RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
57 (1) 286-293, 2025
http://doi.org/10.54910/sabrao2025.57.1.28
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

EFFECT OF NANO-ALUMINUM SILICATE WITH DIFFERENT IRRIGATION PERIODS ON THE GROWTH AND YIELD TRAITS OF WHEAT (*TRITICUM AESTIVUM* L.)

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SUMMARY

The study, carried out during the winter of 2022–2023 at the Fadliyah Region, Thi-Qar Governorate, Iraq, sought to determine the effects of nano-aluminum silicate and irrigation periods on the growth and yield traits of wheat (*Triticum aestivum* L.) cultivar Buhouth-22. The experiment had a randomized complete block design (RCBD) with split-plot arrangement, two factors, and three replications. The first factor (main plot) included irrigation periods (I), irrigation every seven days (I_1), 14 days (I_2), and 21 days (I_3), while the second factor (subplot) comprised the volumetric percentages of mixing nano-aluminum silicate (12 nm) with soil (S) i.e., 3% (S_1), 4% (S_2), 5% (S_3), and 6% (S_4). The results showed increased proportion of nano-aluminum silicate significantly enhanced the studied traits. The nano-aluminum silicate ratio (S_4) was superior in root total length, plant height, leaf area, number of tillers, grains per spike, and grain yield, which did not differ from other ratios (S_3 and S_2). The irrigation period (I_2) appeared superior by giving the highest averages for the above traits, but did not differ significantly from the irrigation period (I_1). The interaction of nano-aluminum silicate ratio (S_4) and irrigation period (I_2) provided the highest grain yield.

Keywords: Wheat (*Triticum aestivum* L.), nano-aluminum silicate, unconventional technologies, irrigation periods, mixing ratios

Key findings: The results of the presented study showed irrigation periods had an influential role in the productivity of wheat (*Triticum aestivum* L.) grains, especially irrigation every 14 days (I_2), as it gave the highest average grain yield (8.202 t ha^{-1}). Moreover, adding nano-aluminum silicate was crucial in increasing productivity, especially the treatment S_4, which gave the highest average (7.752 t ha^{-1}) for grain yield.

Communicating Editor: Dr. A.N. Farhood

Manuscript received: January 21, 2024; Accepted: March 29, 2024.

Citation: Al-Saidan KJY (2025). Effect of nano-aluminum silicate with different irrigation periods on the growth and yield traits of wheat (*Triticum aestivum* L.). *SABRAO J. Breed. Genet.* 57(1): 286-293. http://doi.org/10.54910/sabrao2025.57.1.28.

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is an essential staple cereal crop grown in humid to dry, warm, and temperate regions. For the nutritional requirement of the human body, wheat is a unique crop to mankind and a good supplement, as it contains carbohydrates (70%), starch (59.2%), protein (12%), lipids (1.8%), ash (1.8%), reducing sugar (2%), as well as, providing 314 kcal 100 g^{-1} (Iqbal *et al*., 2017). Wheat yield has to double by 2050 to meet the challenge of feeding almost 10 billion people. However, in the main producing countries, yield increase has slowed down or even stagnated during the past 20 years, and further increases in temperature due to climate change will continue to suppress yields, despite breeders and farmers' adaptation efforts (Gimenez *et al.,* 2021).

Water is a considered diminishing resource in Iraq, comprising the arid and semi-arid regions. Recent years indicated a lack of water revenues resulted due to low rainfall and high temperatures, in addition to the less water share by the Tigris and Euphrates rivers for the non-compliance of riparian countries with international agreements (Al-Zahy *et al.,* 2020). Therefore, it has become obligatory to exploit the available water resources in a scientific and thoughtful manner, distributing them regularly. Not wasting water by using modern technologies also increase their efficient use and enable the crop to withstand insufficient water to continue the optimum crop production process (Mahdy *et al.,* 2023). The use of non-traditional technologies to preserve water revenues has become mandatory for farming communities to apply to adapt to the current conditions and maintain the continuity of the agricultural process.

Among these technologies, nano-aluminum silicate can reduce the effect of water shortage and drought conditions, improve the physical and chemical properties of the soil, and retain water and nutrients and supply them to the plant gradually (Shahsavani *et al.,* 2020). Nano-aluminum silicate has some unique properties to improve the soil qualities. These make them desirable, especially enlarging the soil porosity, enabling more water retention during dry periods, in addition to the uniform distribution of its particle sizes, allowing nutrients' retention and easy release (Wang and Wang, 2019).

