Middle East Journal of Applied Sciences
Volume: 14 | Issue: 04| Oct.– Dec. | 2024

EISSN: 2706 -7947 ISSN: 2077- 4613
DOI: 10.36632/mejas/2024.14.4.50
Journal homepage: www.curresweb.com
Pages: 701-718

The Effect of Nano Spraying and Soil Addition of Potassium On the Yield and Grain Quality of Wheat

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Received: 30 Sept. 2024 **Accepted:** 05 Nov. 2024 **Published:** 15 Nov. 2024

ABSTRACT

A field experiment was carried out in the El-Gemmeiza Agricultural Research Station in the Gharbeya Governorate, Egypt, over the winter seasons of 2021/2022 and 2022/2023. This study examined the effects of Nano potassium as foliar application (0 and 40 ppm) and four levels of potassium (0, 50, 75, and 100% of the recommended rate RR equals 00, 23.70, 35.56, and 47.43 kg K /ha) in the form of potassium sulphate on plant growth, leaf chlorophyll, productivity, and grain quality of wheat cultivar Giza 171 in clay soil. For these treatments, a split-plot design was employed, with Nano potassium concentrations as foliar spray concentrations in the main plot and K levels in the sub-plot. Spraying wheat plants with Nano-K at 40 ppm gave the highest values of leaf pigments, 100 grain weight, grain and straw yield, N, P and K uptake by grain and straw, total protein and total carbohydrates in grain as compared to unsprayed plants. Fertilizing wheat plants with K at 100 % of RR (47.43 kg /ha) produced the highest concentrations of leaf pigments, plant height and yield components, N, P and K concentrations and their uptake in grain and straw as well as available K in soil after harvesting wheat plants. The interaction between foliar spray of wheat plants which grown in clay soil twice after 30 and 60 days from sowing with Nano-K at 40 ppm and soil application of K at 100 % of RR (47.43 kg /ha) increased shoot dry matter percentage , leaf pigments, plant height, 100 grain weight, grain yield and straw yield, N, P and K uptake by grain and straw, total protein and total carbohydrates in grain as well as available K in soil after harvesting , followed by foliar spray with water (control) and K at 100% RR (47.43 kg/ ha).

Keywords: wheat, potassium nana, potassium fertilizer, grain yield and quality

1. Introduction

Wheat (*Triticum aestivum* L.), which is needed in one or more forms every day, is the most essential food source for human sustenance in the world, behind rice and maize. This is Egypt's main winter grain crop and a major source of staple foods. Owing to its unique protein properties, wheat is the most widely cultivated grain globally and is an essential source of energy and food (Abedi *et al*., 2011).

It may be easily processed into a wide range of dishes, such as biscuits, macaroni, bread, and desserts. During the 2021–2022 growing season, Egypt planted 3.404 million feddans a feddan is 4200 m^2 with wheat 9.700 million tonnes (FAO, 2023).

Nanotechnology is a promising tool for improving plant growth and productivity because it increases plant absorption of water and nutrients, which improves production quantity and quality. Additionally, applications of nanotechnology in agriculture reduce costs by increasing fertilizer efficiency with less material cost (Al-Ramadi *et al*., 2016). These factors make nanotechnology one of the modern means of crop development and increasing growth and production on a large scale.

Spraying plants with Nano potassium produced the best plant growth, productivity and grain chemical constituents of wheat plants (Hamouda *et al*., 2015; Burhan, and Al-Hassan 2019; Al-Juthery *et al*., 2020; Noaema *et al*., 2020; Sheoran *et al*., 2021; AL-Zubade and AL-Ubori, 2024) and Al-Falahi and AbdulKafoor 2021) on faba bean.

