Effects of Early Sowing and Tillage Measures on Soil Nitrogen and Phosphorus in Spring Wheat in the Semi-arid Loess Plateau Region Postprint

Authors: Liu Shuainan

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Abstract

To investigate the influence patterns of early sowing and tillage practices on soil nitrogen and phosphorus elements in farmland ecosystems, soil at 0–40 cm depth during the growth period of spring wheat (Triticum aestivum) was analyzed under early sowing and normal sowing with different tillage practices [conventional tillage (T), conventional tillage + straw return (TS), no-tillage (NT), no-tillage + straw mulching (NTS)] in the semi-arid region of the Loess Plateau, using normal-sown conventional tillage spring wheat as the control. The results showed that: (1) Soil nitrogen (TN, NO_3^--N, NH_4^+-N) and phosphorus (TP) contents in spring wheat under different treatments all exhibited surface accumulation characteristics, with the mean soil N:P ratio (1.713) being lower than the national average (5.2), while their coefficients of variation ranged from 26.99% to 77.28%, indicating a moderate variation level; (2) Throughout the entire growth period in the 0–40 cm soil layer, soil TN, NH_4^+-N contents and mean N:P ratio in early-sown spring wheat were significantly lower than those in normal-sown wheat by 23.1%–32.5%, which was unfavorable for the accumulation of soil TN and NH_4^+-N contents, whereas NO_3^--N content and mean NO_3^--N:N ratio were significantly higher than those in normal-sown wheat by 30.5% and 41.5%, respectively, facilitating the retention of soil NO_3^--N content, while soil TP content under early sowing treatments was generally higher than that under normal sowing treatments; (3) Soil TN and TP contents under straw mulching practices (NTS, TS) were higher than those under NT and T, whereas available nitrogen (NO_3^--N, NH_4^+-N) nutrient contents showed the opposite trend; (4) Soil TP content in spring wheat under different treatments remained relatively stable during the growth period, whereas nitrogen content changed more significantly at the tillering and flowering stages. Therefore, selecting appropriate sowing time and tillage management practices can help improve the accumulation and transformation efficiency of soil N and P elements for crops

in this region, and accelerate the restoration process of farmland ecosystems in the semi-arid Loess Plateau area.

Full Text

Effects of Early Sowing and Tillage Measures on Nitrogen and Phosphorus in Spring Wheat Soil in the Semi-arid Loess Plateau

LIU Shuainan, LI Guang, SONG Liangcui, YUAN Jianyu, XIE Mingjun, WEI Xingxing
College of Forestry, Gansu Agricultural University, Lanzhou, Gansu, China

Abstract

To investigate the effects of early sowing and tillage measures on soil nitrogen and phosphorus in farmland ecosystems, we analyzed 0–40 cm soil samples from spring wheat (*Triticum aestivum*) fields in the semi-arid Loess Plateau under different tillage practices: traditional tillage (T), traditional tillage with straw returning (TS), no-tillage (NT), and no-tillage with straw mulching (NTS). Using normal-sown spring wheat under traditional tillage as the control, we examined how early sowing and tillage measures influence soil nitrogen and phosphorus elements. The results showed that: (1) In the 0–40 cm soil layer, early-sown spring wheat had significantly lower total nitrogen (TN) and total phosphorus (TP) contents compared to normal sowing, with variation coefficients ranging from 26.99% to 77.28%, indicating moderate variation. (2) The N:P ratio in early-sown spring wheat was significantly lower than in normal sowing (by 23.1%–32.5%), which was unfavorable for soil nitrogen accumulation, whereas nitrate nitrogen (NO_3^--N) and ammonium nitrogen (NH_4^+-N) contents were significantly higher (by 30.5% and 41.5%, respectively), which was beneficial for soil nitrogen retention. (3) Straw mulching treatments (TS and NTS) generally increased TN and TP contents compared to normal sowing, but showed the opposite effect on available nitrogen (NO_3^--N and NH_4^+-N). (4) Under different treatments, TP content remained relatively stable during the growth period, while NO_3^--N content changed significantly at the tillering and flowering stages. Therefore, selecting appropriate sowing times and tillage management practices can improve the accumulation and transformation efficiency of nitrogen and phosphorus in crop soils and accelerate the restoration of farmland ecosystems in the semi-arid Loess Plateau.