The process of mixing nano-aluminum silicate with soil enables it to absorb and retain the used irrigation water inside their porous structures, and then excrete them at slow rates, sustaining the irrigation process for crop lands. In addressing the lack of water revenues, the promising experiment proceeded to determine the role of mixing nano-aluminum silicate in different proportions with the soil in wheat's growth and yield, with varying irrigation periods. The study also sought the best mixing ratio that reduces the effects of drought.

MATERIAL AND METHODS

The presented wheat experiment, carried out in pots during the winter of 2022–2023, transpired at the Fadliyah Region, Thi-Qar Governorate, Iraq, located below longitude 46.26 east and latitude 31.05 north. Wheat cultivar Buhouth-22 was the sample planted to achieve the goal of this study. Soil sample collections came from the experimental field, comprising 6% sand, 50% silt, and 44% clay. The experiment layout was in a randomized complete block design (RCBD) with split-plot arrangement, two factors, and three replications. The first factor (main plot) included three irrigation periods (I), irrigation every seven days (I_1), 14 days (I_2), and 21 days (I_3), while the second factor (subplot) comprised the four volumetric percentages of mixing nano-aluminum silicate (12 nm) with crop soil (S), i.e., 3% (S_1), 4% (S_2), 5% (S_3), and 6% (S_4). Each concentration received a half liter of water, mixing for half an hour using a mixer to form a homogeneous initial mixture.

Adding the initial mixture to the soil weighing 2.5 kg, continued mixing for two hours with a mixer at a speed of 700 rpm. After living the soil to dry, its transfer to the pot followed, as this method allowed the equal distribution of nano-aluminum silicate to soil particles used in the experiment. The planting of the wheat cultivar Buhouth-22 in pots of 2.5

kg capacity occurred on November 15, 2022, with 10 grains per pot. The N: P fertilizers addition was in the form of urea (N 46%) at the rate of 260 kg ha^{-1}, and DAP P_2O_5 (P 46%) at the rate of 200 kg ha^{-1}, applied in three growth stages (stem elongation, tillering, and booting).

Data recorded and statistical analysis

The data recorded on the traits included root length, plant height, chlorophyll content (Macnack *et al.,* 2014), leaf area, proline content (Bates *et al.,* 1973), tillers per plant, grains per spike, 1000-grain weight, and the grain yield. All the recorded data analysis were according to the RCBD. The treatment means' further comparison and separation used the least significant differences ($LSD_{0.05}$) test (Steel and Torrie, 1980). Statistical analysis ensued using the Gestate 12.1.

RESULTS AND DISCUSSION

Nano-aluminum silicate

Nano-aluminum silicate with increasing proportions of mixing with soil revealed a significant effect and considerable increase in the average mean values for studied traits in wheat crop (Tables 1-9). The mixing ratio S4 exhibited the highest means for the traits, viz., root length (52.939 cm), plant height (103.22 cm), leaf area (59.18 cm^2), number of tillers (11.97 tillers plant^{-1}), grains per spike (67.11 grains spike^{-1}), and grain yield (7.752 t ha^{-1}). Meanwhile, the treatment S1 gave the lowest averages for root length (20.218 cm), plant height (89.00 cm), leaf area (35.47 cm^2), number of tillers (10.50 tillers plant^{-1}), grains per spike (60.00 grains spike^{-1}), and grain yield (6.333 t ha^{-1}). The mixing ratio S2 gave the maximum average in chlorophyll content (0.7267 mg g^{-1}), while the treatment S1 provided the lowest averages (0.6767 mg g^{-1}). The mixing ratio S1 gave the supreme mean of proline content (4.574 mg L^{-1}) and 1000-grain weight (44.72 g) in wheat.

