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EFFECTS OF DIFFERENT TOP-DRESSING METHODS AND NITROGEN LEVEL ON GROWTH AND YIELD OF WINTER WHEAT (*TRITICUM AESTIVUM* L.)

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Abstract

Top-dressing can effectively improve crop yield, reduce extensive use fertilizer and decrease environmental pollution. At present, there are many methods of top-dressing for the winter wheat. However, only a few studies are available. Four top-dressing methods were set to study the effects of top-dressing methods on plant height growth, growth vigour and yield of winter wheat of "Shixin 828". The results showed that the growth and yield of wheat increased with the increase of top-dressing doses. Under the same top-dressing doses, the effect of deep application of prick-hole top-dressing (S1) on the growth and yield of winter wheat was the most significant, and there was no significant difference between other treatments. The highest yield was estimated to be 9.21 t/hm^2 under the treatment of N4 and S1. Compared with other top-dressing methods (S2, S3 and S4), the estimated yield of 8.82 t/hm^2 under the treatment of N3 and S1 was the second highest yield and was better than the other top-dressing methods. It may help in reducing top-dressing doses and increasing grain production. Therefore, S1 top-dressing method was found to be the most suitable method for winter wheat of "Shixin 828".

Introduction

Winter wheat (*Triticum aestivum* L.), as one of the main crops in China, is of great significance in ensuring food security and economic development. The increase of yield of winter wheat can guarantee the national food security and people's living material demand, so the research on winter wheat becomes more and more important (Cong *et al.* 2008, Tao *et al.* 2020). Nitrogen is known as the "life element", which is the essential nutrient element of winter wheat and the main component of protein. Chemical nitrogen fertilizer, as the main source of nitrogen, is widely welcomed by farmers all over the world. Therefore, the use of nitrogen fertilizer is generally regarded as one of the main means to increase grain production (Wang *et al.* 2004, Boyer *et al.* 2011, Zhang *et al.* 2013, Yin *et al.* 2020).

Top-dressing operation is an important part in winter wheat production management. Effective top-dressing management can improve nitrogen utilization rate, reduce environmental pollution and increase crop yield (Yuan *et al.* 2016, Feng *et al.* 2018). In recent years, with the development of top-dressing machinery, more new top-dressing methods are opened for winter wheat. Shi *et al.* (2015) designed a new type of shaft segmented variable top-dressing machine actuator, which could meet the real-time variable top-dressing requirements of precision top-dressing machine in the process of rice and wheat growth. Feng *et al.* (2018) studied the precise row-following and accurate deep fertilizing method based on autonomous navigation system. And then the precise alignment and deep fertilizer application machine for winter wheat was designed

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to achieve deep fertilizer application. Liu *et al.* (2018) designed a kind of notched precision hole-fertilizing apparatus for granular fertilizer application, to optimise the transformation from strip application to point application. Zhang *et al.* (2012) designed a chain conveyor variable rate fertilizer spreader based on the prescription chart, which could optimise the variable rate fertilizer application technology of winter wheat. The water and fertilizer management plan of multiple nitrogen application methods were studied and optimum method was obtained during the growth period of winter wheat under center pivot irrigation system (Cai *et al.* 2018).

In general, most of the current researches were focused on the control and optimization of winter wheat top-dressing for the single way of top-dressing (Chen *et al.* 2015, 2016, Reyes *et al.* 2015, Zhu *et al.* 2018a, 2018b, Alameen *et al.* 2019, Yang *et al.* 2019). A few experiments on the comparison and analysis of effect between different top-dressing methods were carried out. The best method of top-dressing nitrogen fertilizer in the period of winter wheat returning to grow next year was rarely reported. Therefore, the winter wheat in North China Plain was selected as the research object. Plant height, growth vigour, yield and yield components were used as the experimental indexes. And the top-dressing effects of four top-dressing methods, namely prick-hole top-dressing in subsurface, fertilizer spreader in surface, stream of umbrella with liquid, and stream of bar with liquid, were studied to find the optimum method which could provide the technical reference for the top-dressing of winter wheat.

