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Original Research

Characteristics of Phosphorus Loss from Organic Farming and Forestry Land under Simulated Rainfall in the Mountainous Areas of Western Anhui

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Abstract

The representative vegetable plots (*Allium hookeri*) and economic forest lands (Cuilan Tea) were selected as the studied objects to explore the characteristics of phosphorus loss in surface and subsurface runoff from organic farming and forestry in the western Anhui Mountains. Rainfall experiments were carried out by simulating small, medium, and large rainfall intensities (0.6, 0.9, and 1.5 mm/min, respectively) in the field. The results show that the range of phosphorus loss in the surface runoff from organic vegetable plots and tea plots accounts for 52.5%-69.5% and 56%-71.7% of the total phosphorus, respectively. The proportion of phosphorus loss increases with the increase in rainfall intensity. Moreover, vegetation coverage and tillage methods (soil looseness) affect the difference in phosphorus loss in agricultural and forestry land. Particulate phosphorus (PP) is the main form of phosphorus loss in surface runoff in this area. Dissolved phosphorus (DP) is the main form of phosphorus loss in the subsurface runoff, and the main DP is dissolved inorganic phosphorus. Moreover, phosphorus loss in subsurface runoff is still high. This study provided a reference for the accounting of organic farming and forestry pollution sources and the subsequent prevention and control of non-point source pollution.

Keywords: organic agroforestry, phosphorus loss, non-point source pollution, surface runoff, subsurface runoff

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Introduction

Agricultural non-point source pollution is a critical factor in causing water pollution [1-3]. This source of pollution is also a significant factor in causing eutrophication of water, soil pollution, and deterioration of the rural ecological environment, which is related to the sustainable development of rural areas. In general, phosphorus is the most prominent environmental factor in agricultural surface pollution. Thus, identifying the runoff transport mechanisms of phosphorus is important for preventing and controlling agrarian non-point pollution sources.

In recent years, the problem of agricultural non-point source pollution has attracted extensive attention from researchers. Nitrogenous and phosphorous loss can be studied in three main ways, namely, field plot runoff [4], laboratory soil runoff box [5], and watershed SWAT model [6]. Simulated rainfall is generally considered the most practical manifestation of phosphorus loss in the field plots, which can effectively evaluate the influence of various factors on surface runoff and sediment transport processes. Currently, many studies focused on patterns of pollutant transport and their influencing factors in agricultural surface runoff, including the measures to reduce pollutant migration transformation [7-9]. Studies on the transportation and transformation of phosphorus focused on phosphorus entering water bodies during surface runoff [10-12]. Meanwhile, studies were devoted to reducing phosphorous transportation and transformation in agriculture [13-16].

Several studies qualitatively and quantitatively summarized the characteristics of nutrient loss in surface runoff from conventional farmland under different soil backgrounds and management modes under rainfall conditions. However, few studies exist on P loss from organic farms and forestry. P loss from organic agriculture is one of the essential sources of agricultural non-point source pollution in mountainous areas in China, where organic farming is mainly developed. Organic fertilizers are primarily used as nutrient sources for crops. Moreover, phosphorus in organic fertilizers is difficult to move in agricultural soil because of soil fixation and plant adsorption. Generally, the main pathways of phosphorus loss are considered surface runoff and soil erosion [17]. Thus, the characteristics of phosphorus loss in subsurface runoff are easily ignored, and studying the characteristics of phosphorus loss in subsurface runoff is of great significance [18, 19]. Most studies focused on the effects of farmland types [20], fertilization types [21], and soil properties on phosphorus loss in the subsurface runoff. However, few studies regarded the effect of rainfall intensity on the characteristics of phosphorus loss in organic agriculture and forestry. Suppose the characteristics of phosphorus migration in the surface and subsurface runoff from organic agriculture and forestry are studied simultaneously. In this case, understanding the characteristics of phosphorus loss from non-point sources of organic agriculture and forestry in mountainous areas is beneficial.

Low-carbon and energy-saving green modes of production have become the trend of agricultural development in mountainous regions under China's policy of revitalizing rural areas. The west mountain area is one of the ecological barriers of Anhui Province, which has a good environment and is rich in organisms and essential function in water conservation. The superior geographical location has created the basis of organic agriculture in the area. Agricultural cash crops, such as leeks and peppers, and economic woodland crop cuilan tea are residents' primary sources of income. As the terrain of the mountainous region of western Anhui is steep, many natural disasters occurred, such as soil erosion and soil erosion [22]. In recent years, estimating pollutant emissions has been difficult because of abundant rainfall, frequent human activities, and a sensitive ecological environment in this area. In addition, the coverage rate of background plants in mountainous areas is high. Considering the prevention and control arrangement of non-point source pollution based on understanding the characteristics of phosphorus loss is significant for developing a circular economy, environmental protection, and watershed pollution prevention and control in the mountainous area of western Anhui. This experiment studied the characteristics of phosphorus loss in surface runoff and subsurface runoff under different types of land and rainfall intensity. The loss characteristics of different ways of phosphorus in surface runoff and subsurface runoff were studied by measuring and comparing total phosphorus (TP), dissolved phosphorus (DP), and particulate phosphorus (PP) in soil. Clarifying the character of P loss in organic farming and forestry land for the accounting of pollution sources and the subsequent prevention and control of non-point source pollution is significant.

