THE VERTICAL DISTRIBUTION OF PHOSPHORUS NUTRIENT SALTS IN LARGE-SCALE DAIRY FARMING

by

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The rapid development of large-scale livestock breeding and poultry raising industries in China has led to the emergence of a novel approach to the treatment of dairy farm waste – the use of dairy farm waste as organic fertilizer to farmland soil. However, the high phosphorus content of dairy farm waste may pose a risk of environmental contamination to farmland soil and groundwater. The study primarily focused on the alterations in the concentrations of various phosphorus forms in soil and the occurrences of soil phosphorus leaching and depletion. The results indicate that the SQ5075 field management mode exhibits the highest total phosphorus content, which is conducive to the improvement of soil fertility. In comparison to the background value, the phosphorus content under SQ5025 is observed to be lower. Consequently, it results in a continuous depletion of phosphorus, which is detrimental to soil improvement and crop cultivation. The total phosphorus content in soil solution under SQ5050 is the largest, which may increase the risk of soil phosphorus leaching.

Key words: *various forms of phosphorus, field management, soil fertility, phosphorus leaching risk, phosphorus depletion*

Introduction

In recent years, with the continuous advancement of agricultural industrialization in China, the development of large-scale livestock and poultry breeding industries has become a necessity [1]. As a major province of livestock and poultry breeding in the northern region, the breeding industry of Inner Mongolia has developed rapidly, especially the dairy farming industry. This rapid development has the potential to directly aggravate agricultural non-point source pollution, resulting in the pollution of water, soil, and ambient air in the basin [2]. The

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pollutants produced by livestock and poultry breeding are primarily manure, which is treated by composting internationally [3]. In order to achieve the goal of circular agriculture development and zero growth of chemical fertilizers, China applies breeding manure as organic fertilizer to farmland soil. The gradual replacement of chemical fertilizers with fertilizers derived from plant and animal matter represents a strategy for achieving the combination of planting and breeding [4]. A number of studies have demonstrated that the reuse of livestock and poultry manure as organic fertilizer for farmland can effectively reduce nutrient loss and represents a primary means of utilizing livestock manure as a resource [5].

Phosphorus is an essential nutrient element for the growth of crops. The judicious application of phosphorus fertilizer can enhance the quality and yield of crops. However, the current utilization rate of phosphorus fertilizer in soil production and management is generally only 10% to 25%, resulting in a long-term surplus of phosphorus in the soil. A significant quantity of phosphorus fertilizer will flow into rivers with the action of surface runoff, thereby causing non-point source pollution of phosphorus. It is therefore of great importance to gain an understanding of the rules governing the migration and transformation of phosphorus in farmland soil if the efficient utilization of phosphate fertilizer resources and environmental protection are to be achieved.

Experimental design and methods

Experimental design

A total of eleven distinct gradients of organic fertilizer fertilization treatments were established in the field, see tab. 1 for the field treatments. The field test site for the return of livestock and poultry manure to the field is located in Harsha map, Tumd Left Banner, Hohhot City, Inner Mongolia Autonomous Region. The experiment was conducted from April to September in both 2018 and 2019. In the experiment, the effluent from the tertiary oxidation pond in the dairy farming plant was utilized as an organic liquid fertilizer, while the cow manure that had undergone fermentation and composting in the dairy plant was employed as an organic solid fertilizer. Additionally, protected planting areas were established around the test field. Each fertilization treatment was replicated three times (a total of 33 plots), with each replication arranged in a single row. The distance between cells was 1 m, the height of the ridge was 20 cm, each cell was irrigated independently, and corn was planted in the central area 0.5 m away from the surrounding anti-seepage film. The test period was two years. The test crop was corn silage variety 1381, and the test field was an idle soil plot that had not been cultivated or fertilized in the early stages.