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Potassium is not a necessary component of any organic or structural part of the plant, yet it is one of the main nutrients thought to be vital for crop growth and yield improvement. Being the most prevalent cation in plants, it is linked to or participates in a wide range of physiological functions that promote the growth and development of plants. Potassium can affect water relations, photosynthesis, assimilate transport, and enzyme activation (Pettigrew, 2008). Additionally, potassium is essential for plants to survive in the face of abiotic stress since stress impairs a variety of physiological functions in plants, including chlorophyll content, protein synthesis, root and shoot elongation, enzyme activity, water and assimilate transport, and photosynthetic transport (Kanai *et al*., 2011).

Growth parameters, grain, straw productivity and grain quality significantly increased by increasing potassium fertilization (Gharib and Meleha 2016; Mosaad and Fouda 2016; Kumar *et al*., 2018; Sarhan and Abd El-Hamed, 2018; Sharma *et al.,* 2018; Dincsoy and Sonmez, 2019; El-Hamdi *et al.,* 2019; Kubar *et al.* 2019; Abido and El-Moursy 2020; Badawy *et al.,* 2021; El-Saady *et al*., 2023; Abo Basha *et al.,* 2024).

In order to improve the soil's qualities, produce the greatest grain yield, and maximize the grain's ability to use potassium and absorb other elements, this study intends to determine the extent to which wheat plants grown in clay soil will react to treatments with Nano potassium as foliar spray and potassium as soil application.

2. Materials and Methods

A field experiment was carried out in the El-Gemmeiza Agricultural Research Station in the Gharbeya Governorate, Egypt, (longitude 31 7º E and latitude 30 43º N). over the winter seasons of 2021/2022 and 2022/2023. This study examined the effects of Nano potassium as foliar application and levels of potassium soil application on plant growth, leaf chlorophyll, productivity, and grain quality of wheat cultivar Giza 171 in clay soil.

Table 1: Some physical and chemical properties of the experimental soil according to Balck *et al*. (1981).

Parameter	Value	
Physical properties	**2021/2022**	**2022/2023**
Corse sand (%)	3.88	4.50
Fine sand (%)	15.42	15.51
Silt (%)	40.47	40.90
Clay (%)	40.23	39.09
Textural class	Clayey loam	Clayey loam
Chemical properties		
EC dSm^{-1} (soil past extract)	2.41	2.29
pH (1: 2.5 soil : water suspension)	8.08	7.99
$CaCO_3$ (%)	2.51	2.46
Organic matter (%)	1.82	1.77
Available nitrogen (ppm)	31	33
Available phosphorus (ppm)	7.7	8.1
Available potassium (ppm)	250	243

Eight treatments were created in this experiment by combining two Nano potassium applications (foliar application, at 0 and 40 ppm) with four amounts of potassium, 0, 50, 75, and 100 of the recommended rates, equals 0, 23.70, 35.56, and 47.43 kg K /ha. The Nano potassium concentrations were displayed in the main plot, and the potassium levels were displayed in the sub-plot with three replications.

Every sub-plot had an area of 10.5 m² (3.0 m × 3.5 m). In both seasons, the grains were manually seeded on November 25 and 20, respectively, with a seeding rate of 150 kg of grains per hectare.

Nano potassium was obtained by Nanotechnology and advanced materials central lab., Agricultural Research Centre according to Corradini *et al*. (2010).