The rise in averages of the wheat studied traits may be due to the positive changes in the soil characteristics. The soil capacity retained enhanced water with increased mixing ratio of nano-aluminum silicate, enriching specific surface area of the soil and the micro porosity, eventually enhancing the soil's ability to retain more water for wheat crops (Hassan and Al-Barkat, 2023). The said substances also improve soil properties and fertility, which reflected in an increased activity of microorganisms, contributing to the development of a new food environment. Nano-aluminum silicate can further enhance the availability of nutrients, especially nitrate and ammonium, in lowland rice (Palanivell *et al.,* 2016). In addition, it also reduces nitrogen loss in the soil through the leaching process and preventing the volatilization of ammonia due to its ability to reduce the process of reverse nitrification of urea fertilizer in wheat crops (Rehman *et al.,* 2018). These vital processes contribute to raising dry matter formation in plants, augmenting photosynthesis rates, related directly with increased growth rates in wheat.

Increasing the ratio of nano-aluminum silicate (3% to 6%) could also enhance the soil's ability to provide the necessary water for the root zone, secure water quantities for the crop growth period, and improve the efficiency of mineral elements' absorption. These helped the plant reach its maximum plant stature in wheat (Table 2). Likewise, the nano-aluminum silicate helped save the crop plants from the effects of water stress during the cell division and stem elongation period, which is critical in the expansion of plant cells in wheat (Hassan and Al-Barkat, 2023).

Elevated proportions of nano-aluminum silicate enhanced the growth rates of vegetative parts of the plant, especially the leaf area and the number of tillers per plant. It could refer to the positive role of this substance in holding water and nutrients in wheat (Tables 4 and 6). Moreover, this substance could have a positive effect on the meristematic activity to form the largest number of tillers, as a result of the availability of mineral elements, especially nitrogen. It, then, helps increase cell divisions and expansion and the number of tillers in wheat. It also may be due to the ability of this

Table 1. Effect of nano-aluminum silicate ratios and irrigation periods on the root length in wheat.

Irrigation periods	Nano-aluminum silicate ratios				Means (cm)
	S_1	S_2	S_3	S_4	
I_1	22.813	31.600	42.033	57.400	38.462
I_2	20.567	29.570	39.863	51.813	35.453
I_3	17.273	24.467	36.647	49.603	31.998
Means (cm)	20.218	28.546	39.514	52.939	

$LSD_{0.05}$ Irrigation periods: 0.735, Nano-aluminum silicate ratios: 0.585, Interactions: 1.03

Table 2. Effect of nano-aluminum silicate ratios and irrigation periods on the plant height in wheat.

Irrigation periods	Nano-aluminum silicate ratios				Mean (cm)
	S_1	S_2	S_3	S_4	
I_1	85.67	93.33	105.33	95.67	95.00
I_2	91.67	101.00	111.33	109.33	103.33
I_3	89.67	97.00	110.33	104.67	100.42
Means (cm)	89.00	97.11	109.00	103.22	

$LSD_{0.05}$ Irrigation periods: 1.517, Nano-aluminum silicate ratios: 2.523, Interactions: 3.919

Table 3. Effect of nano-aluminum silicate ratios and irrigation periods on the chlorophyll content in wheat.

Irrigation periods	Nano-aluminum silicate ratios				Mean (mg g^{-1})
	S_1	S_2	S_3	S_4	
I_1	0.7033	0.7833	0.8167	0.7767	0.7700
I_2	0.6700	0.7767	0.7200	0.7433	0.7275
I_3	0.6567	0.7000	0.6800	0.6600	0.6742
Means (mg g)	0.6767	0.7533	0.7389	0.7267	

$LSD_{0.05}$ Irrigation periods: 0.045, Nano-aluminum silicate ratios: 0.039, Interactions: 0.067

Table 4. Effect of nano-aluminum silicate ratios and irrigation periods on the leaf area in wheat.

Irrigation periods	Nano-aluminum silicate ratios				Mean (cm^2)
	S_1	S_2	S_3	S_4	
I_1	36.12	38.12	50.08	60.80	46.28
I_2	40.16	44.20	51.29	62.56	49.55
I_3	30.14	34.18	46.42	54.18	41.23
Means (cm^2)	35.47	38.83	49.26	59.18	

$LSD_{0.05}$ Irrigation periods: 5.863, Nano-aluminum silicate ratios: 4.742, Interactions: 8.306

Table 5. Effect of nano-aluminum silicate ratios and irrigation periods on the proline content in wheat.