Experimental method

Sampling point arrangement and sampling time of soil water samples. The sampling point for soil solution samples is situated in the center of each plot. The soil water sampler is employed to collect water samples at the corresponding depths of 20 cm, 40 cm, 60 cm, and 80 cm. This is done 12 hours after irrigation and when the rainfall exceeds 10 mm. The total phosphorus (TP) in the soil solution was determined by the SAN++SYSTEM continuous flow analyzer (Skalar Company of the Netherlands).

Sampling method. The soil samples were collected using the five-point method. This involved drilling at the four corners and the center of the plot at depths of 10 cm, 20 cm, 30 cm, 40 cm, 50 cm, 60 cm, 80 cm, and 100 cm. The TP content of the soil was determined by

Table 1. Field fertilization management measures

Management modes	Base manure				Top dressing			2018	2019
	Solid [kg]	Liquid [t]	Water [t]	Liquid ratio [%]	Solid [kg]	Liquid [t]	Liquid ratio [%]	Phosphorus rate [mgm^{-2}]	
SQ7575	182	1.28	0.4	75	1.28	0.4	75	18.91	18.87
SQ7550	182	1.28	0.4	75	0.84	0.84	50	18.91	18.40
SQ7525	182	1.28	0.4	75	0.4	1.28	25	18.91	17.92
SQ5075	182	0.84	0.84	50	1.28	0.4	75	12.84	13.27
SQ5050	182	0.84	0.84	50	0.84	0.84	50	12.84	12.80
SQ5025	182	0.84	0.84	50	0.4	1.28	25	12.84	12.32
Q100100	0	1.68	0	100	0	0	100	23.20	23.20
Q7575	0	1.28	0.4	75	0.4	0.4	75	17.67	17.68
Q5050	0	0.84	0.84	50	0.84	0.84	50	11.60	11.60
Q2525	0	0.4	1.28	25	0.4	1.28	25	5.52	5.52
Q00	0	0	1.68	0	0	1.68	0	0.00	0.00

Note: S is the solid fertilizer, Q – the liquid fertilizer, and numbers indicate the concentration of liquid fertilizer in base fertilizer and topdressing fertilizer.

the method of alkali melting-molybdenum-antimony resistance spectrophotometry (HJ 632-2011). The organophosphorus content was classified according to the BC method [6] and divided into the following categories: LOP, MLOP, MROP, and HROP. The inorganic phosphorus component was divided into soluble phosphorus (Abs-P), aluminum-phosphorus (Al-P), iron-phosphorus (Fe-P), calcium-phosphorus (Ca-P) [7-9], and occluded phosphorus (Obs-P) using the Peterson and Corey method.

Results and analysis

Distribution characteristics of soil total phosphorus under different manure returning modes

The effect of dairy cow farm manure returning to the field on the vertical distribution of TP in the soil was investigated through research. The changes in TP content in the farmland soil at different depths after harvesting for 11 field management modes are shown in fig. 1. The background value of TP in the soil before fertilization in 2018 demonstrated a decrease in TP range between 0-40 cm and 80-100 cm with increasing depth below the surface. The changing trend of soil TP content at different underground depths after harvest was found to be similar to the background value TP content under different field management measures. This is due to the diffusivity in the soil being poor, 10^{-12}-10^{-15} [m^{2}s^{-1}] [10]. When applying basal fertilizer, only the oxidation pond wastewater is applied, namely, Q100100, Q5050, and Q2525. This results in the soil TP content being at 20-50 cm below the background value. In contrast, the soil TP content of Q00 management at 20-60 cm is found to be lower than the background value. Long-term fertilization in agricultural production has been observed to result in the enrichment of nutrients in the 0-10 cm soil layers, while simultaneously causing a deficiency in nutrients in the soil layers beneath 10 cm. This phenomenon has been documented in numerous studies [11]. After two years of continuous fertilization, only the SQ5025 field management had the soil TP content lower than the background value at 20-80 cm. This indicates that in the long-term fertilization, this management measure is likely to cause continuous phosphorus depletion, which is not conducive to improving soil and crop planting.

