Effects of Combined Application of Humic Acid and Nitrogen Fertilizer on Nitrogen Uptake, Utilization and Yield of Winter Wheat (Postprint)

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Date: 2017-11-09T00:00:00+00:00

Abstract

Studying the effects of combined application of humic acid and nitrogen fertilizer on winter wheat yield, nitrogen uptake, and economic benefits can provide theoretical guidance for improving the yield-increasing benefits of nitrogen fertilizer and reducing its pollution to the ecological environment. Under the winter wheat-summer maize rotation system in the cinnamon soil region of Henan, a field positioning experiment was initiated in 2014 in Wolong District, Nanyang City, Henan Province, with six treatments established: application of phosphorus and potassium fertilizers alone, conventional fertilization, humic acid alone, conventional fertilization + humic acid, conventional fertilization with 15% nitrogen reduction + humic acid, and conventional fertilization with 30% nitrogen reduction + humic acid, to analyze the characteristics of winter wheat yield and nitrogen fertilizer utilization under different combinations of nitrogen fertilizer and humic acid. The results showed that the combined application of humic acid and nitrogen fertilizer could effectively improve winter wheat yield and its components, promote nitrogen accumulation in plants, and enhance nitrogen use efficiency. Among them, under the treatment of conventional fertilization with 15% nitrogen reduction + humic acid, winter wheat yield, grain nitrogen content, grain nitrogen accumulation, total aboveground nitrogen accumulation, nitrogen use efficiency, and net profit all increased; compared with conventional fertilization, winter wheat yield increased by 4.96%, nitrogen use efficiency increased by 23.42%, and net profit increased by 2.18%. Under the condition of conventional fertilization with 30% nitrogen reduction + humic acid, the output value and profit of winter wheat decreased. Therefore, only by applying appropriate amounts of nitrogen fertilizer on the basis of humic acid application can higher output value and profit be obtained. Conventional fertilization with 15% nitrogen reduction + humic acid is the optimal fertilization model in the study area, which is of great significance for achieving high yield and

high efficiency, resource conservation, and ecological environment protection in modern agricultural production.

Full Text

Preamble

Effect of Combined Application of Humic Acid and Nitrogen Fertilizer on Nitrogen Uptake, Utilization and Yield of Winter Wheat

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Abstract: This study investigated the effects of combined humic acid and nitrogen fertilizer application on winter wheat yield, nitrogen uptake, and economic benefits to provide theoretical guidance for improving nitrogen fertilizer productivity while reducing environmental pollution. A field experiment was initiated in 2014 under a winter wheat-summer maize rotation system in the cinnamon soil region of Nanyang, Henan Province. Six treatments were established: phosphorus and potassium fertilizers only, conventional fertilization, humic acid alone, conventional fertilization plus humic acid, conventional fertilization with 15% nitrogen reduction plus humic acid, and conventional fertilization with 30% nitrogen reduction plus humic acid. The results demonstrated that combined application of humic acid and nitrogen fertilizer effectively improved winter wheat yield and its components, promoted nitrogen accumulation in plants, and enhanced nitrogen use efficiency. The treatment with conventional fertilization plus 15% nitrogen reduction and humic acid application increased winter wheat yield by 4.96%, nitrogen use efficiency by 23.42%, and net income by 2.18% compared to conventional fertilization alone. However, the 30% nitrogen reduction treatment decreased productivity and revenue. Therefore, appropriate nitrogen fertilizer rates combined with humic acid are necessary to achieve high yield and income. The conventional fertilization with 15% nitrogen reduction plus humic acid represents the optimal fertilization mode for the study region, offering significant benefits for achieving high yield and efficiency, resource conservation, and ecological protection in modern agricultural production.

Keywords: Humic acid; N fertilizer; Winter wheat; Yield; Nitrogen uptake; Nitrogen fertilizer use efficiency

Fertilizers are the "food" for crops, with China' s annual fertilizer consumption accounting for one-third of global production. However, the current nitrogen use efficiency in Chinese farmland is only 30-35%, causing environmental pollution and affecting crop quality. Reducing nitrogen application while improving nitrogen use efficiency and crop yield is crucial for environmentally friendly agricultural development. Humic acid, a popular new fertilizer type, exhibits strong chemical and biological activity with multiple functional groups (carboxyl, hydroxyl, methoxy) that provide ion exchange and adsorption capacity. Combined application with nitrogen fertilizers promotes crop growth and nitrogen absorption, improving fertilizer efficiency. Previous research showed that humic acid combined with nitrogen and phosphorus increased winter wheat yield by 305.60 kg · hm 2, while humic acid with phosphorus increased soybean yield by 261.90 kg · hm 2 and improved alfalfa yield and quality. Other studies demonstrated that humic acid application promotes crop growth, increases summer maize yield, and enhances soil fertility. Applying humic acid can improve fertilizer efficiency, activate and amend soil, stimulate crop growth, and increase yield and quality, showing great potential in agroecosystems.

