

Response of Wheat to Nano fertilizers Added at the Beginning of the Vegetative and Flowering Growth Stages

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Abstract

A field experiment was carried out during the winter season 2023-2024 in the Al-Galibiya area of Al-Khalis District in Diyala Governorate in a mixed sandy soil, salinity 4.5 dM/m, pH 7.6, organic matter 21%, and ready-made nitrogen, phosphorus and potassium 26.9, 29.0 and 126.8 mg/kg. Sequentially, with the aim of determining the extent of wheat crop response to nanotechnology during the vegetative and flowering growth stages, using some nanofertilizers to improve growth and develop the production of this strategic crop. A factorial experiment was applied according to a Randomized Complete Block Design (RCBD) with three replicates. The first factor included fertilizer treatments (urea nanofertilizer and NPK nanofertilizer at a concentration of 60 g each, and traditional urea fertilizer and NPK traditional fertilizer at a concentration of 100 kg/ha each) as well as the control treatment, while Addition dates parameters (the beginning of the vegetative growth stage, the beginning of the flowering growth stage, and the beginning of both the vegetative and flowering growth stages) represented the second factor. The use of the traditional fertilizer urea led to the highest plant height when added at the beginning of the vegetative growth stage and the beginning of the vegetative and flowering growth stages, as it reached 104.2 and 102.9 cm, respectively'. The use of nanofertilizer urea at the beginning of the vegetative and flowering growth stages resulted in the highest number of tillers, reaching 373.06 tillers/m², and it did not differ significantly from the treatment of using nanofertilizer urea at the beginning of the vegetative growth stage, which achieved 366.50 tillers /m².

Keywords: Wheat, Nanotechnology, Traditional Fertilizers, Nanofertilizers, Vegetative And Flowering Growth Stages

Introduction

Cereal crops are important in human life. Despite the technical industrial progress in the world, increasing agricultural production, especially grains, is the subject of interest for many countries of the world. The most important reasons for this are the problem of food shortages and the increasing demand for these materials, As a result of the rapid increase in population, and the inability to meet human needs, most of the world's population depends on grains for their food, which is estimated at more than 90% of the total world population (Kinnunen et al., 2020).

Wheat is one of the important field crops in the world and is an annual crop belonging to the Poaceae family. It is considered one of the basic crops for providing food (Palta et al., 2006).

Understanding the stages of wheat crop growth and the effect of environmental factors on the physiological activity at each stage is considered important in producing it and obtaining the

highest productivity (Mitra, 2023). It is essential to help farmers improve yields. In general, during its growth and development, the wheat crop goes through several stages, including the germination stage, the vegetative growth stage (including the branching stage and the elongation stage), the flowering stage, then maturity and harvest (Lang, 1997).

The use of nanofertilizers in fertilization programs is considered an effective alternative to traditional fertilizers. It achieves many advantages due to its use in smaller quantities and its high stability under different conditions (Bernela et al., 2021). This increases the ability to store it for longer periods, thus achieving many benefits for the plant and the environment, as well as supporting the agricultural economy in the current circumstances. Knowing the extent of wheat crop response to nanotechnology during the vegetative and flowering growth stages by using some nanofertilizers is with the aim of improving growth and developing the production of this important strategic crop (Singh et al., 2017).

Materials and methods

With the aim of knowing the extent of the wheat crop's response to nanotechnology during the vegetative and flowering growth stages by using some nanofertilizers to improve growth and develop the production of this strategic crop, a field experiment was implemented during the winter season 2023-2024 in the Al-Galibiya area of Al-Khalis District in Diyala Governorate according to a Randomized Complete Block Design (RCBD) with three replicates. The first factor included fertilizer treatments (urea nanofertilizer and NPK nanofertilizer at a concentration of 60 g each, and traditional urea fertilizer and NPK traditional fertilizer at 100 kg/ha each) as well as the control treatment, while the addition dates parameters represented (the beginning of the vegetative growth stage and the beginning of the flowering growth stage and the beginning of both the vegetative and flowering growth stages) the second factor, in a mixed sandy soil, salinity 4.5 dM/m, pH 7.6, organic matter 21%, and nitrogen, phosphorus, and ready-made potassium 26.9, 29.0, and 126.8 mg/kg, respectively.