Materials and Methods

The location of the experimental study area is located in the professional cooperative of Guanghui agricultural machinery service (37°43′30″N, 114°48′49″E), south Yaojiazhuang village, Zhaozhou Town, Shijiazhuang City, Hebei Province, China (Fig. 1). This area belongs to warm temperate continental climate, which is dry and windy in spring, warm and rainy in summer, invigorating climate in autumn, dry and cold in winter. The preceding crop of the test site was summer corn, and the test soil was sandy clay loam. The soil organic matter was 15.3 g/kg, pH was 8.17, available P was 19.45 mg/kg, available K was 180 mg/kg, and total nitrogen was 1.97 g/kg.

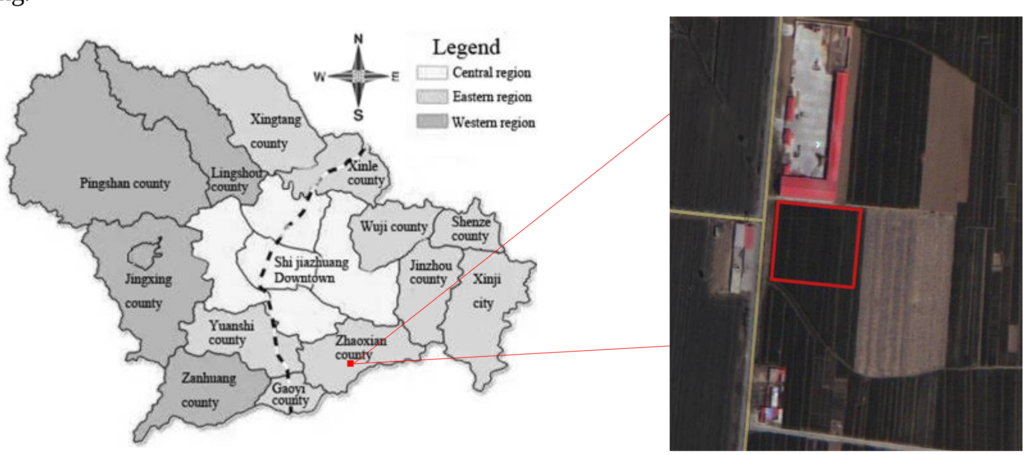

Fig. 1. Location of the experimental study area.

“Shixin 828” was selected as the trial wheat variety. The sowing date was October 10, 2018, and the sowing amount was 187.5 kg/hm^2. The urea was used as test fertilizer, which was produced by Hebei Yangmei Zhengyuan Chemical Industry Group Co., Ltd. The date of top-dressing was 25 March, 2019, when the wheat was in the returning green stage after overwintering (December, 2018~February, 2019). The measuring instrument of crop growth was the Crop circle ACS-430 with post processor. The fertilization machines were respectively deep prick-hole top-dressing applicator, surface fertilizer spreader and liquid spraying applicator (Fig. 2).

(a) Deep prick-hole top-dressing applicator (b) Surface fertilizer spreader (c) Liquid sprayer with umbrella stream (d) Liquid sprayer with bar stream

Fig. 2. Top-dressing equipments of winter wheat.

Two factor randomized block design was adopted in the experiment, with a total composition of two factors and four levels. Top-dressing method was regarded as factor S, which was differentiated as S1 (prick-hole top-dressing in subsurface), S2 (fertilizer spreader in surface), S3 (stream of umbrella with liquid) and S4 (stream of bar with liquid). And the deep prick-hole top-dressing applicator adopts star-shaped disc structure to apply the prick-hole top-dressing densely and quickly. Based on bionics principle, the scattering disc was used in the surface fertilizer spreader to spread the fertilizer particles uniformly on the ground surface. The umbrella stream contains three outlet nozzles and the bar stream contains only one nozzle in liquid sprayer. Top-dressing dose (Nitrogen) was regarded as factor N, which was differentiated as N1 (0 kg/hm^2), N2 (150 kg/hm^2), N3 (225 kg/hm^2) and N4 (300 kg/hm). There were 16 treatments in a single set of test. Each treatment was repeated for three times. Thus, 48 test plots were designed finally. The total test area was 60 m in the east-west direction, 70 m in the north-south direction, and each plot of 60 m^2 (4 m × 15 m). The normal water management was implemented before the harvest. The design and distribution of the test plot are shown in Fig. 3.

