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Effects of Different Fertilization Management Practices on Runoff Phosphorus Loss from Nursery Lands in the Hexi Reservoir Catchment, Changxing County (Postprint)

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Abstract

To protect the water quality of Hexi Reservoir, a major drinking water source, Changxing County has adjusted the agricultural planting structure in the Hexi Reservoir catchment area towards nursery plantation; however, optimized fertilization management modes are lacking. To address this issue, a field experiment was conducted using runoff plots in a typical nursery plantation within the catchment area, with six treatments established: broadcast application (control), plastic film mulching, straw mulching, vegetated buffer strip established outside the plot, strip application, and hole application, to investigate the characteristics of phosphorus loss in runoff from nursery fields under different fertilization management modes and to identify the optimal management mode for maximizing the reduction of phosphorus loss from agricultural land. The results showed that under different fertilization management modes, the annual total phosphorus loss flux via surface runoff from nursery fields followed the order: broadcast application (control) > plastic film mulching > strip application > hole application > vegetated buffer strip outside the plot > straw mulching, with the annual total phosphorus runoff loss fluxes for broadcast application (control), plastic film mulching, strip application, hole application, vegetated buffer strip outside the plot, and straw mulching being 9.60, 9.14, 5.49, 4.44, 2.48, and 1.37 kg hm ^{2} a ^{1}, respectively, indicating that hole application, vegetated buffer strip outside the plot, and straw mulching are superior fertilization management modes, and that their optimized combination would significantly reduce phosphorus loss in runoff from nursery fields in the Hexi Reservoir catchment area and its potential impact on the water quality of Hexi Reservoir. Furthermore, under different fertilization management modes, particulate phosphorus was the primary form of phosphorus loss in runoff water samples from nursery fields, followed by dissolved phosphorus; specifically, the proportions of particulate phosphorus in

total phosphorus loss from runoff plots under broadcast application (control), plastic film mulching, straw mulching, vegetated buffer strip outside the plot, strip application, and hole application were 66.09%, 70.69%, 67.97%, 71.63%, 68.11%, and 67.87%, respectively.

Full Text

Preamble

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Influence of Different Fertilization Management Modes on Phosphorus Loss in Runoff from Nursery Land in the Catchment Area of Hexi Reservoir in Changxing County

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Abstract

To protect the water quality of Hexi Reservoir, the primary drinking water source, the Changxing County government has adjusted the agricultural planting structure to nursery land in the Hexi Reservoir catchment area. However, optimized fertilization management practices are lacking. To address this issue, site-specific observation plots were established in typical nursery lands within the catchment area to investigate phosphorus loss characteristics in runoff under different fertilization management modes. Six fertilization management treatments were selected: broadcast placement (control), plastic mulching, straw mulching, establishment of grass buffer strips around nursery land, band placement, and hole placement, to explore the characteristics of phosphorus loss in surface runoff under different fertilization management modes, screen the optimal fertilization management mode, and implement the best method to reduce farmland phosphorus loss.

The results showed that under different fertilization management modes, the annual total phosphorus runoff loss flux from nursery land followed the order: broadcast placement (control) > plastic mulching > band placement > hole placement > grass buffer strip > straw mulching. The mean annual runoff loads of total phosphorus from broadcast placement (control), plastic mulching, band placement, hole placement, grass buffer strip, and straw mulching were 9.60, 9.14, 5.49, 4.44, 2.48, and 1.37 kg hm ², respectively. This indicates that hole placement, grass buffer strips, and straw mulching were the best fertilization management modes. Additionally, the optimal combination of fertilization management modes for nursery land in the Hexi Reservoir catchment area would significantly reduce non-point source phosphorus runoff from nursery land and decrease the potential impact on water quality in Hexi Reservoir.

Furthermore, particulate phosphorus was the primary and dominant form of phosphorus loss in runoff under all fertilization management modes, followed by dissolved phosphorus. The annual mean proportions of particulate phosphorus loss in runoff from broadcast placement (control), plastic mulching, straw mulching, grass buffer strip, band placement, and hole placement accounted for 66.09%, 70.69%, 67.97%, 71.63%, 68.11%, and 67.87% of total phosphorus loss, respectively.