Materials and Methods

Experimental Site Description and Soil Parameters

The study was conducted at Yuexi County, Anqing City, Anhui Province, between 30°29′-31°11′N latitude and 115°50′-116°33′E longitude. The terrain is dominated by low mountains, hills, and basins (Fig. 1), with an average elevation of 600 m and a humid north subtropical monsoon climate. The annual sunshine duration in the experimental area is 2070.5 h, with significant climatic differences. Yuexi County has sufficient rainfall with an average annual precipitation of 1445.8 mm. The simulated rainfall lasted for a year, and natural rainfall was monitored at the same time as the simulated rainfall. It was found that rainfall was mainly concentrated from May to September, accounting for about 42% of the year.

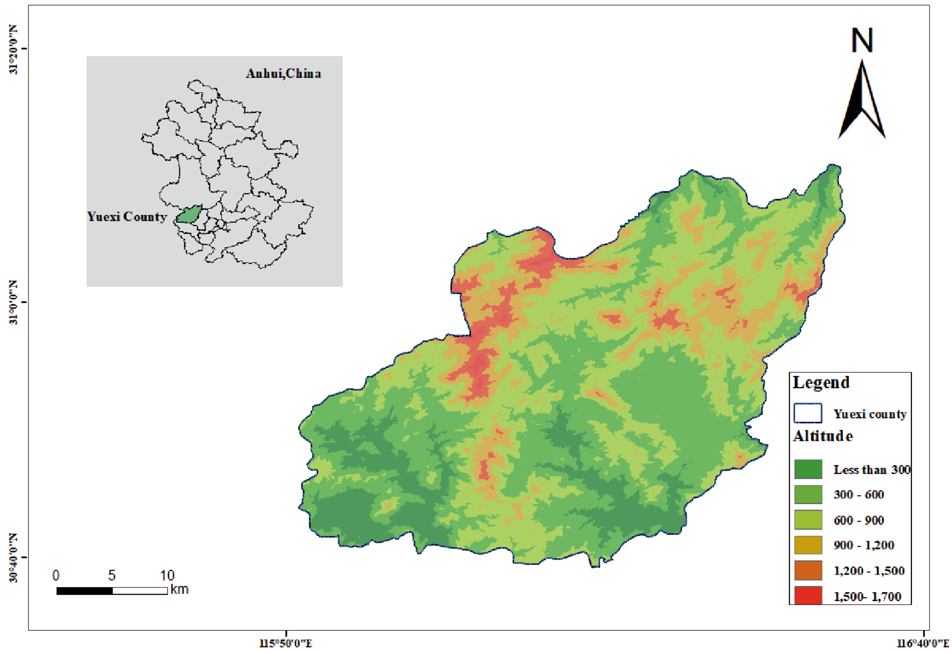

Fig. 1. Geographical location and elevation of Yuexi County, Anqing City.

The agricultural output is rich in mountain tea gardens and mountain vegetables. In this experiment, two sample plots were set up for tea gardens and vegetable plots, and the test plots for tea plants and leeks were 1 m^2 (1 m × 1 m). The leek plot contained 16 leeks (*A. hookeri*) plants, and organic fertilizer (rapeseed cake) was applied once every two weeks. Organic fertilizer (rapeseed cake) was applied to two tea plants (Yuexi cuilan tea) in the tea plant plot every six months. The fertilization method was a hole application. In this experiment, a 5-10 cm diameter pit of about 10 cm was dug in two or three inches of the root of the tea plant, and then a rapeseed cake was added. The tea and vegetable fields were fertilized with 150 grams each time. Table 1 presents the physical and chemical properties of the soil in the experimental area.

Table 1. Physical and chemical properties of tested soil.

Projects	Organic tea garden	Organic dryland
pH	5.28	5.24
Total nitrogen (mg/kg)	263.00	285.00
Total phosphorus (g/kg)	0.60	1.73
Total potassium (g/kg)	12.30	15.10
Available phosphorus (mg/kg)	30.80	140.30
Alkaline nitrogen (mg/kg)	232.00	148.00
Organic matter (g/kg)	102.00	106.00

Simulated Rainfall Experiments

Based on the local rainfall data in the past 20 years (2001-2021), the local light rain, moderate rain, and heavy rain were simulated by 0.6, 0.9, and 1.5 mm/min in this experiment, respectively. The rainfall was repeated three times under each rainfall intensity to ensure the accuracy of the experimental data and the stability of the rainfall intensity. The rainfall simulation device used in this experiment is BX-1 (developed by the Institute of soil and Water Conservation, Chinese Academy of Sciences). The rainfall height was 3 m, and the effective rainfall area was 1 m × 1 m. The control range of raindrop size was 1.6-5.0 mm. The uniformity coefficient was more than 86%, and the rainfall accuracy was 7 mm/h. The rainfall intensity and rainfall time could be controlled manually. Through the analysis of regional soil structure and composition, the sampling depth of subsurface runoff was selected as 20 cm (average infiltration depth of the experimental area). As shown in Fig. 2, each runoff field was surrounded by a PVC board (a PVC board of 40 cm was buried in the soil, and PVC was high above the surface). The lower part of the simulated rainfall system was equipped with an experimental runoff trough. The upper part of the runoff trough was the surface runoff collection trough, and the lower part was the soil flow collection trough. The surface runoff and soil flow were collected simultaneously during the simulated rainfall.

Artificially simulated rainfall experiments of 0.6, 0.9, and 1.5 mm/min were carried out on two plots. Three parallel experiments were set up under each rainfall intensity, and a total of 18 rainfall were carried out. Each simulated rainfall time was set to 40 min.