The top-dressing time of plot test was 25 March, 2019 and the non-directional wind speed was about 3 - 5 m/s. The plant height of winter wheat was measured at 20 days after top-dressing. A sampling area of 2 m × 2 m was randomly selected in each experimental plot. Next 10 wheat plants were randomly selected along the diagonal direction of the sampling area to measure the plant height. The wheat growth vigour in this area was detected by using spectral sensor (Crop circle ACS-430), and then the information of growth was transformed into normalized vegetation index (NDVI). A yield-test quadrat of 1 m × 1.2 m in each sampling area was chosen during the wheat harvest period (7 June, 2019). The ripened wheat of quadrat was dried naturally after harvest. After about one month (8 July, 2019), the wheat was threshed manually to avoid grains loss. The clean grains were stored in independent zip-lock bags and marked with the number of test plot. Then the mean of kernels of 10 wheat plants selected randomly were counted, the weight of 1000 wheat grains (1000-kernel weight) was measured, and the total weight of wheat grains in the yield-test quadrat was taken. Finally, the corresponding yield was estimated under different test conditions following Cai *et al.* (2018) and Zhang *et al.* (2018).

The growth effect of winter wheat was regarded as the index of fertilizer effect. The growth parameters were analysed with different top-dressing amount and methods, including plant height, growth vigour, number of kernels, 1000-grain weight and yield of plants. The test data were recorded and sorted out by Microsoft Excel 2010, and variance analysis, multiple comparison and correlation analysis were carried out by the statistical software of SPSS (Statistical Product and Service Solutions) 22.0. Duncan method was used to compare the significance of each index ($p < 0.05$), and the figure was drawn by the software of Origin 8.0. (Cai *et al.* 2018, Zhang *et al.* 2018).

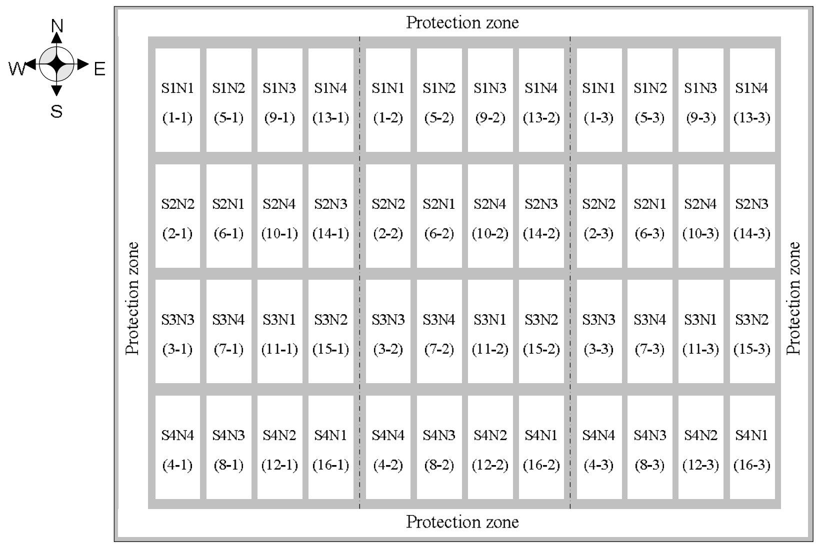

Fig. 3. Design and distribution of treatments in the field experiment plot.

Results and Discussion

The results of two-factor variance analysis showed that 20 days after fertilization, different methods and doses of top-dressing had a significant effect on plant height. The differences of plant height among different top-dressing methods are presented in Table 1. It can be seen from Table 1 that the plant height increased with the increase of top-dressing doses, and it would reach the highest under the maximum doses (N4). There were differences in plant height production among different top-dressing methods under the same doses of top-dressing. The significance of S1 treatment was higher than that of the other three top-dressing methods, and there was no significant difference among S2, S3 and S4. With the increase of the top-dressing doses, the significant difference between S1 and S2 treatment became small, there is no significant difference among the S2, S3, and S4 treatments. Comprehensive analysis showed that S1 treatment had a significant effect on plant height growth, and the highest growth of wheat was found in S1 treatment.

