Effect of Water and Fertilizer on the distribution of Nitrogen and Phosphorus in soil and Partial factor Productivity

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Abstract. In order to explore the water and fertilizer utilization of summer corn and optimize a management scheme of water and fertilizer for summer corn in North China Plain, plot experiments of summer corn were conducted at Shandong Irrigation Experiment Center Station in Jinan. This paper analyzed the characteristics of nitrogen (N) and phosphorus (P) content in soil and partial factor productivity. The NO₃⁻N was the main form of residual N in soil, while P mainly distributed differently in the upper layer. N and P migrated downward more quickly under high irrigation, and the migration speed of N was faster than that of P. When the application of P and N were respectively 90 kg/hm² and 192 kg/hm², the NPFP and the PPFP were respectively the highest. Based on the above research results, it can be suggested that the management with 121.5 mm irrigation, 192 kg/hm² nitrogen and 90 kg/hm² phosphorus was the better cultivation practice for summer corn.

1. Introduction

Water and fertilizer are crucial to crop quality and yield. Reasonable application of water and fertilizer could improve the utilization of water and fertilizer. Fertilizer dissolved by appropriate water could promote the absorption of fertilizer by crops. If too much water is available, nutrient may be lost. Reasonable fertilization can not only improve the ability of soil to conserve water, but also enhance the activity of soil microorganisms. However, excessive fertilization will cause soil hardening and consequently reduce grain production. The reasonable irrigation and fertilizer will inevitably improve crop yield. Aiming at the problem of N and P leaching caused by large amount of fertilizer input and irrigation in summer corn planting in North China, this study explored a management schemes to improve the efficient use of water and fertilizer in crops. Plot experiments of summer corn were conducted at Shandong Irrigation Experiment Center Station in Jinan. Different water and fertilizer application experiments were designed in very plot experiment to reveal the vertical migration of water, N and P under different treatments.

2. Materials and methods

2.1 General

The experimental was conducted in Changqing District, Jinan City, Shandong Province (36 34'N, 116 50'E). The test area is in warm temperate zone with a semi-humid continental monsoon climate and the annual mean temperature is 14.3°C. The annual average precipitation is 654.7 mm and the
precipitation in summer accounts for 62% of the whole year. The soil types are loam and sandy loam and the representative crops are maize, wheat and temperate fruits and vegetables in the test area.

2.2 Treatments
The summer corn Zhengdan 958 was sown on June 4th, 2018 and harvested on October 3rd, 2018. Urea (46.4%), calcium persulfate (12%) and potassium chloride (60%) were chose as the inorganic fertilizers.

Ten treatments were designed in the experiment and each treatment has three replicates (Table 1).

According to the irrigation system used by local farmers, the irrigation treatments consisted of I1 (the irrigation of 67.5 mm at seedling stage and 67.5 mm at whole growth stage) and I2 (the irrigation of 67.5 mm at seedling stage, 54.0 mm at jointing stage and 121.5 mm at whole growth stage). Irrigation water quantity was measured by water meter. Nitrogen treatments consisted of optimum 75% N application (N1), optimum N application (N2) and optimum 125% N application (N3). 40% of N fertilizer was as base fertilizer and 60% of that was fertilized at heading stage. Phosphorus treatments consisted of optimum 70% P application (P1), optimum P application (P2) and optimum 125% P application (P3).

Table 1. Water and fertilizer treatment scheme of summer corn

| Number | Treatments | The amount of irrigation | The amount of N | The amount of P |
|--------|------------|------------------------|----------------|----------------|
|        |            | Coded value (mm)       | Coded value (kg/hm²) | Coded value (kg/hm²) |
| T1     | I1N1P2     | 0.68                   | 67.5             | -1             | 144            | 0             | 90            |
| T2     | I1N3P2     | 0.68                   | 67.5             | 1              | 240            | 0             | 90            |
| T3     | I1N2P2     | 0.68                   | 67.5             | 0              | 192            | 0             | 90            |
| T4     | I1N2P1     | 0.68                   | 67.5             | 0              | 192            | -1            | 63            |
| T5     | I1N2P3     | 0.68                   | 67.5             | 0              | 192            | 1             | 112           |
| T6     | I2N1P2     | 1.22                   | 121.5            | -1             | 144            | 0             | 90            |
| T7     | I2N2P2     | 1.22                   | 121.5            | 1              | 192            | 0             | 90            |
| T8     | I2N3P2     | 1.22                   | 121.5            | 0              | 240            | 0             | 90            |
| T9     | I2N2P1     | 1.22                   | 121.5            | 0              | 192            | -1            | 63            |
| T10    | I2N2P3     | 1.22                   | 121.5            | 0              | 192            | 1             | 112           |

Observation items include: soil water content, the distribution of N and P in soil, partial factor productivity. The specific details and measuring methods of N and P in soil are the same as those in reference [1].

Partial factor productivity: The ratio of summer corn yield under a certain fertilizer to fertilizer application. Partial factor productivity includes nitrogen partial factor productivity (NPFP) and phosphorus partial factor productivity (PPFP). The formulas are as follows:

1. Nitrogen partial factor productivity (NPFP)

$$NPFP = \frac{Y_N}{M_N}$$

NPFP -- Nitrogen partial factor productivity, kg/kg; $Y_N$ -- The summer corn yield under nitrogen fertilizer, kg/hm²; $M_N$ -- Nitrogen application amount, kg/hm².