Irrigation periods	Nano-aluminum silicate ratios				Mean (mg g^{-1})
	S_1	S_2	S_3	S_4	
I_1	3.920	3.370	3.660	2.943	3.473
I_2	4.313	4.150	4.040	3.960	4.116
I_3	5.490	5.230	4.660	4.477	4.964
Means (mg g^{-1})	4.574	4.250	4.120	3.793	

$LSD_{0.05}$ Irrigation periods: 0.1770, Nano-aluminum silicate ratios: 0.1004, Interactions: 0.2043

Table 6. Effect of nano-aluminum silicate ratios and irrigation periods on the number of tillers in wheat.

Irrigation periods	Nano-aluminum silicate ratios				Mean (tillers plant^{-1})
	S_1	S_2	S_3	S_4	
I_1	10.14	9.86	11.16	12.43	10.90
I_2	12.46	13.50	11.79	13.63	12.84
I_3	8.90	8.21	9.74	9.85	9.17
Means (tillers plant^{-1})	10.50	10.52	10.90	11.97	

$LSD_{0.05}$ Irrigation periods: 0.656, Nano-aluminium silicate ratios: 0.902, Interactions: 1.425

Table 7. Effect of nano-aluminum silicate ratios and irrigation periods on the number of grains per spike in wheat.

Irrigation periods	Nano-aluminum silicate ratios				Mean (grains spike^{-1})
	S_1	S_2	S_3	S_4	
I_1	60.00	65.00	66.33	65.33	64.17
I_2	65.00	70.00	62.67	69.00	66.67
I_3	55.00	60.00	69.00	67.00	62.75
Means (grains spike^{-1})	60.00	65.00	66.00	67.11	

$LSD_{0.05}$ Irrigation periods: 7.449, Nano-aluminum silicate ratios: 5.218, Interactions: 9.617

Table 8. Effect of nano-aluminum silicate ratios and irrigation periods on the weight of 1000 grains in wheat.

Irrigation periods	Nano-aluminum silicate ratios				Mean (g)
	S_1	S_2	S_3	S_4	
I_1	44.69	43.15	42.39	40.48	42.68
I_2	43.80	43.21	40.16	37.16	41.08
I_3	45.66	42.03	38.44	35.33	40.37
Means (g)	44.72	42.80	40.33	37.66	

$LSD_{0.05}$ Irrigation periods: 3.667, Nano-aluminum silicate ratios: 1.939, Interactions: 4.107

Table 9. Effect of nano-aluminum silicate ratios and irrigation periods on total grain yield in wheat.

Irrigation periods	Nano-aluminum silicate ratios				Mean (t ha^{-1})
	S_1	S_2	S_3	S_4	
I_1	6.700	8.033	8.323	8.690	7.937
I_2	7.200	8.300	8.463	8.847	8.202
I_3	5.100	5.767	6.197	5.720	5.696
Means (t ha^{-1})	6.333	7.367	7.661	7.752	

$LSD_{0.05}$ Irrigation periods: 0.473, Nano-aluminum silicate ratios: 0.492, Interactions: 0.810

substance to absorb more water and mineral elements, reducing their losses through filtration process, ensuring increased nitrogen in the root zone for further development of the vegetative parts (Shahsavani *et al.,* 2020).

The ability of nano-aluminum silicate to improve the vegetative growth traits clearly manifested in the yield components, as the increased ratio augmented the proportion of fertile spikes, further enhancing the wheat's number of grains per spike (Tables 6 and 7). This material works to boost the efficiency of nutrient readiness in the root zone over the longest possible period, which also reflected in the number of grains by improving vegetative and root growth. It further enriched the efficiency of vital and metabolic processes and photosynthesis, later reflected in improved yield components and grain yield in wheat (Macnack *et al.,* 2014) and *Lycopersicon esculentum* (Virrarreal-Sanchez *et al*., 2022).

The increased percentage of nano-aluminum silicate by 1% in the soil seemed to correspond to an escalation in the average studied traits of wheat, i.e., 10.913 cm in root length, 5.456 cm in plant height, 8.155 cm^2 in leaf area, 0.478 in the number of tillers per plant, 2.23 in the number of grains per spike, and 0.455 in grain yield (Table 9). These expected increases provide a positive indication of the role of nano-aluminum silicate in improving the soil characteristics, as observed in the growth and yield traits of the wheat crop. It also has a significant role in reducing the proline content averages in wheat crop plants, resulting from the effect of the irrigation periods in the study.