The variance analysis results of crop growth vigour 20 days after fertilization, are presented in Table 2 where it is apparent that different methods and doses of top-dressing had an effect on plant growth vigour. The value of NDVI increased with the rise of top-dressing amount, indicating that growth vigour got flourished. And the growth vigour was the best under the maximum doses (N4). Under the same doses of top-dressing, there were significant differences in plant growth vigour among different top-dressing methods. The significance of S1 treatment was higher than that of the other three top-dressing methods and there was no significant difference between S2 and S3, and the significance of S4 treatment was the least. Compared to other treatments of top-dressing, the treatment of S1 could loosen the soil by prick-hole, which was helpful for the growth of wheat.

When the top-dressing doses were zero, S1 treatment was also the most significant. But there was no significant difference between S2 and S3, and the same situation was between S3 and S4. Comprehensive analysis showed that the top-dressing methods (S2, S3 and S4) were easy to generate the nitrogen element of urea volatilization. The method of prick-hole (S1) could improve the utilization rate of urea fertilizer, and the average growth vigour of wheat was the best under this treatment.

Table 1. Effects of plant height (cm) under top-dressing methods with 20 days after top-dressing.

Treatments		Methods of top-dressing			
		Prick-hole (S1)	Fertilizer spreader (S2)	Stream of umbrella (S3)	Stream of bar (S4)
Application doses /(kg/hm^2)	0 (N1)	36.89a	36.77a	36.50a	36.39a
	150 (N2)	39.18a	37.28b	36.77b	36.22b
	225 (N3)	40.38a	38.55b	37.48b	37.08b
	300 (N4)	40.83a	39.35ab	39.02b	37.90b

Lowercase letters indicate that significant difference (Duncan $p < 0.05$), and the difference is expressed by a,b,c and d, respectively (Compared to rows between S1, S2, S3 and S4).

Table 2. Effects of plant growth vigour under top-dressing methods with 20 days after top-dressing.

Treatments		Methods of top-dressing			
		Prick-hole (S1)	Fertilizer spreader (S2)	Stream of umbrella (S3)	Stream of bar (S4)
Application doses /(kg/hm^2)	0 (N1)	0.75a	0.73b	0.72bc	0.71c
	150 (N2)	0.80a	0.77b	0.75c	0.73c
	225 (N3)	0.83a	0.79b	0.78b	0.76c
	300 (N4)	0.85a	0.82b	0.81b	0.77c

The meaning of lowercase letters (a, b, c and d) was same as in Table 1 (Compared to rows between S1, S2, S3 and S4). The value in Table 2 was the NDVI of plant growth vigour obtained by Spectroscopy sensor (Crop circle ACS-430) with the height of 80 cm above ground level.

Variance analysis was carried out for the effect of top-dressing methods and top-dressing doses on yield, and the effect of the factors was obtained (Table 3), where it is apparent that the effect of top-dressing methods and top-dressing doses on yield was highly significant, and the effect of interaction between top-dressing methods and top-dressing doses was not significant (Fig. 3).

Effects of different top-dressing methods on wheat yield and its components are shown in Table 4. Results showed that there was no difference in the effects of different top-dressing methods on the number of kernels. For the wheat 1000-grain weight, S1 treatment was the most significant, the significance of S2 treatment was higher than S3 and S4 treatment and there was no difference between S3 and S4 treatment. The value of 39.87 g for 1000-kernel was the maximum due to S1 treatment. In terms of yield, S1 treatment was the highly significant, and there was no significant difference between S3 and S4 treatments of top-dressing. The utilization rate of urea fertilizer could improve effectively because the soil was loosened and the fertilizer was leached in subsurface soil in S1 treatment. The estimated yield was the highest than other top-dressing methods.

Table 3. Analysis of variance on winter wheat yield under top-dressing methods and doses.

Treatments	f	SS	MS	F	Significance level
Methods of top-dressing /(S)	3	3.82	1.27	29.98	$\alpha = 0.01$
Doses of top-dressing /(N)	3	7.55	2.52	59.21	$\alpha = 0.01$
Methods × doses/(S·× N)	6	0.40	0.07	1.58	No significance
Error	32	1.36	0.04		
Total variation	47	13.13			

The methods × doses means the interaction of application method and dose.