After performing soil service operations such as plowing, smoothing, and leveling, the experimental treatments were fertilized with triple superphosphate fertilizer (45% P₂O₅), which was added at a rate of 100 kg/ha before planting. The field was then divided into several plots, the area of which was (3 m²), and three replicates, the distance between one replicate and another (2 m). The plot was divided into seven lines, the length of each line was (2 m) and the distance between each line was (20 cm). Seeds were placed inside each line. When the wheat crop reached the tillering stage, the following treatments were used: Urea nanofertilizer with a concentration of 60 grams. NPK nanofertilizer at a concentration of 60 grams. Traditional urea fertilizer by an amount of 200 kg/ha. Traditional NPK fertilizer by an amount of 200 kg/ha.

Fertilizers were added depending on the growth stages of the crop, and the treatments were as follows: The beginning of the vegetative growth stage, the beginning of the flowering growth stage, the beginning of the vegetative and flowering growth stage.

The nanofertilizer spraying process was carried out early in the morning, taking into account the absence of wind during the process. The spraying process on the plant continued until drops of the solution fell from the ends of the leaves to the ground (complete wetness).

When the plants reached final maturity, data were recorded from the midlines of each experimental unit at random for the following characteristic: (1) Plant height (cm): It was measured by taking five plants randomly from the center lines of each experimental unit from the soil surface level to the last node; (2) Number of tillers/m²: The number of tillers per square

meter was calculated; (3) Flag leaf area (mm²). The flag leaf area was calculated from five plants that were taken to measure the plant height.

The wheat plants were then harvested from an area of one square meter from the center lines of each experimental unit, and data were recorded for the following characteristics: (1) Number of spikes/m²; (2) Number of grains/spike; (3) mean grain weight (g); (4) Grain yield (tons/ha); (5) Biological yield (tons/ha).

The data were analyzed statistically according to the SPSS program, and the means for the studied traits were compared on the basis of the Least Significant Difference (L.S.D) with a significance level of (0.05).

Results and Discussion

Firstly: Response of vegetative traits of wheat to Nano fertilizers added at the beginning of the vegetative and flowering growth stages.

Plant height (cm)

The results of Table 1 indicate significant effects between fertilizers and crop growth stages and the interaction between them on the mean plant height. The use of both the traditional fertilizer urea and NPK led to an increase in the mean plant height, reaching 91.04 and 87.77 cm compared to the control treatment which recorded 66 cm.

The use of fertilizers at the beginning of both the vegetative growth stage and the vegetative and flowering growth stages also led to an increase in the mean of this trait, as it reached 86.1 and 85.7 cm, respectively, compared to the fertilizer addition treatment at the beginning of the flowering growth stage, which recorded 65.84 cm. As for the interaction, the use of the traditional fertilizer urea led to the highest plant height when added at the beginning of the vegetative growth stage and the beginning of the vegetative and flowering growth stages, as it reached 104.2 and 102.9 cm, respectively, compared to the control treatment, which recorded 66.0 and 65.8 cm, respectively.

Table 1. Response of wheat plant height to nano fertilizers added at the beginning of the vegetative and flowering growth stages.

Fertilizers	Growing Stages			Mean
	The beginning of the vegetative growth stage	The beginning of the flowering growth stage	The beginning of the vegetative and flowering growth stages	
Control	66.0	66.2	65.8	66.0
Urea nonfertilizer	81.5	65.7	82.0	76.4
NPK nonfertilizer	79.7	65.5	79.4	74.87
Urea traditional	104.2	66.0	102.9	91.04
NPK traditional	99.1	65.8	98.4	87.77
Mean	86.1	65.84	85.7	
L.S.D 0.05	for fertilizers 1.7	for growth stages 0.7	for interaction 2.6	

Number of tillers

The results of Table 2 indicate significant effects between fertilizers and crop growth stages and the interaction between them in the mean number of tillers. The use of both nanofertilizer urea and NPK led to an increase in the mean number of tillers, reaching 335.11 and 334 tillers/m² compared to the control treatment, which recorded 265.07 tillers/m².

The use of fertilizers at the beginning of both the vegetative growth stage and the vegetative and flowering growth stages also led to an increase in the mean of this trait, as it reached 337.82 and 344 tillers / m² compared to the fertilizer use treatment at the beginning of the flowering growth stage, which recorded 244.69 tillers / m².