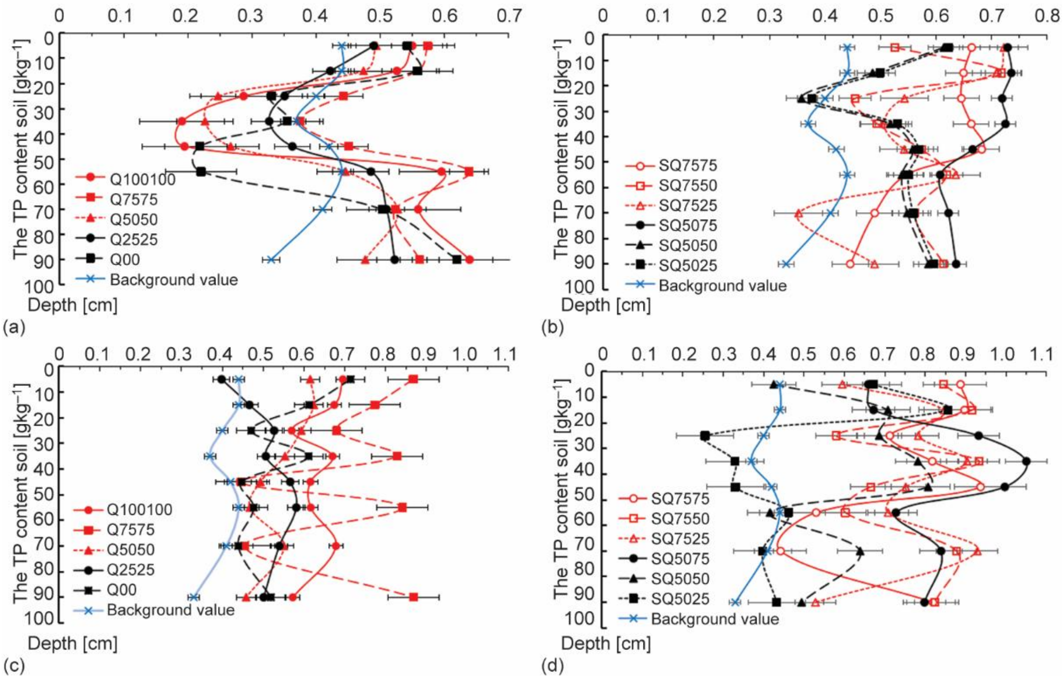

Figure 1. The TP content in soil after harvest in 2018 and 2019

Distribution characteristics of total phosphorus in soil solution under different manure returning modes

The changes in the TP content of the soil solution following fertilization and rainfall are illustrated in fig. 2, which presents the results of a monitoring experiment. The concentration of TP in soil water samples at a depth of 20 cm was found to be significantly lower than that observed in the other three depths, ranging from 0.04 mg/L to 2.27 mg/L, with an average of 0.69 mg/L. The mean TP content in soil water at depths of 40 cm, 60 cm, and 80 cm was found to be 1.63 mg/L, 1.02 mg/L, and 1.65 mg/L, respectively. The second and third rainfall events, basal fertilizer application in 2019, the first rainfall in 2019, and the average TP content of soil water in six times after topdressing in 2019 were 1.46 mg/L, 1.81 mg/L, 1.76 mg/L, 1.03 mg/L, and 0.83 mg/L, respectively. It has been observed that humic acid ions compete with phosphate ions for adsorption sites, thereby increasing the phosphorus content in soil solutions [12]. In 11 field management scenarios, SQ7575 exhibited the lowest average TP content (0.81 mg/L), while SQ5050 exhibited the highest average TP content (1.67 mg/L), which was 2.06 times higher than that of SQ7575. This indicates that the SQ5050 management measures were most likely to result in the risk of soil phosphorus leaching.