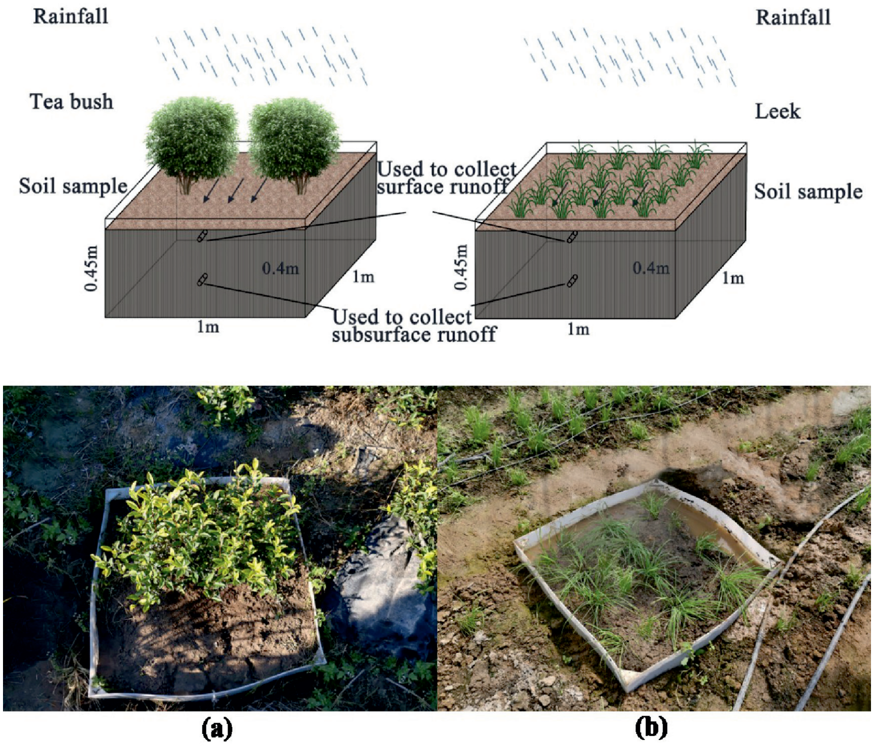

Fig. 2. Experimental collection device of a) Yuexi cuilan tea and b) *A. hookeri*.

The initial runoff production time of surface runoff and subsurface runoff were recorded before the experiment. Water samples of surface and subsurface runoff were collected every 5 min after the runoff was generated. The subsurface runoff was continued for sampling for 35 min to study the characteristics of subsurface runoff when the simulated rainfall stopped. Moreover, the surface runoff was sampled until the surface runoff stopped. Then, nitrogen and phosphorus content and soil water content were determined. The indicators of plots before the next experiment were kept in the same condition as the first experiment by applying organic fertilizer and increasing the study interval.

Sample Collection and Analysis

The outlet of the device is used for sampling after runoff is generated, which was taken once at intervals of 5 min and sampled 250 ml. The sampling time was recorded synchronously. After the water samples were collected and refrigerated in a refrigerator at 4 °C, the test was completed within 24 hours. The surface runoff needed static, and the supernatant was collected after the mud-water separation. TP, DP, dissolved inorganic phosphorus (DIP), and PP were tested. Ammonium molybdate spectrophotometry is utilized for TP determination reference [21]. DP and DIP were measured after a 0.45-μm filter and ammonium molybdate spectrophotometry for reference [23]. TP minus DP was the content of PP.

The analysis of data and graphs of phosphorus loss patterns was conducted using Excel 2016 (Microsoft, USA), Arcmap2020 (Arcgis Developer, USA), and Origin2018 (Originlab, USA).

Results

Runoff Formation Cycle and Runoff

Fig. 3 shows the characteristics of runoff from organic vegetable fields and tea gardens under different rainfall intensities. The production time of surface runoff from organic vegetable fields and tea gardens was earlier than that of the subsurface runoff under the three rainfall intensities of small (0.6 mm/min), medium (0.9 mm/min), and large (1.5 mm/min). Moreover, the higher the rainfall intensity, the earlier the production time of surface runoff. As shown in Table 2, the surface runoff generated by rainfall was relatively more significant under three rain intensities. The surface runoff from organic vegetable fields and tea gardens accounted for 58.75%-67.13% and 64.00%-72.28% of the total P in the runoff, respectively.

Fig. 3 shows that the various characteristics of the runoff rate from tea gardens were similar to those from organic vegetable fields. The average and peak values of runoff increased with the increase in rainfall intensity. As can be seen from Table 2, the surface runoff production time of organic vegetable fields and tea gardens, after the rainfall began, was 8.9, 4.5, 2.1, 6.7, 3, and 1.9 min, respectively. When the rainfall lasted for approximately 25 min, the surface runoff and subsurface runoff under the three kinds of rain intensity reached