2. Phosphorus partial factor productivity (PPFP)

$$PPFP = \frac{Y_P}{M_P}$$

PPFP -- Phosphorus partial factor productivity, kg/kg; $Y_P$ -- The summer corn yield under phosphorus fertilizer, kg/hm²; $M_P$ -- Phosphorus application amount, kg/hm².
3. Results and discussion

3.1 The distribution of NO$_3$-N in soil

Because it is easy to be nitrified and can be adsorbed by negatively charged soil colloids, NH$_4^+$-N is difficult to accumulate in soil. Nitrogen mainly exists in soil with NO$_3$-N. The variation of NO$_3$-N content in soils under different irrigation and fertilizer treatments was analyzed (Figure 1). It was found that: (1) The NO$_3$-N content in soils increased with the increase of nitrogen application under any irrigation condition. (2) The change of NO$_3$-N content in soils was mainly in the 0-60 cm soil layer. Water and fertilizer had little effect on deep NO$_3$-N. The consumption of NO$_3$-N mainly occurred in upper and middle soil [2]. (3) When the same amount of nitrogen fertilizer was applied, NO$_3$-N content decreased with the increase of phosphorus application. It indicated that phosphorus application could reduce the accumulation of NO$_3$-N in soil [3]. (4) It can be seen that the NO$_3$-N content in the soil layer below 80 cm under I2 is higher than that under I1 at the stage of heading and maturity. This may be because of irrigation more than once at the early stage of heading, which indicates that the later irrigation increased the leaching of NO$_3$-N into the deep soil layer [4].
3.2 The distribution of available phosphorous in soil

Figure 1. Soil NO₃⁻-N content in different growth stages.
The change of available phosphorus in soil is not significant in Figure 2 and the deep soil always has a low content of available phosphorus. These may be related to the poor transport ability of phosphorus. The effect of irrigation on soil available phosphorus transport is that the surface soil content under \(I_2\) treatment is lower than that under \(I_1\) treatment, but the deep soil content under \(I_2\) treatment is higher. This may be due to that water promoted phosphorus utilization by summer corn in the upper layer, or that water promoted the acceleration of phosphorus downward migration.

Nitrogen fertilizer promoted the utilization of phosphorus fertilizer by summer corn, but more than 240 kg/hm\(^2\) of N application would have a negative effect. After one-time application of phosphorus fertilizer, the content of available phosphorus in surface soil was positively correlated with the amount of phosphorus applied. The content of available phosphorus in P3 was the highest, and the application of phosphorus fertilizer had a significant effect on the increase of available phosphorus.

### 3.3 Effect of irrigation and fertilizer on partial factor productivity

Table 2. NPFP and PPFP with different treatments

| Number | NPFP (kg/kg) | PPFP (kg/kg) |
|--------|--------------|--------------|
| T1     | 44.58±0.60   | 71.32±0.96   |
| T2     | 28.86±0.22   | 76.97±0.34   |
| T3     | 36.90±0.61   | 78.71±1.31   |
| T4     | 35.81±0.57   | 109.13±1.21  |
| T5     | 34.37±0.20   | 58.92±0.52   |
| T6     | 58.02±0.03   | 92.83±0.99   |
| T7     | 38.19±0.22   | 101.85±0.68  |
| T8     | 50.68±1.55   | 108.12±4.73  |
| T9     | 45.98±0.10   | 140.14±1.17  |
| T10    | 44.06±0.19   | 75.53±0.32   |

As is shown in Table 2, higher irrigation can improve the utilization of nitrogen fertilizer by summer corn. Under the same irrigation amount and P application amount, the NPFP of summer corn decreased with the increase of N application amount \(^{[5,6]}\). Under the same irrigation amount and N application amount, the NPFP of summer corn increased at first and then decreased with the increase of P application amount \(^{[7]}\). When the application of P fertilizer was 90 kg/hm\(^2\), the NPFP was the highest. It indicated that the effect of P and water on NPFP was positive.

Under the same irrigation amount, the PPFP of summer corn under the same N application decreased with the increase of phosphorus application amount. Under the same irrigation and
phosphorus application, the PPFP of summer corn increased at first and then decreased with the increase of nitrogen application. When the amount of N application was 192 kg/hm$^2$, the PPFP was the highest. It indicated that the PPFP would be reduced when the N application exceeded a certain limit.

4. Conclusions
The residual nitrogen in soil mainly exists in the form of NO$_3^-$-N. NO$_3^-$-N migrates downward with the development of growth period. The deep soil always has a low content of available phosphorus, which may be related to the migration ability of nitrogen and phosphorus. By calculating the partial factor productivity of nitrogen and phosphorus in each treatment, the following conclusions were drawn: the partial factor productivity of nitrogen and phosphorus increased with the increase of irrigation amount; under the same irrigation condition, NPFP decreased with the increase of nitrogen fertilizer application amount and increased at first and then decreased with the increase of phosphorus application amount. PPFP increased at first and then decreased with the increase of nitrogen and phosphorus application amount. Therefore, in actual production, reasonable water and fertilizer is conducive to the full play of fertilizer efficiency. In this study, the management with 121.5 mm irrigation, 192 kg/hm$^2$ nitrogen and 90 kg/hm$^2$ phosphorus was the better cultivation practice for summer corn.

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