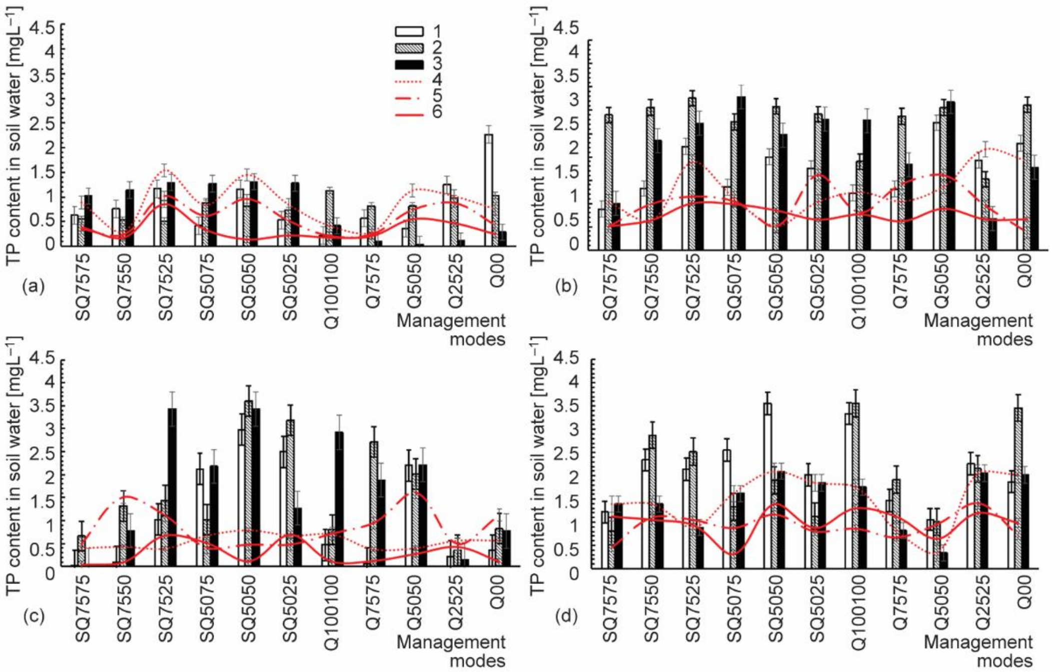

Figure 2. Effect of different field management measures on TP content in soil water;
(a) 20 cm underground, (b) 40 cm underground, (c) 60 cm underground, and (d) 80 cm underground.
1 – TP content in soil water after base manure in 2019, 2 – TP content in soil water of the first rainfall in 2019, 3 – TP content in soil water after topdressing in 2019, 4 – TP content in soil water of the first rainfall in 2018, 5 – TP content in soil water of the second rainfall in 2018, and 6 – TP content in soil water of the third rainfall in 2018

Distribution characteristics of organophosphorus in different manure returning modes

Figure 3 depicts the average organic phosphorus content in field management soil at varying depths. Among the four organic phosphorus forms, the average content of MLOP in the field management soil at different depths is the highest, exceeding the average content of LOP and MROP in the soil. In 2018 and 2019, the average content of MLOP in the field-managed soil at 0-40 cm and soil depth exhibited a wave-like pattern of change. The mean concentration of LOP in soil exhibited a gradual decline with increasing depth in 2018.

In contrast, the mean content of LOP in soil in 2019 exhibited a gradual increase with depth. The study demonstrated that the addition of litter significantly elevated the organic phosphorus content of the topsoil [13]. In 2018, plants that were not fully harvested were directly placed in the experimental field, resulting in an inverse relationship between LOP content and depth in soil in 2018 and 2019.