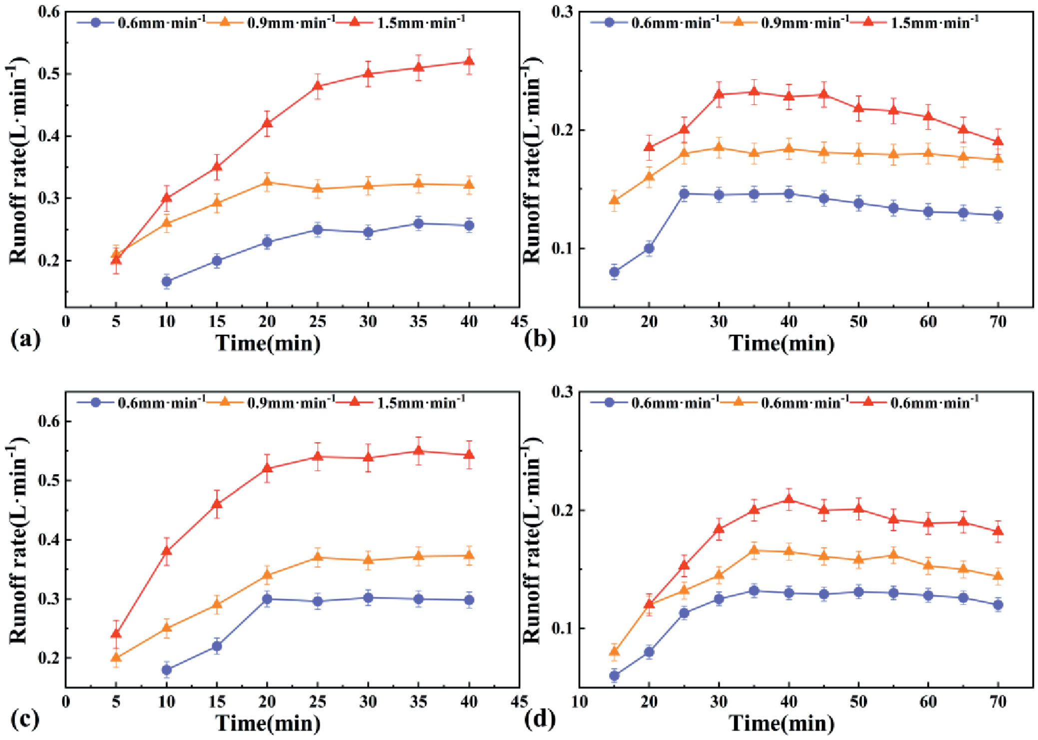

Fig. 3. Runoff flow characteristics of a) surface runoff and b) subsurface runoff from vegetable fields, c) surface runoff, and d) subsurface runoff from tea gardens.

Table 2. Phosphorus loss in vegetable fields and tea gardens under different rainfall conditions.

Rainfall intensity (mm/min)	Runoff mode	Runoff generation time (T/min)		Runoff (L)		Proportion of runoff (%)		TP loss concentration (mg/L)	
		VF	TG	VF	TG	VF	TG	VF	TG
0.6	Surface	8.90	6.70	11.05	12.48	58.75	64.00	2.48	2.34
	Subsurface	10.50	10.20	7.83	7.02	41.25	36.00	3.19	3.15
0.9	Surface	4.50	3.00	16.34	17.30	60.86	66.59	3.36	3.07
	Subsurface	10.70	10.20	10.51	8.68	39.14	33.41	3.42	3.79
1.5	Surface	2.10	1.90	23.90	26.34	67.13	72.28	4.84	4.16
	Subsurface	16.80	16.90	11.70	10.10	32.87	27.72	4.33	4.27

Note: VF, vegetable fields; TG, tea gardens.

distributed balance. This dynamic balance continued until the rainfall stopped. Under the condition of small and moderate rain, the subsurface runoff production time of the two kinds of land was 10- min after the beginning of rainfall. Meanwhile, the subsurface runoff yield of the two types of land was mainly in 16-17 min under 1.5 mm/min rainfall. The above results showed that the greater the rainfall intensity, the shorter the runoff generation time. Still, the subsurface runoff generation time would lag to a certain extent under heavy rainfall intensity. The average phosphorus loss concentration under three kinds of rain intensity in subsurface runoff from organic vegetable fields and tea gardens was higher than that in the surface runoff. The loss concentration of TP increased with the increase of rainfall intensity. The average loss concentration of TP in the surface and subsurface runoff from the vegetable field was higher than that in the tea gardens.

DP, PP, and TP in the Surface Runoff

Fig. 4a) shows the variation of DP and PP concentrations in surface runoff from organic vegetable fields. The average loss concentrations of DP under small, moderate, and large rainfall intensities after 40 min of rainfall duration were 1.05, 1.20, and 1.20 mg/L, respectively. Then, the average loss