Irrigation periods

The irrigation periods showed a significant effect and considerable differences for most of the studied traits in wheat crop (Tables 1-9). Irrigation treatments I_2 and I_3 displayed a notable decrease in root length (35.453 and 31.998 cm), chlorophyll content (0.7275 and 0.6742 mg g^{-1}), and weight of 1000 seeds (41.08 and 40.37 g), while treatment I_1 gave the highest averages of 38.462 cm, 0.7700 mg g^{-1}, and 42.68 g, respectively. The results also indicated treatment I_2 exhibited the maximum average for leaf area (49.55 cm^2), number of tillers (12.84 tillers $plant^{-1}$), number of grains per spike (66.67 grains $spike^{-1}$), and grain yield (8.202 t ha^{-1}), while treatment I_1 gave averages, reaching 46.28 cm^2, 10.99 tillers $plant^{-1}$, 64.17 grains $spike^{-1}$, and 5.696 t ha^{-1}, respectively. The I_3 treatment remarkably recorded with the optimum average of plant height (103.33 cm) and proline content (4.964 mg $100g^{-1}$), compared with the I_1 treatment, providing the means 95.00 cm and 3.473 mg 100 g^{-1}, respectively. The treatment providing the suitable amount of water, and also close to the requirements and needs of the wheat plants, enables them to form a large root system capable of absorbing more water and nutrients. This was evident in the irrigation period (I_1) (Tables 1 and 3). The sufficient water and nutrients emerged positively in the series of vital activities indirectly related to the formation of a large root system and vegetation and chlorophyll content (Zhao *et al.,* 2020). The superiority of the plant height with irrigation period I_2 was due to fewer effects of water stress in general on the wheat plants during the early stages of plant growth. This also caused competition between plant members and, in turn, favored this trait, especially with the elongation of the first internodes and its superiority in competition for the products of photosynthesis in wheat (Al-Daami, 2015).

The reduction in leaf area due to the different irrigation periods could be due to a decrease in the speed of cell division and their elongation. It also refers to intensification of competition for photosynthesis products among the wheat stems, which began with rapid elongation (Table 2) and the number of leaves per plant, also started to grow and expand in wheat (Table 4) (Al-Tamimi and Lateef, 2020). The decline in the number of tillers during the irrigation period (I_3) may refer to the death of some tillers, causing a decrease in their number (Table 5). An explanation could be the negative effects of water shortage on the formation of stem nodes below the soil surface in wheat (Al-Fatlawi *et al.,* 2022).

For the number of grains per spike, the decline might be due to insufficient water at the stages of growth, especially at the flowering stage, significantly decreasing the number of fertile florets and the number of grains per spike. The lessened formation and transmission of dry matter under the influence of water stress, also reduces the vital activities that make up the dry matter transferred in the last stages to the sinks and grain formation in spring wheat (Ma *et al.,* 2014). It was also evident in the wheat plants with high proline content, which could be because of influences from the irrigation period (I_3).

Nano-aluminum silicate and irrigation interactions

The results revealed a significant effect of the interaction between the study factors on all studied traits in wheat crop. The interaction of treatments S_4 and I_2 provided the highest average grain yield (8.847 t ha^{-1}), while the interaction between the treatments S_1 and I_3 gave the lowest average yield (5.100 t ha^{-1}) in wheat. Overall, it was noteworthy that a variation occurred in the average mean values of the interactions for the studied traits; however, the general trend indicated an improvement in most of the wheat traits by treating with different ratios of nano-aluminum silicate and irrigation periods. It was also notable that increasing the irrigation period to 14 days and adding nano-aluminum silicate improved the level of vital processes within the plant under conditions of water stress, ultimately apparent in wheat's studied growth and yield characteristics (Ismailova and Azizov, 2022; Bakry *et al*., 2024). The study also observed the nano-aluminum silicate ratio S_4 reduced the proline content inside the plant during different irrigation periods (7, 14, and 21 days) compared with other ratios. It visibly reflects the importance of the nano-aluminum silicate ratio S_4 and its effects on the growth and yield-related traits of wheat.

CONCLUSIONS

The study concludes aluminum silicate nanoparticles have worked to raise the level of efficiency in bio-processes of the plant under drought conditions, which contributed to improving crop performance and increasing its productivity.

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