Keywords: Hexi Reservoir; nursery land; runoff; phosphorus loss

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1. Study Area Overview

The study area is located in Meishan Town, Changxing County, Huzhou City, Zhejiang Province (31°5 30 N, 119°42 22 E), approximately 10 km from the rainwater inlet of Hexi Reservoir. This region has a subtropical maritime monsoon climate with an average annual rainfall of 1309 mm, 144 rainy days per year, average annual sunshine hours of 1810.3 h, and a mean annual temperature of 15.6°C.

The basic soil physicochemical properties of the area are: organic matter 6.25 g/kg, total nitrogen 0.15 g/kg, available phosphorus 17.23 mg/kg, available potassium 21.83 mg/kg, and total phosphorus 256.62 mg/kg. The main soil type is paddy soil with medium fertility level.

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2. Experimental Design and Treatments

To investigate the effects of different fertilization management modes on phosphorus loss in runoff from nursery land in the Hexi Reservoir catchment area, this study adopted a runoff plot positioning experiment. Six fertilization management treatments were established in the nursery land: broadcast placement (control), plastic mulching, straw mulching, establishment of grass buffer strips around nursery land, band placement, and hole placement. Grass buffer strips of equal area were established outside the broadcast placement plots. Each plot measured 1-3 m^2, with ridges raised between plots and separated by plastic film to prevent water exchange between plots. A 10 cm long pipe was installed at the drainage outlet to measure surface runoff volume when runoff occurred, and a runoff collection pool with a capacity of about 80 cm was connected to the outlet to simultaneously collect surface runoff samples.

During the monitoring period, the annual fertilization amount was based on local nursery land fertilization practices, using compound fertilizer (N-P O -K O = 16-16-16, total nutrient content 48%) at 450 kg hm ², applied twice in March and July. The runoff plot positioning experiment lasted from 2015.

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3. Runoff Water Sample Collection and Analysis Methods

During the monitoring period in 2015, after each rainfall event producing runoff, mixed samples were collected from the runoff pool after water accumulation, placed in 500 mL plastic bottles with tight caps, and promptly brought to the laboratory for water quality analysis. Before sampling, the runoff pool was manually stirred. After each sample collection, the remaining water in the pool was completely drained to prepare for the next surface runoff event. Rainfall amount was recorded after sample collection.

Samples were frozen and stored in a refrigerator below -4°C and analyzed within 7 days. For analysis, samples were divided into two portions: one portion was used directly for total phosphorus (TP) determination, and the other was filtered through a 0.45 m microporous membrane for dissolved phosphorus (DP) determination. TP and DP were measured using potassium persulfate digestion and molybdenum-antimony spectrophotometry. Particulate phosphorus (PP) was obtained by subtracting DP from TP.

The phosphorus loss amount equals the sum of the product of pollutant concentration and runoff water volume for each runoff event during the detection period:

$$P = \sum C_i \times V_i$$

where P is the phosphorus runoff loss amount, C_i is the phosphorus concentration in the ith runoff event, and V_i is the water volume of the ith runoff.

Data processing used Excel 2007 and Origin 8.0 software for statistical analysis. SPSS 11.5 was used for significance analysis with a significance level of $P < 0.05$.

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4. Results and Discussion

4.1 Effects of Different Fertilization Management Modes on Runoff Volume from Nursery Land in the Hexi Reservoir Catchment Area

Table 1 shows the rainfall and runoff statistics for nursery land under different fertilization management modes in the Hexi Reservoir catchment area. The annual rainfall from April to November 2015 was approximately 1606.7 mm, 22.74% higher than normal years, with 28 rainfall events. July was the most concentrated rainfall period, accounting for 86.1% of annual rainfall. The maximum monthly rainfall was 259.9 mm, and the minimum was 28.5 mm. According to Chinese meteorological standards, there were 7 heavy rain events (50-99.9 mm/24h), 9 heavy rain events (25.0-49.9 mm/24h), and 8 moderate rain events (10.0-24.9 mm/24h). Moderate rain and above accounted for 36.76% of all rainfall events but 76.62% of annual rainfall.