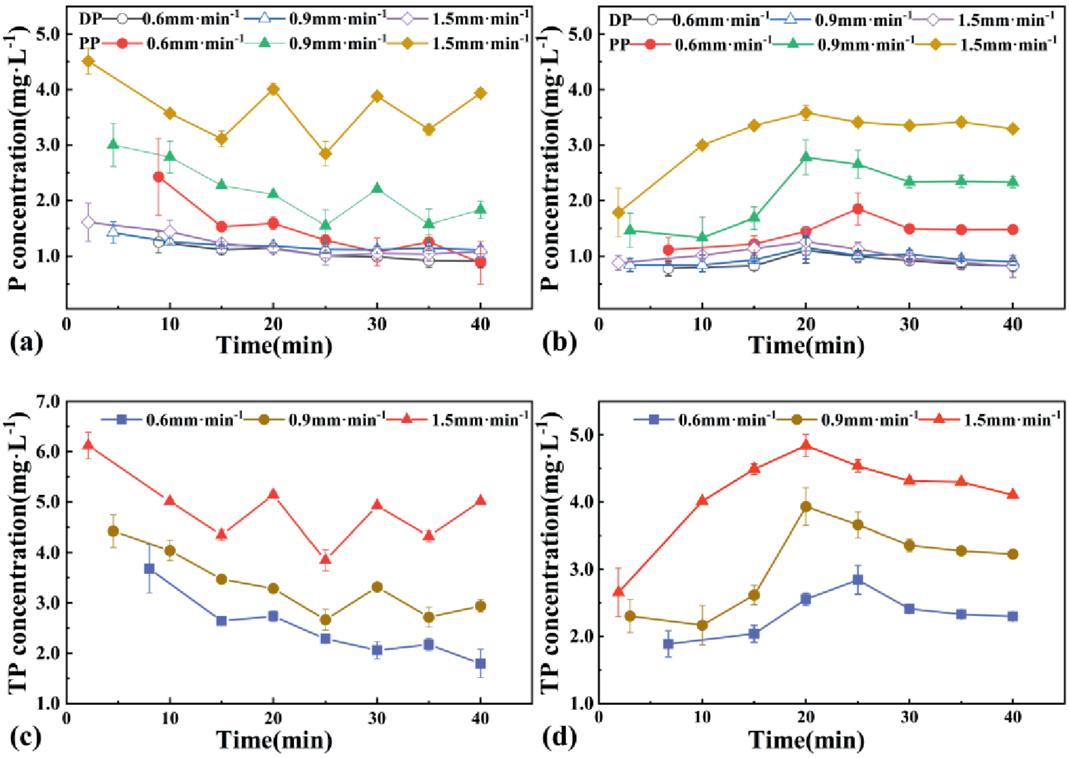

Fig. 4. Characteristic changes of a) DP and PP in surface runoff from vegetable fields, b) DP and PP in surface runoff from tea gardens, c) TP in surface runoff from vegetable fields, and d) TP in surface runoff from tea gardens.

concentrations of PP were 1.44, 2.16, and 3.64 mg/L, respectively. Moreover, the loss concentration of PP in the organic vegetable field is significantly higher than that of DP, comparing the loss concentration of DP and PP under the same rainfall intensities. Fig. 4c) shows that the various rules of TP and PP in the surface runoff from organic vegetable fields were similar under three kinds of rainfall intensity. The more significant the rain intensity was, the more remarkable the average loss concentration was. The peak value of loss concentration appeared in the early stage of runoff production and then showed a fluctuating trend. The variation range of TP loss concentration was from 3.68 to 6.12 mg/L.

The characteristics of surface runoff from tea gardens were different from that in organic vegetable fields. Fig. 4b) shows that concentrations of DP and PP reached the peak at approximately 20-25 min after the beginning of rainfall under the three rainfall intensities. The greater the rainfall intensity, the greater the concentration of DP and PP. As shown in Fig. 4d), the loss concentration of TP in surface runoff from tea gardens showed an overall trend of increasing first and then decreasing slowly with time. When the rainfall intensity increased from small to large, the TP loss concentration surface runoff increased by 33.45%, 41.22%, and 45.04%, respectively. In general, PP was more affected by rainfall intensity than DP in surface runoff from organic tea gardens.

DP, PP, and TP in Subsurface Runoff

Fig. 5a) shows that the maximum value and average value of DP loss concentration in subsurface runoff from vegetable plots increased with rainfall intensity from small to large. However, no significant correlation exists between PP loss concentration and rainfall intensity. The loss concentration of PP in the subsurface runoff from vegetable plots did not change much with the continuous rainfall, which was approximately 1 mg/L. According to Fig. 5(a-c), the loss concentrations of DP and TP in the subsurface runoff increased continuously after the beginning of runoff. Both reached the maximum value in 5-10 min after rainfall stopped. The higher the rainfall intensity, the earlier the peak appeared. This case indicates that rainfall intensity had a great influence on the trend and maximum values of DP and TP loss concentrations in subsurface runoff from organic vegetable plots.

The loss characteristics of DP and PP in the subsurface runoff from organic tea gardens were similar to those of organic vegetable fields. As shown in Fig. 5b) and d), the loss concentrations of DP in subsurface runoff from organic tea gardens under three rain intensities were significantly higher than those of PP. The loss concentrations of DP and TP fluctuated upward and then smoothly decreased with runoff production time. The average concentrations of DP under three rainfall intensities were 2.42, 2.83, and 2.97 mg/L, respectively. This case showed that the average