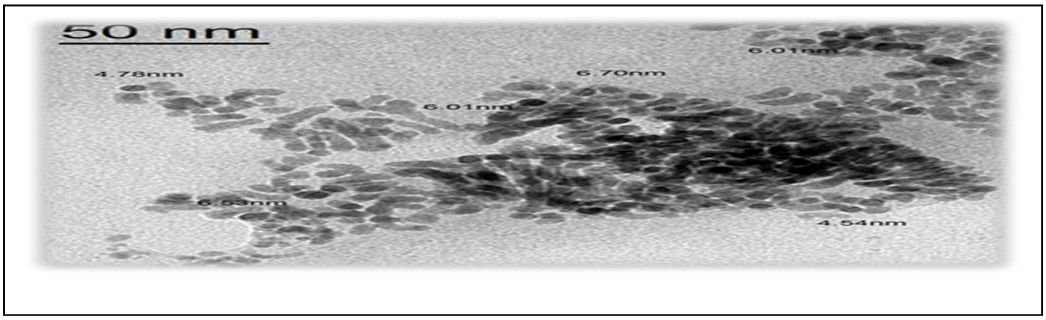

Fig. 1: Transmission electron microscope

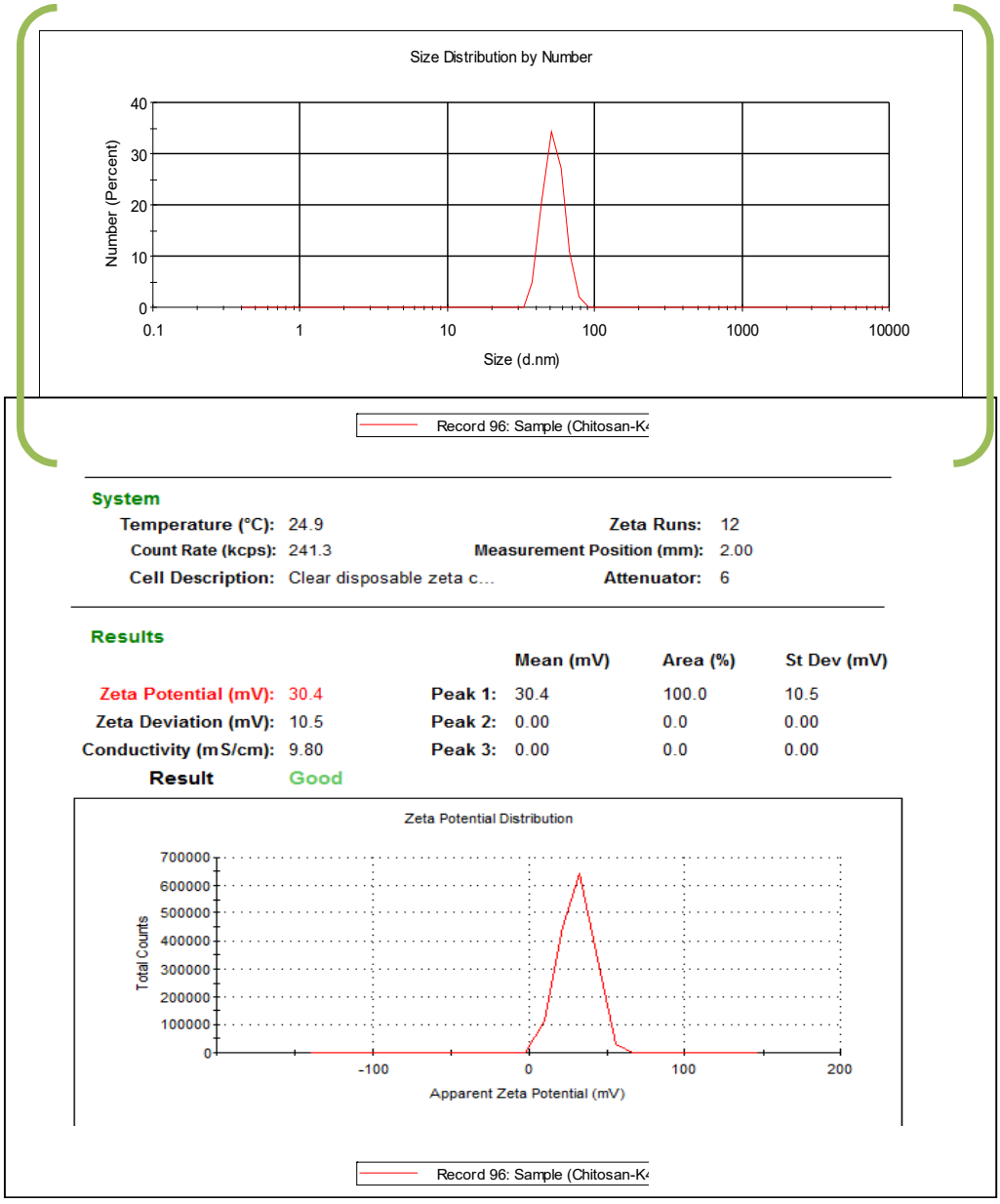

Fig. 2: Particle distribution of K-NPs.