As for the interaction, the use of nanofertilizer urea at the beginning of the vegetative and flowering growth stages led to the highest number of tillers, reaching 373.06 tillers/m², and it did not differ significantly from both the treatment of using the traditional NPK fertilizer at the beginning of the vegetative and flowering growth stages, which achieved 371.74 tillers/m², and the treatment of using Urea nanofertilizer at the beginning of the vegetative growth stage, which reached 366.50 tillers/m²

Table 2. Response of the number of wheat tillers to nanofertilizers added at the beginning of the vegetative and flowering growth stages

Fertilizers	Growing Stages			Mean
	The beginning of the vegetative growth stage	The beginning of the flowering growth stage	The beginning of the vegetative and flowering growth stages	
Control	264.90	265.26	265.04	265.07
Urea nanofertilizer	366.50	265.77	373.06	335.11
NPK nanofertilizer	352.71	289.94	359.35	334.00
Urea traditional	348.06	195.06	350.83	297.98
NPK traditional	356.93	207.41	371.74	312.03
Mean	337.82	244.69	344.00	
L.S.D 0.05	for fertilizers 14.22 for growth stages 10.06 for interaction 19.51			

Flag leaf area (cm²)

The results of Table 3 indicate significant effects between fertilizers and crop growth stages and their interaction on the mean leaf area. The use of both NPK nanofertilizer and urea nanofertilizer led to an increase in the mean of this characteristic, reaching 13.59 and 13.20 cm², respectively, compared to the control treatment, which recorded 9.82 cm².

The use of fertilizers at the beginning of both the vegetative growth stage and the vegetative and flowering growth stages also led to an increase in the mean of this trait, as it reached 12.90 and 12.89 cm², respectively, compared to the fertilizer addition treatment at the beginning of the flowering growth stage, which recorded 9.26 cm². As for the interaction, the use of NPK nanofertilizer led to the highest leaf area when added at the beginning of the vegetative growth stage, as it reached 15.60 cm², followed by the treatment of adding the same fertilizer at the beginning of the vegetative and flowering growth stage, which recorded 15.25 cm² compared to the control treatment, which recorded 9.82 and 9.84 cm², respectively.

Table 3. Response of wheat leaf area to nano fertilizers added at the beginning of the vegetative and flowering growth stages.

Fertilizers	Growing Stages			Mean
	The beginning of the vegetative growth stage	The beginning of the flowering growth stage	The beginning of the vegetative and flowering growth stages	
Control	9.82	9.79	9.84	9.82
Urea nonfertilizer	15.04	9.58	14.98	13.20
NPK nonfertilizer	15.60	9.92	15.25	13.59
Urea traditional	11.77	8.33	11.93	10.68
NPK traditional	12.26	8.67	12.47	11.13
Mean	12.90	9.26	12.89	
L.S.D 0.05	for fertilizers 0.62 for growth stages 0.37 for interaction 0.91.			

Biological yield (tons/ha)

The results of Table 4 indicate significant effects between fertilizers and crop growth stages and the interaction between them on the mean biological yield. The use of both NPK nonfertilizer and urea nonfertilizer led to an increase in the mean of this trait, reaching 13.01 and 12.53 tons/ha, respectively, compared to the control treatment, which recorded 10.51 tons/ha.

As for the interaction, the use of NPK nonfertilizer at the beginning of the vegetative and flowering growth stages led to recording the highest biological yield of 13.64 tons/ha, and it did not differ significantly from the treatment of using the same fertilizer and the treatment of using the urea nonfertilizer at the beginning of the vegetative growth stage, which recorded 13.58 and 13.11 tons/ha, respectively.

Table 4. Response of wheat biological yield to nano fertilizers added at the beginning of the vegetative and flowering growth stages

Fertilizers	Growing Stages			Mean
	The beginning of the vegetative growth stage	The beginning of the flowering growth stage	The beginning of the vegetative and flowering growth stages	
Control	10.46	10.50	10.57	10.51
Urea nonfertilizer	13.11	12.07	12.42	12.53
NPK nonfertilizer	13.58	11.82	13.64	13.01
Urea traditional	11.14	11.27	11.54	11.32
NPK traditional	11.61	11.45	11.66	11.57
Mean	11.98	11.42	11.97	
L.S.D 0.05	for fertilizers 0.38 for growth stages 0.26 for interaction 0.70			

Secondly: Response of the flowering characteristics of wheat to nano fertilizers added at the beginning of the vegetative and flowering growth stages.