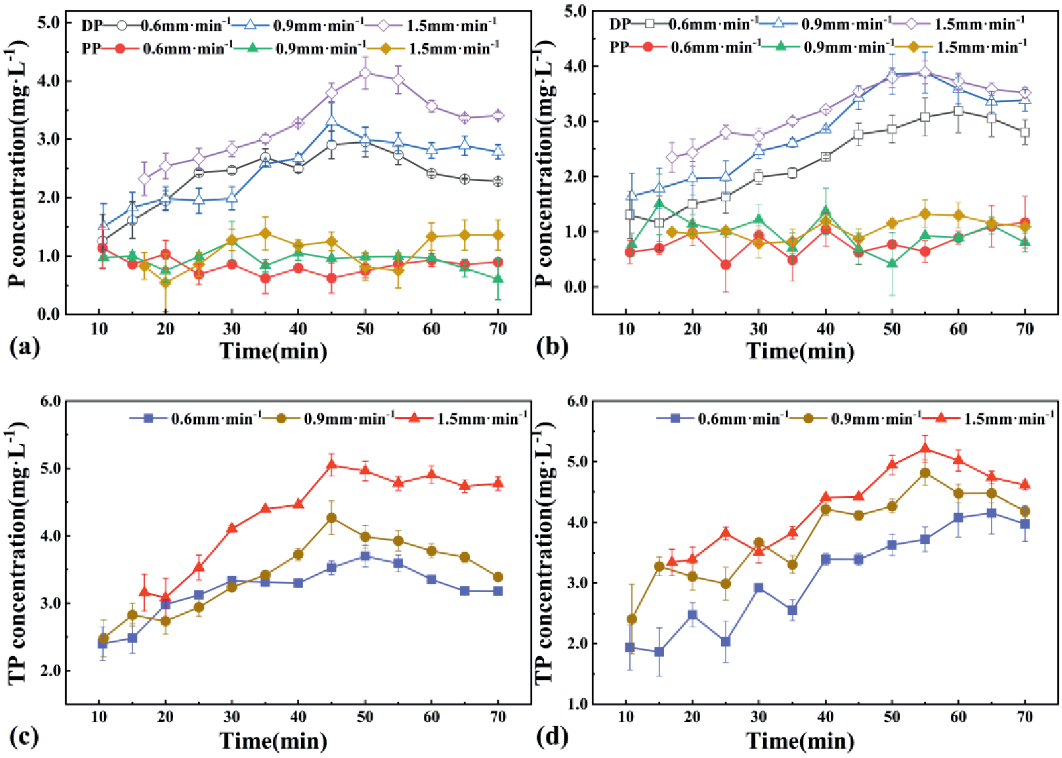

Fig. 5. Characteristic changes of a) DP and PP in subsurface runoff from vegetable fields, b) DP and PP in subsurface runoff from tea gardens, c) TP in subsurface runoff from vegetable fields, and d) TP in subsurface runoff from tea gardens.

concentration magnitude of DP loss became more significant, and the peak value of DP increased with the increase in rainfall intensity. The DP loss concentration of subsurface runoff gradually tended to be stable without subsequent rainfall.

Form and Proportion of Phosphorus Loss

Fig. 6 shows the form of phosphorus loss in runoff. Under three rainfall intensities, PP was the main loss form in surface runoff from organic vegetable fields, and DP was the main form of phosphorus loss in the subsurface runoff. DIP was the main loss form of DP. The ratio of PP to TP loss of surface runoff from organic vegetable fields ranges from 56.7% to 75.2%. DP of the subsurface runoff from organic vegetable fields accounted for 71.89%-75.06% of TP, whereas DIP accounted for 53.33%-59.83%. Combined with Table 2, the phosphorus loss of subsurface runoff accounted for 47.5%, 44.2%, and 31.5% of the TP in the runoff.

The loss form of runoff from organic tea gardens and organic vegetable fields was consistent. PP was the primary loss form in the surface runoff, and DP was the main loss form in the subsurface runoff. The proportion of PP to TP loss in the surface runoff from organic tea gardens was 61.6% to 75.7% under the three rainfall intensities. The proportion of DP to TP loss in the surface runoff from organic tea gardens was 73.4% to 75.3%, whereas DIP was 56.3% to 59.8%. The proportion of phosphorus loss was similar to that from organic vegetable plots under the three rainfall intensities. The phosphorus loss of subsurface runoff from organic tea plots accounted for 44%, 38.3%, and 28.3% of TP in the runoff, respectively.

Discussion

Impact of Rainfall Intensity on Phosphorus Loss

The results showed that the average concentration of phosphorus loss in surface and subsurface runoff from organic farming and forestry in the mountainous areas of western Anhui Province was closely related to the magnitude of rainfall intensity. The higher the rainfall intensity, the higher the average phosphorus loss concentration. Summer and autumn, with high rainy intensity and sufficient precipitation are speculated to be the seasons of serious phosphorus loss. Surface runoff is the main form of rainfall–runoff loss. At the initial time of rainfall, the soil moisture content did not reach saturation, and the runoff production rate of the rainwater surface was greater than the infiltration rate of the rainwater. Thus, surface runoff was generated before the subsurface runoff, which was consistent with the results of Dai et al. [24]. Rainwater will infiltrate rapidly as the rainfall continues. The soil moisture content gradually increased to saturation after the absorption, leakage, and infiltration phases. Moreover, the subsurface runoff was generated [25]. After that, the infiltration rate of