Although different fertilization management modes had varying effects on runoff from corresponding plots, statistical analysis showed that runoff volume in all experimental plots was significantly positively correlated with rainfall amount, with correlation coefficients of $R^2 = 0.5497$ for broadcast placement, $R^2 = 0.5919$ for plastic mulching, $R^2 = 0.6610$ for band placement, $R^2 = 0.6717$ for hole placement, $R^2 = 0.7183$ for grass buffer strip, and $R^2 = 0.7879$ for straw mulching.

Runoff volume differed significantly among different fertilization and surface management modes. Straw mulching and grass buffer strips reduced runoff volume by 9.20% and 4.94%, respectively, while plastic mulching increased runoff volume by 342.05%. Band placement and hole placement increased runoff volume by 42.25% and 36.97%, respectively. In summary, rainfall amount and runoff volume showed good correlation under different fertilization management modes in the Hexi Reservoir catchment area, and runoff volume was mainly controlled by rainfall amount, consistent with studies by He Yan [15] and Xiong Yalan [16].

The large differences in runoff volume among different fertilization management mode plots were caused by: band placement and hole placement loosened surface soil during application, increasing the scouring area between rainfall and surface soil and thus increasing runoff volume; plastic mulching blocked direct contact between rainwater and soil, causing some rainfall to discharge with runoff; grass buffer strips outside plots reduced direct scouring of soil by rainfall and increased surface water retention capacity.

Table 1 shows the detailed effects of rainfall on runoff under different fertilization management modes.

4.2 Dynamic Characteristics of Total Phosphorus Concentration in Runoff from Nursery Land Under Different Fertilization Management Modes

Figure 1 shows the dynamic characteristics of total phosphorus (TP) concentration in runoff water samples from nursery land under different fertilization and surface management modes in the Hexi Reservoir catchment area. During the runoff plot experiment period, TP concentrations in runoff water samples from different fertilization management mode plots showed fluctuating characteristics. For broadcast placement, plastic mulching, straw mulching, and grass buffer strip management modes, TP runoff loss concentrations all peaked in July, with maximum concentrations of 1.19, 0.47, 0.37, and 0.67 mg/L, respectively. For band placement and hole placement, TP runoff loss concentrations peaked in June, with maximum concentrations of 1.11 and 0.70 mg/L, respectively.

TP concentration fluctuations were most intense and highest for the broadcast placement treatment, with concentration ranges of 0.33-1.59 mg/L and an average of (0.78±0.40) mg/L. In contrast, plastic mulching, straw mulching, grass buffer strip, band placement, and hole placement treatments all had TP concentrations significantly lower than broadcast placement, with concentration ranges and averages of: 0.05-0.47 mg/L, (0.17±0.12) mg/L; 0.11-0.37 mg/L, (0.19±0.09) mg/L; 0.13-0.67 mg/L, (0.32±0.20) mg/L; 0.11-1.11 mg/L, (0.40±0.30) mg/L; and 0.11-0.83 mg/L, (0.34±0.25) mg/L, respectively.

The TP concentration fluctuation pattern for broadcast placement plots showed an initial decrease, gradual increase from May to July, followed by a gradual decrease. This pattern may be caused by frequent human activities loosening the soil surface during plot establishment in April, relatively stable soil layers after establishment, and increased runoff loss concentrations due to seasonal fertilization in March and July. That is, hydraulic erosion caused by rainfall runoff splashing and scouring the soil surface [17] caused maximum soil phosphorus leaching loss.

The relatively stable TP concentration fluctuations and significantly lower concentrations in plastic mulching, straw mulching, grass buffer strip, band placement, and hole placement treatments were due to: plastic mulching and straw mulching blocking direct scouring between rainwater and soil, reducing direct leaching of applied fertilizer by rainwater; grass buffer strips forming interception buffer zones that filtered and intercepted phosphorus loss in direct runoff.