Number of spikes / m²

The results of Table 5 indicate significant effects between fertilizers and crop growth stages and the interaction between them in the mean number of spikes. The use of NPK nonfertilizer led to an increase in the mean of this trait, reaching 290.37 spikes/m², and it did not differ significantly from the treatment using the urea nonfertilizer, which was 285.07 ears/m² compared to the control treatment, which recorded 168.37 spikes/m².

The use of fertilizers at the beginning of both the vegetative and flowering growth stages and the vegetative growth stage also led to an increase in the means of this trait, as it reached 287.02 and 267.26 spikes/m², respectively, compared to the fertilizer addition treatment at the beginning of the vegetative growth stage. As for the interaction, the use of NPK nonfertilizer led to the highest number of spikes when added at the beginning of the vegetative and flowering growth stages, and it did not differ significantly from both the treatment of adding NPK nonfertilizer and the urea nonfertilizer at the beginning of the vegetative growth stage, which recorded 322.8 and 301 spikes/m², respectively. Compared to the control treatment, which recorded 167.8 spikes/m².

Table 5. Response of the number of wheat spikes to nano fertilizers added at the beginning of the vegetative and flowering growth stages

Fertilizers	Growing Stages			Mean
	The beginning of the vegetative growth stage	The beginning of the flowering growth stage	The beginning of the vegetative and flowering growth stages	
Control	167.8	169.0	168.3	168.37
Urea nonfertilizer	301.0	221.6	332.6	285.07
NPK nonfertilizer	322.8	213.3	335.0	290.37
Urea traditional	264.2	193.7	297.8	251.90
NPK traditional	280.5	204.1	301.4	262.00
Mean	267.26	200.34	287.02	
L.S.D 0.05	for fertilizers 10.83 for growth stages 7.16 for interaction 18.04			

Number of grains/spikes

The results of Table 6 indicate significant effects between fertilizers and crop growth stages and the interaction between them in the mean number of grains/spikes. The use of both NPK nonfertilizer and urea nonfertilizer led to an increase in the mean of this trait, reaching 38.0 and 36.47 grains/spike, compared to the control treatment, which recorded 18.17 grains/spike. This was followed by the traditional fertilizer treatments, urea and NPK, which recorded 28.60 and 30.03 grains/spike compared to the control treatment, which recorded 18.17 grains/spike

The use of fertilizers at the beginning of the vegetative and flowering growth stages also led to an increase in the mean of this trait, as it reached 33.28 grains/spike compared to the two fertilizer application treatments at the beginning of the flowering growth stage and the beginning of the vegetative growth stage, which recorded 29.16 and 28.32 grains/spike, respectively. As for the interaction, the use of NPK nonfertilizer at the beginning of the vegetative and flowering growth stage led to the highest increase, reaching 40.7 grains/spike, and it did not differ significantly from the treatment of using the urea nonfertilizer at the

beginning of the vegetative growth stage, which recorded 39.1 grains/spike compared to the control treatment that recorded 17.8 grains/spike.

Table 6. Response of the number of grains in a wheat spike to nano fertilizers added at the beginning of the vegetative and flowering growth stages

Fertilizers	Growing Stages			Mean
	The beginning of the vegetative growth stage	The beginning of the flowering growth stage	The beginning of the vegetative and flowering growth stages	
Control	18.2	18.5	17.8	18.17
Urea nonfertilizer	33.3	37.0	39.1	36.47
NPK nonfertilizer	35.2	38.1	40.7	38.00
Urea traditional	27.0	25.0	33.8	28.60
NPK traditional	27.9	27.2	35.0	30.03
Mean	28.32	29.16	33.28	
L.S.D 0.05	for fertilizers 2.52 for growth stages 2.28 for interaction 3.48			

Mean weight of 1000 grains (g)

The results of Table 7 indicate significant effects between fertilizers and crop growth stages and their interaction on the mean weight of 1000 grains. The use of both NPK nanofertilizer and urea led to an increase in the means of this trait, reaching 38.0 and 36.2 grams compared to the control treatment, which recorded 21.2 grams.