The Nanyang Basin cinnamon soil region is a major grain production area where winter wheat is the primary crop. Most humic acid research has focused on mechanistic studies, with few reports on direct application with inorganic fertilizers for winter wheat production, particularly in Henan' s cinnamon soil region. Given China' s limited land resources, modern agriculture must pursue intensive yet environmentally friendly development, requiring fertilizer technologies that maintain soil fertility and high yields while reducing ecological pressure. This study explores nitrogen management modes that reduce nitrogen application through humic acid addition, seeking reasonable nitrogen measures that ensure stable and increased winter wheat production and farmer income while improving nitrogen use efficiency and reducing environmental pollution.

1.1 Experimental Design

The field experiment was conducted in 2014 (the third year of a long-term trial) at Qianyingzhuang Village, Yingzhuang Town, Wolong District, Nanyang City, Henan Province. The test soil was yellow-cinnamon soil following a corn crop. After corn harvest, all straw was returned to the field, and deep plowing was performed before winter wheat sowing. The 0-20 cm soil layer had the following properties: pH 6.57, alkali-hydrolyzable nitrogen 69.97 mg · kg 1, available phosphorus 23.57 mg · kg 1, available potassium 84.25 mg · kg 1, and organic matter 11.32 g · kg 1.

The experiment was established on permanent cropland with six treatments: (1) T1: no nitrogen (phosphorus and potassium only); (2) T2: conventional fertilization with 180 kg · hm 2 nitrogen; (3) T3: humic acid alone at 3,000 kg · hm 2; (4) T4: conventional fertilization plus 3,000 kg · hm 2 humic acid; (5) T5: conventional fertilization with 15% nitrogen reduction (153 kg · hm 2) plus 3,000 kg · hm 2 humic acid; (6) T6: conventional fertilization with 30% nitrogen reduction (126 kg · hm 2) plus 3,000 kg · hm 2 humic acid. The experiment used a randomized block design with three replications, with plot size of 6 m × 8 m (48 m^2), protected by buffer rows and observation paths. The wheat cultivar was 'Zhoumai 16' . Fertilizers included urea (46% N), superphosphate (12% P O), potassium chloride (60% K O), and humic acid (pH 4.74, organic matter 809.2 g · kg 1, total nitrogen 7.6 g · kg 1, total phosphorus 3.8 g · kg 1, total potassium

2.3 g · kg ^{1}, supplied by Nanyang Wotai Fertilizer Co., Ltd.).

All treatments except T3 received 90 kg · hm ^{2} P O and 75 kg · hm ^{2} K O as basal fertilizers. Treatments T2, T4, T5, and T6 received nitrogen in a split application: 50% as basal fertilizer and 50% at the wheat jointing stage. Humic acid was applied as powder in a single basal application. Planting density and other management practices followed local high-yield wheat production protocols, with all operations completed by designated personnel on the same day.

1.2 Sampling and Measurement Methods

At winter wheat maturity, yield was measured by harvesting 1 m^2 of each plot, and yield components were investigated using the 1 m double-row method. Plant samples from each plot were separated into grain, chaff, and stems/leaves to calculate biomass. Samples were dried, ground, and analyzed for nitrogen content and accumulation to calculate nitrogen use efficiency.

Plant samples were digested using sulfuric acid-hydrogen peroxide method, and total nitrogen was determined by the Kjeldahl method. The following parameters were calculated based on methods by Peng et al. and Zou et al. to characterize fertilizer utilization efficiency:

Nitrogen accumulation (kg · hm ^{2}) = non-harvest dry weight × non-harvest N content + harvest dry weight × harvest N content (1)
Nitrogen partial factor productivity (kg · kg ^{1}) = yield in N-applied plot / N application rate (2)
Nitrogen agronomic efficiency (kg · kg ^{1}) = (yield in N-applied plot - yield in N-free plot) / N application rate (3)
Nitrogen recovery efficiency = (aboveground N accumulation in N-applied plot - aboveground N accumulation in N-free plot) / N application rate (4)
Nitrogen contribution efficiency (%) = (yield in N-applied plot - yield in N-free plot) / yield in N-applied plot × 100% (5)

All data were analyzed using Microsoft Excel 2003 and SAS software.