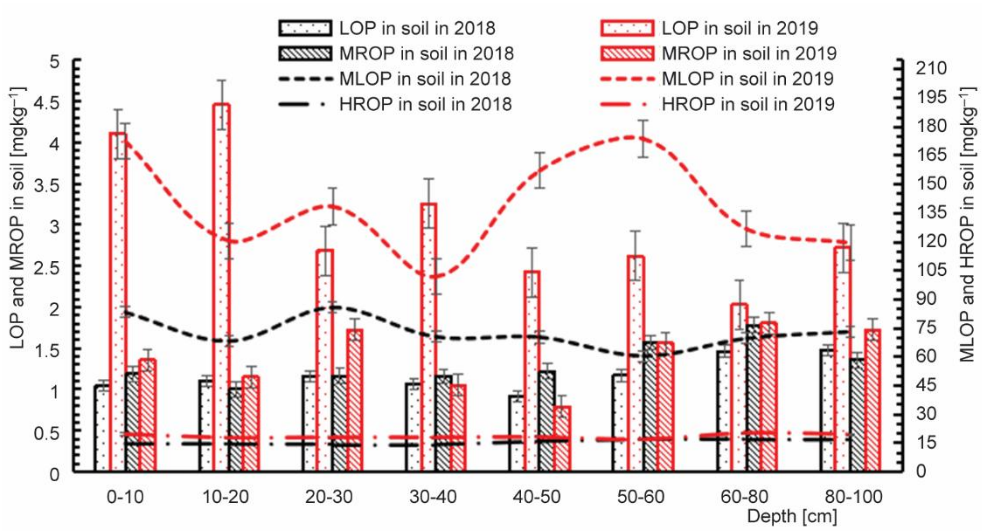

Figure 3. Variation law of the average content of soil organic phosphorus forms under different soil depths under different field management measures

Distribution characteristics of inorganic phosphorus under different manure returning modes

Figure 4 illustrates that the mean concentration of Abs-P in the soil of management measures that apply fermented cow manure during basal fertilizer application is more than twice that of management measures that apply only oxidation pond wastewater during basal fertilizer application. This is likely due to the fact that fermented cow manure has the effect of water retention and reduces the evaporation of soil water. The process of water evaporation will result in the rapid accumulation of Abs-P in the upper soil layer, with the upward migration of soil water. The upper soil phosphorus is taken up and utilized by the maize roots, which are primarily distributed in the upper soil. With the exception of SQ5025 field management, the content of Al-P in all field management soils exhibited the highest levels at underground depths of 0-40 cm, 40-60 cm, and 80-100 cm, with an increase in depth.

With the exception of Q2525 and Q00, the Fe-P content in the soil of the other field management measures exhibited a discernible wave-like pattern with increasing soil depth. This suggests that the quantity of phosphorus applied may influence the Fe-P content in the soil. With the exception of the Q2525 and Q00 field management measures, the Fe-P content in the soil at a depth of 0–20 cm below the surface was found to be higher than that at a depth of 20-100 cm below the surface. The Ca-P content in the soil following the 2019 harvest was observed to range from 4.38-491.12 mg/kg, which was found to be significantly higher than the Ca-P content observed in 2018. This indicates that the application of fertilizers on a continuous basis can facilitate the accumulation of Ca-P in the soil [14]. Figure 4 illustrates that the calcium and phosphorus content in the field management soil where only oxidation pond wastewater is applied is greater than that in field management soil where fermented cow manure and oxidation pond wastewater are applied.