Nano K was applied twice as a foliar application, i.e., 30 and 60 days after planting. During the soil preparation procedure, phosphorus was applied as super-phosphate (15.5% P_2O_5) at a rate of 16.12 kg P/ha. After 42 days from planting, wheat plants got all potassium fertilizer dosages in the form of

potassium sulphate (48% K). However, two equal dosages of nitrogen fertilizer were applied: one before the first irrigation (21 days after sowing) and the other before the second irrigation (21 days later) in the form of urea (46.5%N) at 178.5 kg N /ha. Harvesting was done in the last week of April. On the basis of suggestions from the Field Crops Research Institute, additional farming techniques for wheat fields were implemented**.**

2.1. Recorded data

2.1.1. Vegetative growth

A random selection of ten plants was made from each plot to determine the proportion of dry matter in the shoots after 75 days from sowing.

2.1.2. Photosynthetic Pigments

According to **Moron (1982**), chlorophyll a, b, and total chlorophyll (a+b) were extracted and measured at 75 days after seeding.

2.1.3. Yield and its components

When the wheat plants reached physiological maturity, they were harvested, and their height in cm was recorded. The 100-grain weight (g) of each plot was then determined by selecting ten randomly located spikes. The grain yield, straw yield, and biological yield (grain yield + straw yield), all expressed in tonnes per hectare, were determined by harvesting 2.0 m^2 from each plot and converting it to a hectare. Utilizing the grain to biological yield ratio, the harvest index (%) was computed and presented as a percentage.

2.1.4. Grains quality

The nitrogen, phosphorus, and potassium percentages of grains and straw were measured throughout both seasons' harvest, according to A.O.A.C. (2012). According to Craswell and Godwin (1984), grain yield was multiplied by the corresponding N, P, and K% concentrations to determine the N, P, and K uptake in grains and straw (kg/ha).

2.1.5. Protein percentage

As stated by A.O.A.C. (2012), the nitrogen percentage was multiplied by 5.7 to determine the crude protein percentage.

Total percentage of carbohydrates: Dubois *et al*. 1956 method was used to analyze the whole wheat grains' total percentage of carbohydrates.

2.6. Statistical analysis

A statistical analysis was performed on all of the collected data. To compute the analysis of variance, Snedecor and Cochran (1980) were utilized, and Duncan (1958) was employed to separate the means at the 0.05 probability levels.

3. Results and Discussion

3.1. Shoot dry matter (%)

3.1.1 Effect of Nano K as foliar application

Data in Table 2 indicated that foliar spray of wheat plants with Nano K at 40 ppm increased shoot dry matter percentage of wheat at 75 days after sowing in both seasons. The increases in shoot dry matter percentage were about 9.07 and 6.86 % over the control (unsparing) in the 1st and 2nd seasons, respectively.

In this regard, Liu and Liao (2008) found that Nano K was absorbed into the plants, thus the dry matter production was also increased. Plant gene expression and related biological pathways may be altered by Nano potassium, which could ultimately have an impact on the growth and development of plants. Additionally, Nano potassium increases the nutrients that are available to the growing plant, improving its overall growth by increasing the production of dry matter, photosynthetic rate, and chlorophyll (Ghormade *et al*., 2011).