The use of fertilizers at the beginning of the vegetative and flowering growth stage also led to an increase, reaching 35.24 grams, compared to the two fertilizer application treatments at the beginning of the flowering growth stage and the beginning of the vegetative growth stage, which recorded 29.72 and 28.88 grams, respectively. As for the interaction, the use of NPK nanofertilizer at the beginning of the vegetative and flowering growth stages led to the highest increase, reaching 41.5 grams, and it did not differ significantly from the treatment using the urea nanofertilizer in the same two growth stages, which achieved 40.8 grams, respectively.

Table 7. Response of wheat grain weight to nanofertilizers added at the beginning of the vegetative and flowering growth stages

Fertilizers	Growing Stages			Mean
	The beginning of the vegetative growth stage	The beginning of the flowering growth stage	The beginning of the vegetative and flowering growth stages	
Control	20.9	21.6	21.1	21.20
Urea nonfertilizer	34.3	33.5	40.8	36.20
NPK nonfertilizer	37.6	34.9	41.5	38.00
Urea traditional	24.7	28.8	36.0	29.83
NPK traditional	26.9	29.8	36.8	31.17
Mean	28.88	29.72	35.24	
L.S.D 0.05	for fertilizers 1.90 for growth stages 1.28 for interaction 2.66			

Grain yield (tons/ha)

The results of Table 8 indicate significant effects between fertilizers and crop growth stages and the interaction between them on the mean grain yield. The use of all fertilizer treatments led to an increase in the mean of this characteristic, reaching 4.03, 3.622, 2.37, and 2.15 tons/ha compared to the control treatment, which recorded 0.645 tons/ha.

The use of fertilizers at the beginning of the vegetative and flowering growth stages also led to an increase in the mean of this trait, reaching 3.53 tons/ha, followed by the fertilizer use treatment at the beginning of the vegetative growth stage, which reached 2.37 tons/ha compared to the fertilizer use treatment at the beginning of the flowering growth stage. As for the interaction, the use of nonfertilizer NPK at the beginning of the vegetative and flowering growth stages led to the highest increase, reaching 5.285 tons/ha, followed by the two treatments of using nonfertilizer at the beginning of the vegetative and flowering growth stages and the treatment of using nonfertilizer NPK at the beginning of the vegetative growth stage, which recorded 4.806 and 4.108 tons. / ha respectively.

Table 8. Response of wheat grain yield to Nano fertilizers added at the beginning of the vegetative and flowering growth stages.

Fertilizers	Growing Stages			Mean
	The beginning of the vegetative growth stage	The beginning of the flowering growth stage	The beginning of the vegetative and flowering growth stages	
Control	0.643	0.669	0.624	0.645
Urea nonfertilizer	3.410	2.650	4.806	3.622
NPK nonfertilizer	4.108	2.700	5.285	4.03
Urea traditional	1.688	1.366	3.391	2.15
NPK traditional	1.992	1.583	3.544	2.37
Mean	2.37	1.79	3.53	
L.S.D 0.05	for fertilizers 0.28 for growth stages 0.19 for interaction 0.49			

The results of the study show the role of nanofertilizer in causing an increase in the mean number of tillers Table 2 and increasing the leaf area Table 3. This may be attributed to its role in reducing the mean plant height Table 1 and thus enabling it to store large quantities of nutrients in the stem, which later turns into buds, that is a reduce of competition for nutrients between the apical buds of the stem, which usually have active growth and the lateral buds located at the base of the stem (Lang, 1997).

The increase in the mean number of spikes per square meter as a result of using nanofertilizer may be due to its role in increasing the number of tillers in the plant Table 2, as increasing the number of tillers means increasing the number of spikes bearing them due to the high nutritional energy resulting from increasing the leaf area Table 3 and increasing biological yield Table 4.

The increase resulting from the use of nanofertilizer in the mean number of grains/spike may be due to the important role of nanofertilizer in the processes of flowering, cell division, germination and pollen tube growth, and increasing the level of carbohydrates transferred to

the active areas of growth during the reproductive stage of the plant (Sadek & Jayasuriya, 2007).

Its presence in quantities appropriate to the crop played a role in increasing the transfer of the products of the photosynthesis process and food stored in the parenchymal tissues (during the vegetative growth stage) to the sink represented by the number of ovaries, which works to increase the percentage of fertilized ovaries, which is reflected positively in increasing the number of grains/spike (Naderi & Danesh-Shahraki, 2013).