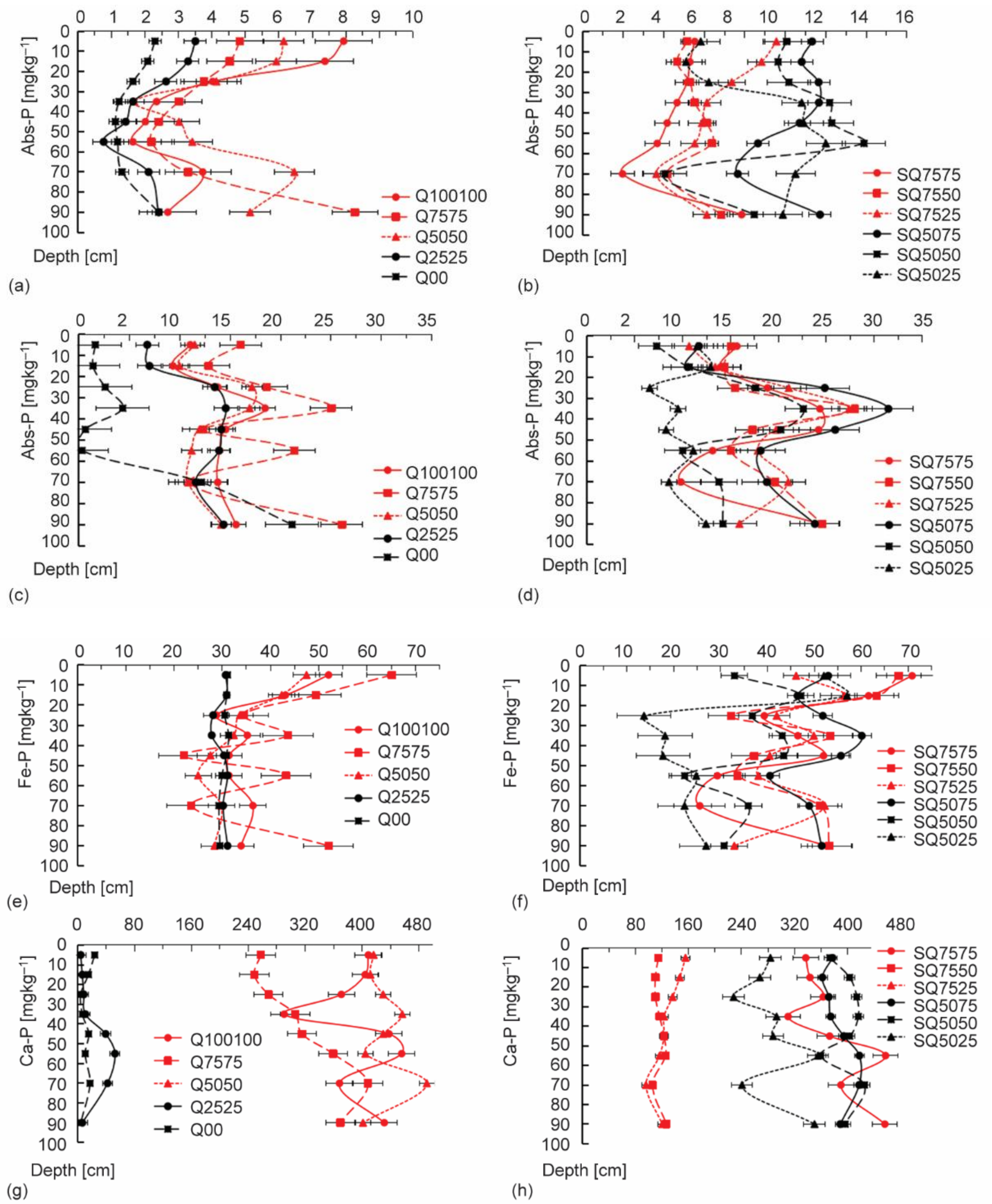

Figure 4. Average inorganic phosphorus content in the soil after harvesting in 2019

Conclusion

The application of oxidation pond wastewater is conducive to the formation of calcium and phosphorus, which facilitates the precipitation of soluble phosphorus in the soil. This process inhibits the absorption of phosphorus by crops and contributes to the accumulation of soil phosphorus. Among the four organic phosphorus forms, the average content of MLOP in the field-managed soils at different depths was the highest, indicating that it may be a potential source of available phosphorus. It can be reasonably concluded that SQ5050 management measures are the most likely to result in the leaching of soil phosphorus. A small amount of multiple fertilization is conducive to the adsorption of soil phosphorus. SQ5075 management measures have the largest soil TP content at each depth, which is conducive to the improvement of soil fertility.

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