Throughout the runoff plot experiment period, different fertilization and surface management modes all had positive effects on reducing phosphorus loss concentrations in runoff. Compared with broadcast placement, plastic mulching, straw mulching, grass buffer strip, band placement, and hole placement reduced runoff loss concentrations by 78.46%, 75.21%, 59.03%, 48.09%, and 56.02%, respectively. This further indicates that rainfall intensity, rainfall interval, and antecedent rainfall are key factors determining runoff phosphorus loss [18-19].

[Figure 1: see original paper] Figure 1 shows the dynamic changes of total phosphorus concentration in runoff under different fertilization management modes.

4.3 Dynamic Characteristics of Dissolved Phosphorus Concentration in Runoff from Nursery Land Under Different Fertilization Management Modes

During the monitoring period, dissolved phosphorus (DP) concentrations in runoff water samples from different fertilization and surface management mode plots showed varying degrees of fluctuation. For broadcast placement, plastic mulching, straw mulching, and grass buffer strip management modes, DP runoff loss concentrations peaked in July, with maximum concentrations of 0.40, 0.14, 0.12, and 0.17 mg/L, respectively. For band placement and hole placement, DP concentrations peaked in June, with maximum concentrations of 0.27 and 0.23 mg/L, respectively.

DP concentration fluctuations were most intense and significantly higher in broadcast placement treatment plots, with annual fluctuations of 0.13-0.47 mg/L and an average of (0.27±0.11) mg/L. For band placement and hole placement, DP concentration fluctuation ranges and averages were: 0.01-0.12 mg/L, (0.05±0.04) mg/L; 0.03-0.15 mg/L, (0.06±0.04) mg/L; 0.03-0.24 mg/L, (0.09±0.07) mg/L; 0.01-0.27 mg/L, (0.11±0.07) mg/L; and 0.05-0.23 mg/L, (0.11±0.06) mg/L, respectively.

DP concentration fluctuations for broadcast placement showed an initial increase to a relative peak in July, then gradually decreased to lower levels. This pattern was caused by heavy rainfall in July leading to maximum runoff concentrations. The trend for plastic mulching, straw mulching, grass buffer strip, band placement, and hole placement was basically: a small peak formed in June followed by a decrease, with relatively small annual runoff loss concentration variation.

The DP concentration pattern of initially decreasing, reaching a relative peak in July, then gradually decreasing was caused by frequent human activities in April and seasonal fertilization effects. These four management modes had weak leaching effects on dissolved phosphorus, with seasonal fertilization having a major influence. DP concentrations remained relatively stable and at low levels when rainfall was relatively low.

Plastic mulching, straw mulching, grass buffer strip, band placement, and hole placement significantly reduced DP concentrations compared with broadcast placement, with reduction effects of 81.72%, 77.02%, 66.35%, 59.24%, and 59.10%, respectively. This demonstrates that reasonable fertilization management can effectively reduce dissolved phosphorus loss from nursery land.

[Figure 2: see original paper] Figure 2 shows the dynamic changes of dissolved phosphorus concentration in runoff under different fertilization management modes.

4.4 Dynamic Characteristics of Particulate Phosphorus Concentration in Runoff from Nursery Land Under Different Fertilization Management Modes

For broadcast placement, plastic mulching, straw mulching, grass buffer strip, band placement, and hole placement management modes, particulate phosphorus (PP) runoff loss concentrations all peaked in July, with maximum concentrations of 1.14, 0.42, 0.23, 0.49, 0.65, and 0.55 mg/L, respectively.

PP concentration fluctuations were most intense for broadcast placement, with fluctuation ranges of 0.20-1.14 mg/L and an average of (0.62±0.32) mg/L. For plastic mulching, straw mulching, grass buffer strip, band placement, and hole placement, PP concentration fluctuation ranges and averages were: 0.07-0.49 mg/L, (0.23±0.14) mg/L; 0.05-0.65 mg/L, (0.29±0.23) mg/L; 0.06-0.55 mg/L, (0.21±0.18) mg/L; 0.02-0.42 mg/L, (0.11±0.11) mg/L; and 0.07-0.23 mg/L, (0.13±0.05) mg/L, respectively.