Keywords: semi-arid Loess Plateau; early sowing; tillage measures; spring wheat; soil nitrogen and phosphorus

Introduction

With ongoing global climate warming, selecting optimal sowing dates has become a critical issue in agricultural meteorology research. Climate change affects the original growth and development rhythms of crops such as spring wheat, disrupting their relationship with water, light, and heat resources. Traditional sowing times can significantly interfere with crop growth, yield, climate resource utilization, and soil nutrient responses. Nitrogen (N) and phosphorus (P) are essential components of soil nutrients and vital for terrestrial plant growth and development. Their contents effectively influence soil microbial biomass, nutrient accumulation and transformation, and crop decomposition rates, and can be used to characterize the suitability of crop sowing dates, farmland soil quality, and environmental conditions. Different tillage measures create distinct differences in soil nutrient cycling within farmland ecosystems. Previous studies have shown that subsoiling and no-tillage significantly affect total nitrogen and available phosphorus in the tillage layer, influencing crop nutrient absorption and utilization. Long-term conventional tillage destroys the soil environment of the tillage layer, leading to nutrient loss, while conservation tillage measures such as no-tillage, reduced tillage, and straw mulching can effectively reduce soil erosion and improve nutrient storage.

Numerous studies have investigated optimal sowing dates for crops. However, due to differences in cultivation conditions and variety characteristics across experimental regions, results vary. Bai et al. found that appropriate early sowing can significantly improve crop utilization of soil water and nitrogen resources and increase yield, while Wei et al. reported that normal sowing effectively improves spring wheat yield and thousand-grain weight in the Loess Plateau region. Currently, few studies have combined sowing date with soil management practices to examine crop-soil nutrient dynamics. Research on nitrogen and phosphorus changes in spring wheat soil under different sowing dates and tillage measures can help maintain farmland ecosystem stability, address research gaps, and provide a scientific basis for sustainable and healthy development of regional farmland ecosystems.

1. Materials and Methods

1.1 Study Area This study conducted field surveys in the semi-arid Loess Plateau, selecting the Anding District Soil and Water Conservation Science Research Institute Experiment Station in Dingxi City (35°64 N, 104°64 E) as the research area. Located in southern Longzhong on the Loess Plateau, this typical semi-arid rain-fed agricultural region has an average elevation of 2000 m, mean annual temperature of 6.5 °C, mean annual precipitation of 390.99 mm (concentrated in July–September), mean annual evaporation of 1540 mm, and mean annual solar radiation of 141.6×1.48 $kJ \cdot cm^{-2}$ with $ $10 °C accumulated temperature of 2240.2 °C. The study area has flat terrain, with spring wheat as a widely planted crop. In 2018, wheat planting area reached 2.4766×10^4 hm^2, accounting for 6.67×10^5 of total grain crop area, with local tillage practices dominated by conventional tillage. The experimental soil is loessal soil with bulk density of 1.17 $g \cdot cm^{-3}$, organic matter content of 1.77 $g \cdot kg^{-1}$, total nitrogen of 1.17 $g \cdot kg^{-1}$, and total phosphorus of 0.76 $g \cdot kg^{-1}$.

1.2 Experimental Design To verify the response mechanisms of early sowing and tillage measures on spring wheat soil N and P elements, the experiment was conducted from March to July 2018. Based on experimental requirements, two sowing dates (early sowing and normal sowing) and four tillage measures [traditional tillage (T), traditional tillage + straw returning (TS), no-tillage (NT), and no-tillage + straw mulching (NTS)] were established using a two-factor randomized block design. There were eight treatments (Table 6) , each with three replicate plots (24 total plots), with each plot measuring 4 m × 4 m. The spring wheat variety "Dingxi 42" was used with a seeding rate of 187.5 $kg \cdot hm^{-2}$ and row spacing of 25 cm. Before sowing, each plot received a one-time application of pure nitrogen at 105 $kg \cdot hm^{-2}$ (as urea) and P_2O_5 at 105 $kg \cdot hm^{-2}$ (as calcium superphosphate).

1.3 Sample Collection Based on literature review and local conditions, spring wheat growth stages were determined. During the experiment, soil samples were collected at five growth stages (pre-sowing, tillering, jointing, flowering, and maturity) using an S-shaped sampling method. Five sampling points were randomly selected in each plot, and soil was collected by layers (0–10 cm, 10–20 cm, 20–40 cm) using a soil auger. After removing stones and roots, soil from the same layer was mixed to obtain one composite sample per layer, placed in sterile bags, sealed in ice-filled containers, and transported to the laboratory for storage at 4 °C. Meteorological data (average temperature and total precipitation) for each growth period in 2018 spring wheat were automatically measured by the Dingxi Soil and Water Conservation Institute meteorological station (Table 1) .