As for increasing the mean weight of the grain using nanofertilizer, it may be due to its role in increasing the effectiveness of photosynthesis and increasing the materials manufactured in the leaves and their subsequent transfer to the sink (seeds), and then increasing their growth, in addition to its role in increasing the movement of nutrients when added at the beginning of the vegetative and flowering growth stage. From their locations to the storage areas in the seeds, which results in filling the storage organs to a better degree, which was reflected positively in an increase in the mean weight of the seed (Rameshaiah et al., 2015).

What is known to us is that reducing competition between tillers due to nano-fertilizer may make the crop receive the appropriate or needed amounts of water and mineral elements from the soil, in addition to its high potential in carrying out the process of photosynthesis (Ahmed et al., 2020). These may be factors that help in transporting these stored nutrients and mineral elements, as well as materials manufactured through the process of photosynthesis, from their locations to the sinks represented by the number of grains per spike and the weight of the grain, which reflects positively on the grain yield (Sultan et al., 2009).

It is clear from the results - in general - that there was a positive response of the wheat crop to the nanofertilizer, as it caused a significant increase in grain yield, and this is consistent with many studies in this field, which attributed this to its role in increasing the number of tillers of the crop table 2 thus increasing the number of tillers bearing spike, which leads to an increase in the number of spikes/m² table 5. As well as the role of nanofertilizer in hindering the stem elongation of the crop and increasing the leaf area table 3, which causes an increase in the food stock in it, which benefits the crop when it enters the flowering stage and moves from the source to the sink to increase the mean grain weight table 7 all of these positive results that occurred in vegetative traits as well as in floral traits were reflected positively on the grain yield of the plant, causing an increase in grain yield per unit area.

Conclusion

(1) The use of the traditional fertilizer urea led to the highest plant height when added at the beginning of the vegetative growth stage and the beginning of the vegetative and flowering growth stages, as it reached 104.2 and 102.9 cm, respectively'; (2) The use of nanofertilizer urea at the beginning of the vegetative and flowering growth stages resulted in the highest number of tillers, reaching 373.06 tillers/m², and it did not differ significantly from the treatment of using nanofertilizer urea at the beginning of the vegetative growth stage, which achieved 366.50 tillers /m²; (3) The use of NPK nanofertilizer resulted in the highest flag leaf area when added at the beginning of the vegetative growth stage, as it reached 15.60 cm², and did not differ significantly from the treatment of adding the same fertilizer at the beginning of the vegetative and flowering growth stages, as it achieved 15.25 cm²; (4) The use of traditional fertilizer urea led to the highest biological yield when added at the beginning of the vegetative growth stage and the beginning of the vegetative and flowering growth stages, as it reached 13.64 tons/ha and did not differ significantly from the treatment using nanofertilizer urea, as

it achieved 13.58 tons/ha; (5) The use of NPK nanofertilizer resulted in the highest number of spikes/m² when added at the beginning of the vegetative and flowering growth stages, as it reached 335 spikes/m² and did not differ significantly from the treatment of using the urea nanofertilizer at the beginning of the vegetative and flowering growth stages, which recorded 332.6 spikes/m² and the fertilizer treatment. nanofertilizer NPK at the beginning of the vegetative growth stage, which recorded 322.8 spikes/m²; (6) The use of NPK nanofertilizer at the beginning of the vegetative and flowering growth stages led to the highest increase in the mean number of grains/spikes, as it reached 40.7 grains/spike. It also did not differ significantly from the treatment using the urea nanofertilizer at the beginning of the vegetative and flowering growth stages, which recorded 39.1 grains/spike, compared to the control treatment, which recorded 17.8 grains/spike; (7) The use of NPK nanofertilizer at the beginning of the vegetative and flowering growth stages led to the highest increase in the mean weight of 1000 seeds, as it reached 41.5 grams, and it did not differ significantly from the treatment of adding urea nanofertilizer at the beginning of the vegetative and flowering growth stages, which recorded 40.8 grams; (8) The use of NPK nanofertilizer at the beginning of the vegetative and flowering growth stages led to the highest increase in the mean grain yield, reaching 5.285 tons/ha compared to the control treatment, which recorded 0.624 tons/ha.

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