These results are harmony with those obtained with Hamouda *et al*. (2015). Who found that spraying with potassium at 1000 ppm significantly increased dry weight of wheat shoots as compared

to control treatment. Also, Hussein *et al*. (2019). They indicated that application of Nano potassium at 100 or 200 ppm significantly increased top dry matter of wheat plant compare to the control. Also, Al-Falahi and AbdulKafoor (2021) came the similar results on bean.

3.1.2 Effect of K levels as soil application

Shoot dry matter percentage significantly increased with increasing K levels up to 100 % of the recommended rate (RR) in both seasons (Table 2).

This means that 100% RR K, which equals 47.43 kg/ha, gave the highest values of shoot dry matter, followed by 75% RR K, which equals 35.56 kg/ha, at 75 days after sowing in both seasons.

In comparison to control plants (0 K), the increases in shoot dry matter were approximately 10.57 and 14.22%, 17.96 and 22.58%, and 21.82 and 36.20% for fertilizing with 50,75, and 100% of RR K in the first and second seasons, respectively.

One of the most important nutrients for plant development is potassium. It is essential for several physiological functions, including transpiration and stomata management, photosynthetic translocation, ionic balance maintenance, activation of plant enzymes, and many more (Trehan *et al.,* 2001).

3.1.3 Effect of the interaction

The obtained results in Table 2 show that the interaction between Nano-K at 40 ppm and K at 100% of RR (47.43 kg K/ha) recorded the highest values of dry matter of shoots, followed by the interaction between spraying with water without Nano-K and K at 100 % of RR in both seasons.

Shoot dry matter percentage increased by approximately 43.87 and 45.65% in each of two seasons as a result of the interaction between Nano-K at 40 ppm and K at 100% of RR as a soil application over unsprayed plants and 0 K.

Table 2: Effect of Nano potassium as foliar spray and potassium levels as soil application and their interactions on shoots dry matter (g) of wheat at 75 days after sowing in 2021/2022 and 2022/2023 seasons

Nano K asfoliar spray	K levels (kg/ha)				Mean (Nano K)
	0	50% RR	75% RR	100 % RR	
			2021/2022		
Without	11.33 g	12.44 f	13.60 e	15.10 b	**13.11 B**
40 ppm	12.50 f	13.90 d	14.50 c	16.30 a	**14.30 A**
Mean (K)	**11.91 D**	**13.17 C**	**14.05 B**	**15.70 A**	
			2022/2023		
Without	11.26 g	12.70 e	13.90 d	15.20 b	**13.26 B**
40 ppm	11.94 f	13.80 d	14.55 c	16.40 a	**14.17 A**
Mean (K)	**11.60 D**	**13.25 C**	**14.22 B**	**15.80 A**	

50 %RR= kg 23.70 K/ha, 75 % RR=35.56kg K/ha and 100 %RR= 47.43 kg K/ha.

3.2. Leaf pigments

3.2.1 Effect of Nano K as foliar application

Foliar spray with Nano-K at 40 ppm increased the concentration of chlorophyll a, b, and total a+b in leaf tissues of wheat compared to without Nano-K in both seasons at 75 days from sowing (Table 3). Nano-K had no significant effect on chlorophyll b in both seasons.

In two seasons, the increases in total chlorophyll a+b as a result of Nano-K spraying at 40 ppm were roughly 3.84 and 3.62% over unsprayed plants.

Nano potassium fertilizer has a higher physical and chemical activity than traditional fertilizers because of the high surface area of the Nano fertilizer which reflected on the increasing and improving the metabolic activities and accelerate the enzymatic activities of the photosynthesis as well as the chlorophyll (Morteza *et al*., 2013).

These results are harmony with those reported with Noaema *et al*., 2020. They showed that the concentration of potassium nanoparticles at 8g/l as foliar fertilization gave the highest value of leaves chlorophyll, while the non-spray treatment (control) gave the lowest value in this respect. Also Sheoran

et al. (2021) indicated that spraying wheat plants with Nano potassium at 60 ppm recorded the best photosynthetic pigments of wheat as compared to 20 and 40 ppm. Also, AL-Zubade and AL-Ubor (2024). They indicated that foliar application of 2g/L nano-potassium produced the highest chlorophyll content in wheat leaf as compared to unsprayed plants.