1.4 Sample Measurement Soil nitrate nitrogen (NO_3^--N) and ammonium nitrogen (NH_4^+-N) were extracted with 1 $mol \cdot L^{-1}$ KCl solution (soil:water ratio of 1:5). After shaking for 30 minutes and clarification, 50 mL of supernatant was distilled in a Kjeldahl apparatus. At the condenser outlet, 5 mL of H_3BO_3 solution was added to absorb ammonia, which was then titrated with H_2SO_4 standard solution to determine NH_4^+-N content. After distillation, 0.5 g of Devarda' s alloy powder was added to the solution, distilled again for 3 minutes, and titrated with H_2SO_4 standard solution to determine NO_3^--N content. For total nitrogen (TN), soil samples were digested with H_2SO_4-H_2O_2 until milky white, then measured by the Kjeldahl method. Total phosphorus (TP) was measured by the molybdenum-antimony colorimetric method using a UV spectrophotometer.

1.5 Data Processing Data were processed using SPSS 24.0 software. One-way ANOVA was used to test differences in soil nutrients among treatments and across growth stages, with Duncan' s method for multiple comparisons. Pearson correlation analysis was used to examine relationships between soil N and P elements. Significance was set at $P < 0.05$.

2. Results

2.1 Characteristics of Soil TN and TP Under Different Spring Wheat Treatments Characteristics of TN and TP in spring wheat soil across growth periods are shown in Table 2 . The coefficient of variation for soil N:P ratio across treatments ranged from 26.99% to 70.35%, with mean values of 34.29% for normal sowing and 43.69% for early sowing, indicating moderate variation and lower variability under early sowing.

The contents of TN, TP, and N:P ratio across treatments were: TN (TS) $\neq$ TN (NTS) > TN (T) $\neq$ TN (NT); TP (NTS) $\neq$ TP (TS) > TP (NT) $\neq$ TP (T); N:P (TS) $\neq$ N:P (NTS) > N:P (T) $\neq$ N:P (NT). Under the same tillage measure, TN values were significantly higher for normal sowing than early sowing by 21.5%-24.7%. TP content showed early sowing > normal sowing by 19.9%-35.2%. The N:P ratio was significantly higher under early sowing than normal sowing by 23.1%-32.5%, indicating more severe nitrogen deficiency under early sowing.

All treatments showed surface aggregation of TN and TP contents, with the highest values in the 0-10 cm layer (Figure 2) [Figure 2: see original paper]. Contents decreased with soil depth, and TP remained relatively stable across growth periods. As shown in Figure 3 [Figure 3: see original paper], TN content showed an "N-shaped" trend during growth periods, with peaks at tillering (20.3%-49.4% higher than pre-sowing) and flowering stages (30.1%-45.3% higher than pre-sowing), while TP remained relatively stable throughout the growth period.

2.2 Characteristics of Soil NO_3^--N and NH_4^+-N Under Different Spring Wheat Treatments Characteristics of NO_3^--N and NH_4^+-N in 0-40 cm soil under different treatments are shown in Table 3 . The coefficient of variation ranged from 29.52% to 77.28%, with mean values of 59.22% for normal sowing and 41.60% for early sowing, indicating moderate variation with lower variability under early sowing.

Across treatments, NO_3^--N content showed: NT > NTS > T > TS, with normal sowing significantly lower than early sowing by 32.5%. NH_4^+-N content showed: TS $\neq$ NTS > T $\neq$ NT, with normal sowing significantly higher than early sowing by 30.5%. The NO_3^--N:NH_4^+-N ratio was 0.009-0.022 under early sowing, significantly higher than 0.008-0.016 under normal sowing (by 32.1%-52.2%), indicating that early sowing better facilitated soil nitrogen retention during the full growth period.

Both NO_3^--N and NH_4^+-N showed surface aggregation, with highest contents in the 0-10 cm layer (Figure 4) [Figure 4: see original paper], decreasing with depth. As shown in Figure 5 [Figure 5: see original paper], NO_3^--N showed an "N-shaped" trend during growth periods, peaking at tillering and flowering stages, while NH_4^+-N peaked at tillering and gradually increased from jointing or flowering to maturity. Pre-sowing NO_3^--N was significantly lower than tillering (by 23.5%-28.3%) and higher than flowering (by 18.2%-43.3%).

Correlation analysis (Table 4) showed that under early sowing, TN was extremely significantly positively correlated with NO_3^--N and NH_4^+-N across all tillage measures ($P < 0.01$), and TP was significantly positively correlated with NO_3^--N under TS and NTS ($P < 0.05$). Under normal sowing, TN showed significant positive correlations with NO_3^--N and NH_4^+-N, while TP showed significant positive correlations with NO_3^--N under T and TS ($P < 0.05$).