2.1 Effects of Combined Humic Acid and Nitrogen Application on Winter Wheat Yield and Components

The results showed that different fertilization treatments affected yield components across the 2014-2015 growing seasons . Effective panicles followed the trend: T5 > T6 > T2 > T4 > T3 > T1, with T5 significantly higher than other treatments and T1 significantly lower. Grains per panicle and 1000-grain weight showed the pattern: T5 > T6 > T4 > T2 > T1 > T3. Yield performance was: T5 > T6 > T4 > T2 > T3 > T1. Overall, nitrogen treatments significantly outperformed the no-nitrogen treatment, and humic acid combined with nitrogen was superior to chemical fertilizer alone. The T5 treatment performed best, with effective panicles, grains per panicle, 1000-grain weight, and yield increasing by 2.97%, 1.30%, 0.62%, and 4.96% respectively compared to

T2. The T6 treatment showed slightly better performance than T2 and T4 in yield components but remained lower than T5.

2.2 Effects of Combined Humic Acid and Nitrogen Application on Nitrogen Content and Accumulation in Winter Wheat Plant Parts

As shown in [Figure 1: see original paper], nitrogen content in different organs followed the trend: T5 > T6 > T4 > T2 > T1 > T3. Nitrogen treatments (T2, T4, T5, T6) had significantly higher nitrogen content than non-nitrogen treatments (T1, T3), indicating that nitrogen application increased plant nitrogen content while humic acid alone could not meet nitrogen demand. Grain nitrogen content in T4, T5, and T6 increased by 3.97%, 23.02%, and 17.46% respectively compared to T2, with T5 showing significant difference ($P < 0.05$). This demonstrates that humic acid combined with conventional fertilization promoted nitrogen absorption in plant organs.

Total nitrogen accumulation in different organs showed the pattern: T5 > T6 > T4 > T2 > T3 > T1 [Figure 2: see original paper], with nitrogen treatments significantly higher than non-nitrogen treatments. The T3 treatment had higher nitrogen accumulation than T1 but without significant difference. Compared to T1, T2, T4, T5, and T6 increased grain nitrogen accumulation and total nitrogen accumulation by 88.49-143.77% and 80.71-114.89% respectively, indicating that nitrogen application substantially enhanced nitrogen accumulation, with humic acid alone being slightly better than phosphorus-potassium fertilizer alone.

Treatments T4, T5, and T6 showed higher grain and total nitrogen accumulation than T2, with T5 significantly different in total nitrogen accumulation ($P < 0.05$). However, stem and leaf nitrogen accumulation in T4, T5, and T6 decreased by 3.22%, 18.81%, and 36.61% respectively compared to T2, suggesting that humic acid combined with conventional fertilization increased aboveground total nitrogen accumulation while reducing stem and leaf nitrogen accumulation and enhancing grain nitrogen accumulation. The T5 treatment (15% nitrogen reduction) performed best in promoting nitrogen accumulation and its transfer to grains.

2.3 Effects of Combined Humic Acid and Nitrogen Application on Nitrogen Use Efficiency in Winter Wheat

As shown in , nitrogen partial factor productivity followed the trend: T6 > T5 > T4 > T2. Nitrogen agronomic efficiency and recovery efficiency showed patterns: T5 > T6 > T4 > T2. Nitrogen contribution efficiency was: T5 > T4 > T2 > T6. These results indicate that humic acid combined with conventional fertilization improved nitrogen partial factor productivity, agronomic efficiency, contribution rate, and recovery efficiency. The T5 treatment performed best, achieving maximum nitrogen use efficiency, contribution efficiency, and agronomic efficiency, all significantly higher than T2. Although the 30% nitrogen reduction treatment showed reduced nitrogen use efficiency, it remained higher than conventional fertilization.

2.4 Effects of Combined Humic Acid and Nitrogen Application on Economic Benefits of Winter Wheat

As shown in , all treatments except T1 showed significantly higher output value and net income ($P < 0.05$). Output value followed the trend: T5 > T6 > T4 > T2 > T3 > T1, while net income was: T5 > T2 > T6 > T4 > T3 > T1. The output-input ratio showed: T2 > T5 > T6 > T3 > T4 > T1, indicating that nitrogen application significantly improved output value, net income, and output-input ratio.