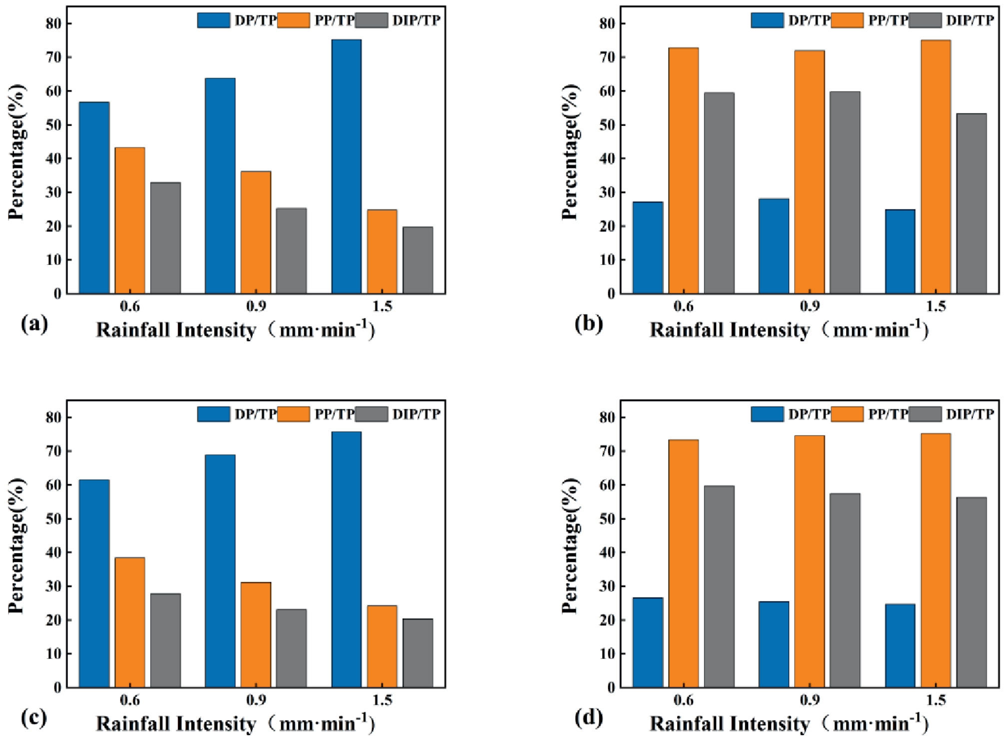

Fig. 6. Analysis of the percentage of a) DP, PP, and DIP in surface runoff from vegetable fields, b) DP, PP, and DIP in subsurface runoff from vegetable fields, c) DP, PP, and DIP in surface runoff from tea gardens, and d) DP, PP, and DIP in subsurface runoff in tea gardens.

rainwater remained unchanged [26]. Rainfall and runoff were the power sources of soil erosion. The intensity of rainfall determined the magnitude of runoff and the intensity of rainfall erosion. Thus, rainfall erosion was the main cause of soil phosphorus loss [27].

Different agroforestry land uses had varying forms of phosphorus loss. The results showed that PP in the surface runoff was more influenced by rainfall intensity than DP, specifically in surface runoff at the beginning of runoff production of vegetable fields. Then, the opposite conclusion was observed in the subsurface runoff. The reason was that the surface fertilization pattern caused phosphorus to be more likely lost with runoff, and rainfall scouring led to the dissolution and dilution of phosphorus [28]. This also explains the large fluctuation of TP concentration in surface runoff of organic vegetable plots. From another aspect, vegetable fields were cultivated in a way that required regular tillage, which led to soil looser, large soil voids, and low water content. Moreover, phosphorus in the sediment-bound state becomes the primary mode of P loss in surface runoff [29]. Rainfall makes the DP in the topsoil easy to infiltrate into the deep soil with rainwater, particularly DIP [30]. As PP is mainly attached to coarse granular soils that are difficult to access, DP is the main way of phosphorus loss in subsurface runoff from organic vegetable plots. The changing pattern of DP and TP in subsurface runoff is also consistent, which is consistent with the results of phosphorus loss in mountainous areas [31].

The fluctuation range and peak value of TP, DP, and PP in runoff from organic tea gardens increased with the increase in rainfall intensity, and the peak value of TP appeared 20–25 min after rainfall. Surface runoff played a dominant role in PP, whereas DP in subsurface runoff was the main form of loss, which was the same as organic vegetable fields. The concentration of TP and DP decreased slowly with continuous rainfall, but the downward trend was not evident. On the one hand, the erosion of surface soil was weakened because of the continuous increase of surface runoff, and the loss concentration of DP, PP, and DIP was diluted. On the other hand, organic matter and minerals in the soil could quickly replenish the lost phosphorus, and the soil surface was easy to absorb phosphorus [30]. Therefore, although the loss concentration of PP showed a downward trend, the decline rate was relatively slow [32]. The trend of phosphorus loss concentration of subsurface runoff from organic vegetable fields and that in tea gardens was similar to surface runoff. Still, the average phosphorus loss concentration in subsurface runoff was higher, and the peak appeared in the middle and later stages of rainfall. This finding is consistent with the study of the loss of phosphorus in subsurface runoff of mountain forests [19]. Owing to the unique topography and local farming habits in the western Anhui Mountain, the fertilization method of Cuilan tea is a hole application, so the soil phosphorus content is high. Continuous fertilizer application will migrate organic phosphorus to the deeper ground [33]. Soluble mineral substances in the soil will increase the leaching of phosphorus by leachate. The runoff decreased when the rainfall stopped. Still, the migration of DP and PP with runoff did not stop, so the peak value of subsurface runoff mostly appeared in the middle and later stages. However, the dynamic migration process of phosphorus was out of balance with the gradual decrease of runoff. Therefore, the loss concentration of phosphorus fluctuated after reaching the peak. The results showed that more attention should be paid to the runoff phosphorus loss in organic agricultural and forestry areas. The pollution sources in organic agriculture and forestry may be alleviated by controlling the contact of rainfall to soil or intercepting it before the peak concentration of phosphorus loss.