PP concentration fluctuations for broadcast placement showed an initial decrease, reaching a relative peak in July, then gradually decreasing, with another relative peak in September before gradually decreasing again. This pattern was caused by seasonal fertilization in March and heavy rainfall in July leading to large runoff loss concentrations, but with small differences in annual runoff loss concentration variation.

For plastic mulching, straw mulching, grass buffer strip, band placement, and hole placement, PP concentration fluctuations showed an initial increase to a peak in July, then gradual decrease to lower levels. This pattern was caused by seasonal fertilization in March and continuous rainfall in July leading to increased runoff PP loss concentrations. Hole placement reduced rainwater leaching of soil, grass buffer strips intercepted runoff phosphorus loss, and plastic mulching and straw mulching blocked direct scouring of soil by rainwater, all showing obvious effects.

Throughout the monitoring period, PP concentrations remained relatively stable and at low levels under these four management modes. Compared with broadcast placement, plastic mulching, straw mulching, grass buffer strip, band placement, and hole placement significantly reduced PP concentrations by 81.08%, 79.07%, 63.54%, 53.24%, and 65.76%, respectively.

Comparing Figures 1, 2, and 3 shows that PP concentrations were significantly higher than DP concentrations. Rainfall is the most important natural cause of phosphorus loss. When runoff flows over the soil surface, it can transport fine soil particles and light organic matter, making particulate phosphorus the main form of phosphorus loss in cropland soil runoff. Studies by Mei [21] and Yuan Xingcheng [22] also showed that phosphorus in runoff is mainly lost in sediment-bound form. Runoff loss is the main form of phosphorus loss, and this study confirms this characteristic of cropland soil phosphorus runoff loss.

Different fertilization management modes had significant effects on different phosphorus forms in runoff. Phosphorus loss from cropland mainly depends on runoff volume, soil erosion amount, and phosphorus content in runoff and eroded soil [23]. This study shows that different fertilization management modes in nursery land produced significant differences in runoff volume and soil erosion amount, leading to obvious differences in runoff phosphorus concentration changes. Straw mulching and grass buffer strips provided abundant surface cover, facilitating rainfall infiltration and reducing surface runoff velocity [24], reducing runoff volume and raindrop detachment of soil, thus showing lower phosphorus loss concentrations in runoff. This further demonstrates that reasonable fertilization management is an important measure to effectively reduce phosphorus loss from nursery land runoff.

4.5 Annual Average Phosphorus Loss Fluxes per Unit Area Under Different Fertilization Management Modes

Affected by both runoff phosphorus loss concentration and runoff volume, the annual phosphorus loss fluxes under different fertilization management modes are shown in Table 2. The annual runoff loss fluxes of TP, DP, and PP under broadcast placement (control), plastic mulching, straw mulching, grass buffer strip, band placement, and hole placement were: 9.60, 9.14, 1.37, 5.49, 4.44, and 2.48 kg hm ², respectively.

Among different phosphorus forms, the annual average runoff loss fluxes from largest to smallest all followed the order: broadcast placement > plastic mulching > band placement > hole placement > grass buffer strip > straw mulching. These accounted for 15.00%, 14.31%, 2.25%, 9.50%, 7.67%, and 4.28% of total phosphorus input, respectively. The annual average runoff loss fluxes of DP followed the order: broadcast placement > plastic mulching > band placement > hole placement > grass buffer strip > straw mulching, accounting for 12.71%, 1.91%, 7.62%, 6.16%, and 3.44% of total phosphorus input, respectively.

The results show that straw mulching, grass buffer strip, band placement, and hole placement significantly reduced phosphorus loss fluxes compared with broadcast placement. The annual average TP runoff loss fluxes were 95.24%, 74.17%, 57.17%, and 46.27% of broadcast placement, respectively. The annual average DP runoff loss fluxes were 14.31%, 25.83%, 46.69%, and 30.49% of broadcast placement, respectively. The annual average PP runoff loss fluxes were 167.43%, 24.20%, 96.83%, and 78.10% of broadcast placement, respectively.