The 15% nitrogen reduction with humic acid treatment achieved the highest output value and net income, increasing output value by 44.46%, 4.96%, 34.54%, 4.80%, and 3.68% compared to T1, T2, T3, T4, and T6 respectively, and net income by 52.57%, 2.18%, 36.44%, 10.66%, and 3.89% respectively ($P < 0.05$). However, 30% nitrogen reduction decreased output value and income. Due to increased input costs from humic acid application, the output-input ratio of humic acid treatments was lower than conventional fertilization alone. Overall, the T5 treatment (15% nitrogen reduction with humic acid) demonstrated the most practical value in the study region.

3 Discussion and Conclusion

Appropriate nitrogen application rates in agricultural production can increase winter wheat yield and its components, improve soil fertility, enhance nitrogen use efficiency, and achieve resource conservation and environmental protection. Studies by Cheng and Li on mixed humic acid and urea application showed significant slow-release and synergistic effects, increasing crop yield and nitrogen use efficiency by 6.9-11.9%. Research by Zhao et al. demonstrated that humic acid promotes nutrient absorption and significantly increases crop yield. Studies by Xu and Sun found that nitrogen application improves summer maize growth and yield, but requires optimal rates as higher amounts are not necessarily better. International research also indicates that appropriate nitrogen rates significantly increase winter wheat yield, with humic acid further enhancing yield components.

Our results show that nitrogen application promotes winter wheat growth and significantly increases yield and its components, with the best performance from conventional fertilization plus 15% nitrogen reduction and 3,000 $kg \cdot hm^{2}$ humic acid, achieving a 4.96% yield increase over conventional fertilization. This demonstrates that moderate nitrogen reduction with humic acid is feasible, increasing both wheat yield and overall benefits, consistent with findings by Sun et al.

Nitrogen absorption and accumulation in winter wheat plant parts are closely related to nitrogen application rates, forming the basis for crop yield and dry matter production. Appropriate nitrogen rates promote crop growth and nitrogen accumulation. Wang et al. found that humic acid promotes wheat absorption of M^2 or Fe^2 and increases dry matter accumulation. Chen et al. reported that humic acid promotes maize nitrogen, phosphorus, and potassium absorption but does not synchronously enhance nitrogen translocation to grains. Our results show that nitrogen application significantly increases nitrogen content in winter wheat organs, thereby increasing nitrogen accumulation. Humic acid combined with conventional fertilization further increases nitrogen content and accumulation, promotes nitrogen transfer to grains, and reduces nitrogen accumulation in stems, leaves, and chaff while enhancing grain nitrogen accumulation. The conventional fertilization with 15% nitrogen reduction plus 3,000 $kg \cdot hm^{2}$ humic acid performed best, significantly increasing grain nitrogen content, grain nitrogen accumulation, and nitrogen use efficiency compared to conventional fertilization.

Humic acid combined with nitrogen fertilizer substantially improves nitrogen use efficiency, possibly due to its active functional groups (amino, quinone, hydroxyl). Nitrogen absorption characteristics indicate reasonable nitrogen management. This study showed nitrogen agronomic efficiency of 12.60-17.51 $kg \cdot kg^{1}$, recovery efficiency of 34.72-58.14%, partial factor productivity of 46.07-64.24 $kg \cdot kg^{1}$, and contribution efficiency of 34.35-44.46%, relatively higher than other studies. This suggests that humic acid significantly improves nitrogen fertilizer efficiency. The relatively low nitrogen application rates (126-180 $kg \cdot hm^{2}$) with humic acid promotion of nitrogen absorption, combined with relatively low yields in the no-nitrogen control, resulted in high agronomic efficiency and recovery efficiency calculated by the subtraction method. This demonstrates that humic acid combined with nitrogen fertilizer is an important measure for achieving high yield, high efficiency, and fertilizer savings without reducing soil nutrients.

Evaluating practical application value requires considering both yield increase and economic benefits. All nitrogen treatments achieved higher output value and net income. However, conventional fertilization with 15% nitrogen reduction plus 3,000 $kg \cdot hm^{2}$ humic acid achieved the highest output value and net income, while 30% nitrogen reduction decreased them. This confirms that appropriate nitrogen rates with humic acid are necessary for high output value and income.

In conclusion, combined humic acid and nitrogen application promotes winter wheat growth, improves yield components, increases yield, enhances nitrogen accumulation, and improves nitrogen use efficiency. The conventional fertilization with 15% nitrogen reduction plus 3,000 $kg \cdot hm^{2}$ humic acid performed best, achieving yield and efficiency increases while conserving resources and protecting the environment. Therefore, applying humic acid in modern agricultural production is significant for building an environmentally friendly and resource-saving society.

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