Factors that Influence Phosphorus Loss in Organic Farmland and Forest

According to Table 3, surface runoff was the main pathway of P loss for some nonorganic agricultural areas, accounting for more than 80% of the loss and mainly in the form of PP or colloidal phosphorus (CP). The results showed that the causes of phosphorus loss in these nonorganic agricultural and forestry areas were mostly rainfall intensity, vegetation cover, soil water content, and surface runoff. Compared with nonorganic farming areas, this study found that surface runoff was the primary way of runoff in organic farming and forestry areas in the mountainous regions of western Anhui Province. Moreover, the proportion of phosphorus loss through surface runoff was relatively large. The range of phosphorus loss of surface runoff from organic vegetable and tea gardens accounted for 52.5%-69.5% and 56%-71.7% of TP, respectively. Meanwhile, rainfall intensity was a critical factor for phosphorus loss in the mountainous areas of western Anhui. The reason might be that the erosion effect of rainfall on surface soil becomes stronger with the increase in rainfall intensity. PP carried by soil particles was more likely to be washed away. However, passing through soil pores in large quantities is difficult for PP. Organic fertilizer in soil and phosphorus in runoff enter subsurface runoff with rainwater in the form of DP. Therefore, surface runoff is dominated by PP loss, and subsurface runoff is dominated by DP loss. This result is the same as the study on soil phosphorus loss under different land use practices in the Shibanqiu sub-basin [34]. Studies showed that surface runoff is the main pathway of phosphorus loss [35, 36]. However, the percentage of phosphorus loss under small rainfall intensities in subsurface runoff from organic vegetable fields and tea gardens reached the highest of 47.5% and 44%, respectively. The smaller the rainfall intensity, the greater the percentage of phosphorus loss in the subsurface runoff, which should be related to the type of fertilizer application. Industrial fertilizers are mainly used in traditional agroforestry to replenish soil nutrients. On the contrary, organic fertilizers in organic agroforestry are farmyard manure mainly from plants or animals. The presence of soluble organic carbon in organic fertilizers will reduce the adsorption of organic and inorganic phosphorus in organic fertilizers while increasing the risk of loss of phosphorus [37, 38]. Moreover, the methods of fertilizer application have an impact on phosphorus loss. The burrow application method increases phosphorus loss in subsurface runoff compared with the surface application management mode. Therefore, we should pay more attention to the P loss in surface runoff from organic farming forests and strengthen the management of surface runoff phosphorus loss.

The average TP loss concentration in surface and subsurface runoff from organic agricultural and forestry land in western Anhui under three rainfall intensities showed that vegetable land was more significant than tea gardens. Vegetable fields are fertilized all year round, and a large amount of phosphorus accumulates on the surface. Farming, irrigation, and other agricultural activities accelerate the damage to the soil, resulting in a large amount of phosphorus loss after rainfall. This case indicated that different land use modes will change the form of soil phosphorus and then affect the loss of phosphorus in runoff [43]. From another aspect,

Table 3. Phosphorus loss in nonorganic agricultural and forestry areas.

Research object and region	Loss mode of study	Loss proportion (%)	Main loss forms/ways	Main influencing factors	References
Vegetable fields (Taihu Lake, China)	Surface runoff	74-88	PP	Rainfall intensity	[39]
Woodland (Mount Tai, China)	Surface runoff and subsurface runoff	82.2-83.1	surface runoff	Vegetation coverage	[19]
19Farmland (New York)	Surface runoff and subsurface runoff	80.0-90.0	DRP[1]	Soil moisture content	[40]
Sloping farmland (Tuojiang River, China)	Surface runoff	64.3	CP[2]	Surface runoff	[41]
USDA[3] (Beijing, China)	Surface runoff	>80.0	PP	Rainfall intensity, SS	[42]

Notes: DRP[1], dissolved reactive phosphorus; CP[2], colloidal phosphorus; USDA[3], high permeability sandy loam.

a higher vegetation cover can effectively reduce non-point source pollution [44]. A high vegetation cover in tea gardens hinders the washout of rainwater on tea garden soils, reducing the phosphorus content in the runoff. The phosphorus loss was arable land>grassland >forest land in a small watershed in southern Yunnan [45]. The loss of retained nitrogen and phosphorus was irrigated grass>herbaceous>scrub>bare ground in the hilly area of Yichang City. The greater the vegetation cover, the better the retention effect [46].

This study explored phosphorus loss from organic farming in mountainous areas and provided reliable data for controlling non-point source pollution in mountainous areas. The results showed that rainfall intensity was the main causes of phosphorus loss in organic farming and forestry land in this region. The type of fertilization may also affect the phosphorus loss, and the specific mechanism needs to be further studied. In addition to surface phosphorus loss, we should also pay enough attention to phosphorus loss in subsurface runoff. Moreover, vegetation cover and land tillage method (soil looseness) affect the difference in phosphorus loss in agricultural and forestry land. The conditions of this experiment were limited, and the simulated rainfall could not perfectly replicate the actual situation of natural rainfall. Long-term monitoring of the area should still be needed to obtain more accurate and stable phosphorus loss patterns.

Conclusions

(1) The occurrence time of surface runoff from the organic vegetable field and tea garden in this area was earlier than that of subsurface runoff under the three rainfall intensities of small (0.6 mm/min), moderate (0.9 mm/min), and large (1.5 mm/min). Surface runoff was the main form of runoff production. The phosphorus loss in surface runoff from organic vegetable land under three rain intensities accounted for 52.5%-69.5% of the total runoff loss. In addition, the phosphorus loss in surface runoff from tea gardens accounted for 56%-71.7% of the TP in the runoff.

(2) The average loss concentration of TP in surface runoff and subsurface runoff of organic farming and forestry land under three kinds of rain intensity showed that vegetable plot was higher than tea gardens. PP was the main loss form of surface runoff. DP was the primary form of phosphorus loss in the subsurface runoff, and DIP was the main loss form of DP.

(3) Rainfall intensity, fertilizer application type, and method were the main factors causing phosphorus loss from organic farming and forestry land in the region. Vegetation cover and land tillage method (soil looseness) also influenced the differences in phosphorus loss from farming and forestry land.

The results showed that the soil surface pollution of agroforestry could be effectively alleviated by controlling the contact between rainwater and soil at the beginning of rainfall or by intercepting phosphorus loss before it reached maximum concentration. Meanwhile, more attention should be paid to the phosphorus loss in runoff from organic agricultural and forestry land and strengthen the management of phosphorus loss in surface runoff.

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Conflict of Interest

The authors declare no conflict of interest.

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