Hole placement reduced phosphorus loss fluxes most effectively, followed by straw mulching. Although plastic mulching had low runoff loss concentrations, its large runoff volume (342.05% of broadcast placement) resulted in relatively large annual phosphorus loss fluxes, exceeding those of broadcast placement. Straw mulching and grass buffer strip performed significantly better than hole placement ($P < 0.05$). Among the six fertilization management modes, broadcast placement and plastic mulching showed no significant difference in annual TP runoff loss flux ($P < 0.05$), indicating that plastic mulching did not significantly mitigate phosphorus loss due to its large surface runoff generation.

Straw mulching, grass buffer strip, band placement, and hole placement reduced annual average TP loss fluxes by 85.69%, 74.17%, 42.83%, and 53.73%, respectively. This demonstrates that reasonable fertilization management can effectively reduce phosphorus loss from nursery land. After the planting structure in the Hexi Reservoir catchment area was shifted to nursery land, the optimized fertilization management mode combination of hole placement with straw mulching and increased peripheral grass buffer strips would maximize the reduction of phosphorus non-point source loss from nursery land and minimize the potential threat of agricultural non-point source pollution to Hexi Reservoir water quality.

Table 2 shows the detailed annual average runoff phosphorus loss situation under different fertilization management modes.

4.6 Composition Characteristics of Phosphorus Loss Under Different Fertilization Management Modes

The proportions of different phosphorus forms in annual average loss fluxes are shown in Table 3. For broadcast placement, plastic mulching, straw mulching, grass buffer strip, band placement, and hole placement, the proportions of annual average DP runoff loss were 33.91%, 29.31%, 32.03%, 28.37%, 31.89%, and 32.13%, respectively. The proportions of annual average PP runoff loss were 66.09%, 70.69%, 67.97%, 71.63%, 68.11%, and 67.87%, respectively.

This indicates that particulate phosphorus is the main form of phosphorus loss in runoff water samples. Interception measures such as grass buffer strips and straw mulching can reduce the amount of phosphorus entering water bodies.

Table 3 shows the detailed composition characteristics of annual phosphorus runoff loss under different fertilization management modes.

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5. Conclusion

1. In the Hexi Reservoir catchment area, rainfall amount and runoff volume in different fertilization management treatment plots were positively correlated, with correlation coefficients of $R^2 = 0.5497$ for broadcast placement, $R^2 = 0.5919$ for plastic mulching, $R^2 = 0.6610$ for band placement, $R^2 = 0.6717$ for hole placement, $R^2 = 0.7183$ for grass buffer strip, and $R^2 = 0.7879$ for straw mulching. Runoff volume was mainly controlled by rainfall amount, but significant differences existed among different fertilization management modes. Straw mulching and grass buffer strip reduced runoff volume by 9.20% and 4.94%, respectively, while plastic mulching

increased runoff volume by 342.05%. Band placement and hole placement increased runoff volume by 42.25% and 36.97%, respectively.

2. Under different fertilization management modes, the annual total phosphorus runoff loss flux from nursery land in the Hexi Reservoir catchment area followed the order: broadcast placement > plastic mulching > band placement > hole placement > grass buffer strip > straw mulching. The annual total phosphorus runoff loss fluxes under broadcast placement, plastic mulching, straw mulching, grass buffer strip, band placement, and hole placement were 9.60, 9.14, 1.37, 5.49, 4.44, and 2.48 kg hm ², respectively. Compared with broadcast placement, straw mulching, grass buffer strip, band placement, and hole placement reduced annual average total phosphorus loss fluxes by 85.69%, 74.17%, 42.83%, and 53.73%, respectively, demonstrating that appropriate fertilization management modes can significantly reduce phosphorus loss from nursery land runoff.

3. Under different fertilization management modes, the primary form of phosphorus loss in runoff water samples from nursery land in the Hexi Reservoir catchment area was particulate phosphorus, followed by dissolved phosphorus. The annual average proportions of particulate phosphorus loss in runoff from broadcast placement, plastic mulching, straw mulching, grass buffer strip, band placement, and hole placement accounted for 66.09%, 70.69%, 67.97%, 71.63%, 68.11%, and 67.87% of total phosphorus, respectively.

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