3. Discussion

Nitrogen and phosphorus are important components of soil nutrients and essential for plant growth. Their contents can characterize soil quality and farmland environmental conditions. In this study, different treatments resulted in varying soil N:P ratios, affecting soil organic nitrogen mineralization rates, plant absorption and loss rates, and soil inorganic nitrogen accumulation. Spring wheat soil N:P ratio showed obvious surface aggregation (Figure 2) [Figure 2: see original paper], consistent with previous studies, because root exudates and plant residues transport nutrients to the surface layer during growth. Basal fertilizer application before sowing facilitates nutrient accumulation in the upper soil, where better aeration promotes soil-fertilizer integration and enhanced microbial activity accelerates litter decomposition and organic nitrogen mineralization.

Under both normal and early sowing, TN and TP contents under straw mulching (TS and NTS) were significantly higher than under T and NT. This occurs because straw mulching minimally disturbs soil, and returned crop residues create favorable conditions for fungi, bacteria, and microorganisms, facilitating decomposition and nutrient release. Additionally, straw mulching reduces raindrop erosion, decreases evaporation, enhances water storage, and improves water and nutrient retention. Conventional tillage without straw cover reduces microbial activity, decreases nutrient return rates, and lowers organic matter input, resulting in lower TN and TP accumulation. The correlation between TN and TP under TS and NTS was lower than under other measures (Table 4) because conventional tillage improves surface aeration, accelerates organic matter mineralization, and enhances nitrification and ammonification, accumulating NO_3^--N and NH_4^+-N. No-tillage soils are compacted, limiting soil-fertilizer integration, while straw mulching inhibits evaporation and increases water infiltration, but excessive moisture can leach NO_3^--N and NH_4^+-N from the tillage layer, resulting in lower contents in the order: TS $\neq$ NTS $>$ T $\neq$ NT, similar to Zhao' s findings.

During the full growth period, normal sowing facilitated TN and TP accumulation and increased crop absorption and loss rates of NO_3^--N compared to early sowing, differing from Zhang's results on annual forage grasses in eastern Gansu. Under normal sowing, higher soil temperatures (Figure 1) [Figure 1: see original paper] strengthened correlations between TN and soil inorganic nitrogen (Table 4) , indicating that suitable temperatures enhance microbial and nitrifying bacteria activity, accelerating decomposition and mineralization. Sowing date effects were more pronounced during vegetative growth, when NO_3^--N is most readily absorbed by spring wheat. Under normal sowing, sufficient NO_3^--N was rapidly absorbed, while differences diminished later. NH_4^+-N is less absorbed, positively charged, and easily adsorbed by soil with poor mobility, resulting in higher accumulation under normal sowing.

The N:P ratio in this region' s spring wheat soil was 1.713, lower than the national average of 5.2, indicating severe nitrogen deficiency. Early sowing had a significantly higher N:P ratio (29.6% higher than normal sowing), confirming more severe nitrogen deficiency, consistent with Zhu' s research on the Loess Hilly Region. During growth stages, soil TN and TP under both sowing dates increased from tillering to flowering then decreased to maturity, while NO_3^--N increased from flowering to maturity and NH_4^+-N decreased. During tillering, nutrient demand was weak but basal fertilizer began releasing nutrients. From flowering to maturity (July–August), nutrient demand weakened but favorable water-heat conditions enhanced microbial activity. Due to the correlation between TN and TP (Table 4) , microbial decomposition released more NH_4^+-N than NO_3^--N. Additionally, NO_3^--N is not easily adsorbed and was partially leached by concentrated rainfall in the Loess Plateau, while being readily absorbed by vegetation, causing losses.

4. Conclusion

Spring wheat soil in the study area showed obvious surface aggregation of N and P elements, with nitrogen deficiency. Normal sowing facilitated TN and TP accumulation and increased crop absorption and loss rates of NO_3^--N, while early sowing showed more severe nitrogen deficiency. Straw mulching effectively increased TN and TP contents but had opposite effects on available nitrogen (NO_3^--N and NH_4^+-N). Soil TP content remained stable during growth periods, while NO_3^--N and NH_4^+-N changed significantly at tillering and flowering stages. Selecting suitable sowing times and tillage management measures can improve nutrient accumulation and transformation efficiency and promote farmland ecosystem restoration in the semi-arid Loess Plateau.

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Note: Figure translations are in progress. See original paper for figures.