Effects of top-dressing doses on yield should be analyzed showing that there was significant difference in the effect on wheat yield (Fig. 4). The significance of top-dressing doses on wheat yield was N4, N3, N2 and N1 from strong to weak. The yield could improve 14.25% from 7.51 to 8.58 t/hm^2 when the top-dressing dose increased from 0 to 300 kg/hm^2. Combined with the above analysis, the growth and yield of wheat could be increased with the increase of top-dressing doses. The yield of winter wheat could be significantly improved when the top dressing amount was as in N4. The yield of winter wheat could also be significantly improved when the top dressing method was S1. The estimated yield of wheat was the highest (9.21 t/hm^2) under the treatments of S1 and N4, which was increased by 7.34 to 12.18% compared to other methods (the maximum yield being 8.58, 8.33 and 8.21). Compared to other top-dressing methods (S2, S3 and S4), the estimated yield of 8.82 t/hm^2 under the treatment of N3 and S1 was the second highest yield and was better than the other top-dressing methods. It may help in reducing top-dressing doses and increasing grain production. The most suitable method of top-dressing (S1) was verified for winter wheat in the regreening period. Besides, the estimated yields of wheat under all treatments are presented in Fig. 5.

Table 4. Effects of different top-dressing methods on winter wheat yield and its related parameters.

Treatments	No. of kernels /(plant)	Thousand kernel weight/(g)	Estimated yield/(t/hm^2)
S1	28.23a	39.87a	8.57a
S2	28.21a	38.87b	8.11b
S3	28.20a	38.35c	7.95bc
S4	28.08a	38.29c	7.83c

The estimated values of the most parameters used such as plant height, growth vigour, and yield showed that the increase was significant with increasing top-dressing doses for all four methods. There was a positive correlation between yield and top-dressing doses within the test range. Compared to the other three top-dressing methods (S2,S3 and S3), the estimated yield of winter wheat conducted with method S1 was much higher because of loosening the soil and reducing fertilizer volatilization by prick-hole. Therefore, the best method (S1) was obtained for top-dressing of winter wheat returning to green. The yield of winter wheat could reach the highest under the treatments of N4 and S1 and reached the highest when the top-dressing dose of nitrogen increased to maximum N4. However, the changing trend of yield may vary as the top-dressing dose continues to increase. Further tests are necessary to find the inflection point of the yield-dose curve. In-depth analysis of the fertilization effect can provide references for reducing top-dressing doses and increasing grain production.

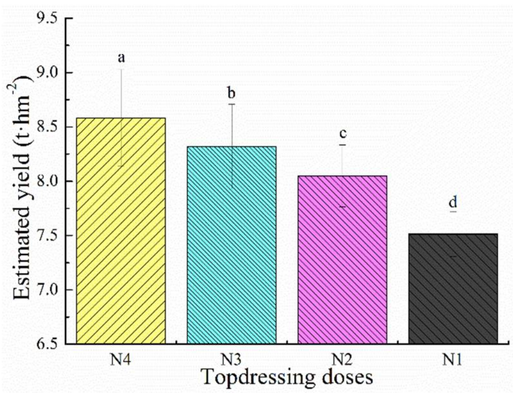

Fig. 4. Effect of top-dressing doses on yield.

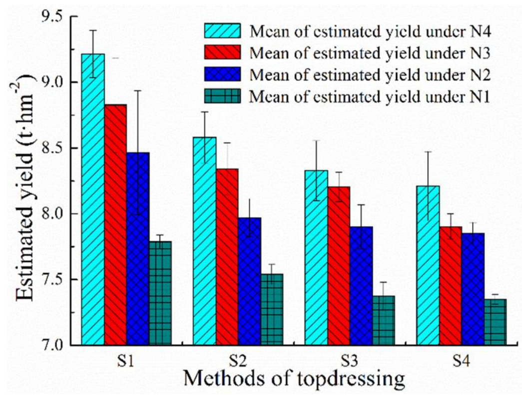

Fig. 5. Estimated yield of winter wheat under all treatments.

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