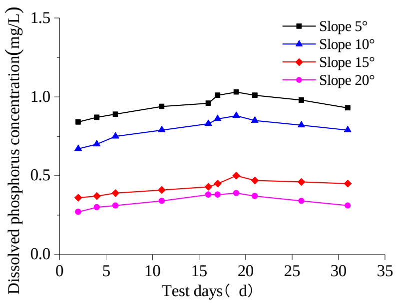

Figure 7: Changes of dissolved phosphorus concentration in 40cm soil depth under different slopes

4. Influence of soil slope on phosphorus loss in contaminated soil

4.1 Influence of rainfall intensity on the phosphorus loss in surface runoff water

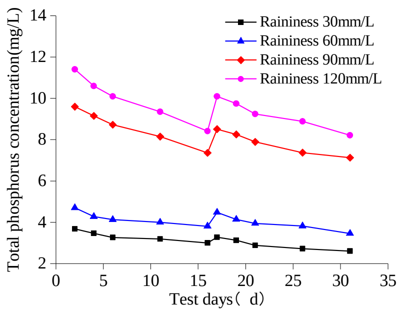

Figure 8: Changes of phosphorus concentration in surface runoff under different rainfall intensity

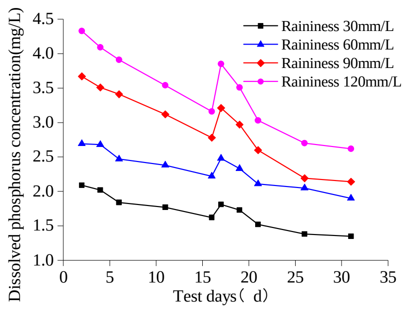

Figure 9: Changes of dissolved phosphorus concentration in surface runoff under different rainfall intensity

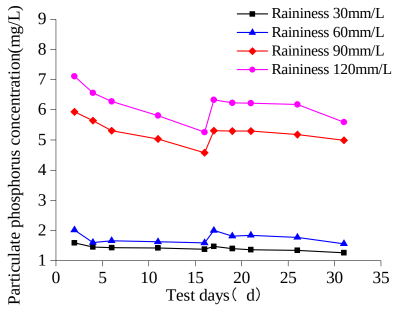

Figure 10: Changes of particulate phosphorus concentration in surface runoff under different rainfall intensity

In this experiment, the soil slope was set to be 10°, and the rainfall intensity was 30mm/h, 60mm/h and 120mm/h, respectively. Figure 8, 9, and 10 show the changes of TP, DP and particulate phosphorus concentration with test days, respectively, by measuring the phosphorus concentration in surface runoff water. It can be seen from the experimental results that the TP concentration, DP concentration and particulate phosphorus concentration in surface runoff water increase with the increase of rainfall intensity. When the rainfall intensity is small, it has little effect on the phosphorus concentration in surface runoff, and the change trend of phosphorus concentration with test days isn't significant. When the rainfall intensity reaches above 90mm/h, the effect of rainfall intensity on the phosphorus concentration in surface runoff water is significant.

4.2 Influence of rainfall intensity on the phosphorus loss in seepage water

Figure 11-14 show the trends of TP concentration and DP concentration in the leakage water at 20cm and 40cm soil depth with the test days at different rainfall intensity. It can be seen that the concentration of TP and DP in the leakage water at the depth of 20cm and 40cm soil gradually increase with the increase of rainfall intensity. In the leakage water at the depth of 20cm soil layer, the change of TP concentration shows a small increase first and then decreases rapidly. In the leakage water at the depth of 40cm soil layer, the TP concentration increases first, then decreases with the test days, and finally tends to be stable.

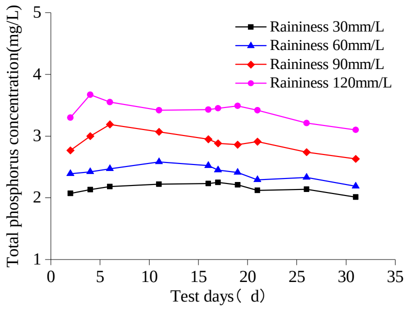

Figure 11: Changes of phosphorus concentration in 40cm soil depth under different rainfall intensity

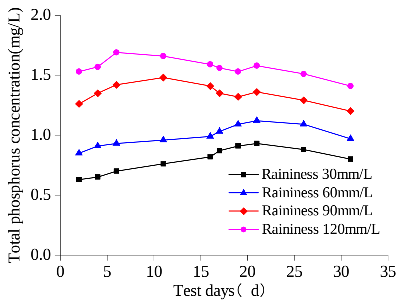

Figure 12: Changes of phosphorus concentration in 40cm soil depth under different rainfall intensity

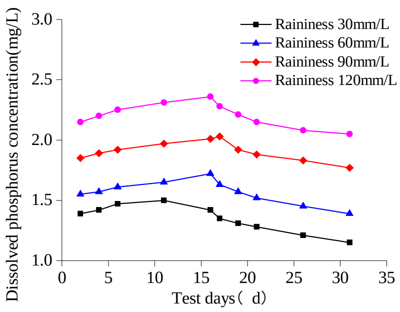

Figure 13: Changes of dissolved phosphorus concentration in 20cm soil depth under different rainfall intensity

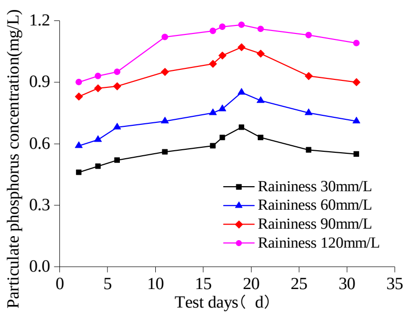

Figure 14: Changes of dissolved phosphorus concentration in 40cm soil depth under different rainfall intensity

5. Conclusions

Based on the principle of surface runoff, this paper uses potassium sulfate- MO-Sb spectrophotometry to test and analyse the phosphorus concentration in the collected water samples, and obtains the influence rule of soil slope and rainfall intensity on the surface runoff water and phosphorus concentration in leakage depth water at different soil depth. The main conclusions are as follows:

(1) The TP concentration and solid phosphorus concentration in the surface runoff water are positively correlated with the soil slope, and the slope change has no significant effect on the TP concentration when the soil slope is 5° and 10°, but when the soil slope reaches above 10°, the slope has a greater influence on the TP concentration in the surface runoff water; the concentration of DP in the surface runoff water decreases with the increase of the soil slope.

(2) Due to the effect of soil phosphorus fixation, the total amount of phosphorus infiltrated to the pot bottom is relatively small; in the leakage water at the depth of 20cm and 40cm soil layer, the concentration of TP decreases with the increase of soil slope, and the concentration of liquid phosphorus is also negatively correlated with the soil slope.

(3) The TP concentration, DP and particulate phosphorus concentration in surface runoff increase with the increase of rainfall intensity, and the effect of rainfall intensity on phosphorus concentration in surface runoff water is more significant when the rainfall intensity reaches more than 90mm/h. The TP concentration and DP concentration in the leakage water at the depth of 20cm and 40cm soil gradually increase with the increase of rainfall intensity.

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