3.2.2 Effect of K levels as soil application

The concentration of chlorophyll a, b, and total a+b in leaf tissues of wheat increased with increasing K levels up to 100 % of RR (47.43 kg/ha) in both seasons (Table 3). Fertilizing with K at 100 % of RR increased chlorophyll a, b, and total a+b in leaf tissues, followed by K at 75 % of RR (35.56 kg /ha) in both seasons.

When plants were fertilized with 50, 75, or 100% of RR K above 0 K in the first and second seasons, respectively, the relative increases in total chlorophyll a+b in wheat leaf tissues after 75 days from sowing were approximately 7.48 and 7.24%, 15.19 and 16.15%, and 23.60 and 21.45%.

Potassium is essential for increasing photosynthetic capability and the rate at which CO_2 is assimilated (Mengel and Kirkby, 1987). According to Gardener *et al*. (1985), potassium was also discovered to play a critical role in photosynthesis by promoting growth and the leaf area index, which in turn promotes CO_2 uptake and increases photosynthate outward translocation.

These results are harmony with those obtained with Abo Basha, *et al*. (2024). They showed that a gradual increment in the chlorophyll content in wheat induced by potassium fertilizer from 0 to 45 kg/ feddan.

Table 3: Effect of Nano potassium as foliar spray and potassium levels as soil application on leaf pigments (mg/dm^2) in leaves of wheat after 75 days from sowing in 2021/2022 and 2022/2023 seasons

	Chlorophyll a		Chlorophyll b		Chlorophyll a +b	
	2021/2022	**2022/2023**	**2021/2022**	**2022/2023**	**2021/2022**	**2022/2023**
	Effect of nano potassium as foliar spray					
Without	3.507 b	3.542 b	1.177 a	1.192 a	4.685 b	4.735 b
40 ppm	3.632 a	3.660 a	1.232 a	1.247 a	4.865 a	4.907 a
	Effect of potassium levels as soil application					
0.00	3.275 d	3.315 d	1.005 d	1.020 d	4.280 d	4.335 d
50 % RR	3.480 c	3.500 c	1.120 c	1.150 c	4.600 c	4.650 c
75% RR	3.655 b	3.715 b	1.275 b	1.320 b	4.930 b	5.035 b
100 % RR	3.870 a	3.875 a	1.420 a	1.390 a	5.290 a	5.265 a

50 %RR= kg 23.70 K/ha, 75 % RR=35.56kg K/ha and 100 %RR= 47.43 kg K/ha.

3.2.3 Effect of the interaction

The interaction between spraying with Nano-K at 40 ppm and fertilizing with K at 100 % of RR (47.43kg/ha) gave the highest concentrations of chlorophyll a (3.950 and 3.900mg/dm^2), chlorophyll b (1.470and 1.400 mg/dm^2), and total chlorophyll a+b (5.420 and 5.300 mg/dm^2) in leaf tissues of wheat with no significant differences with the interaction between spraying with water (without Nano) and K at 100% of RR respecting chlorophyll a, b and total a+b in the second season (Table 4).

This means that K at 47.43 kg /ha (100% RR) and Nano K at 40 ppm, and K at 47.43 kg /ha (100% RR) and without Nano K increased chlorophyll a, chlorophyll b, and total chlorophyll a+b in leaf tissues.

The relative increases in total chlorophyll a+b resulting from the interaction between Nano K at 40 ppm and fertilization with K at 100 percent RR (47.43 kg K/ha) were approximately 29.04 and 25.59% in both seasons.

Table 4: Effect of the interaction between nano potassium as foliar spray and potassium levels as soil application on leaf pigments (mg/dm^2) in leaves of wheat after 75 days from sowing in 2021/2022 and 2022/2023 seasons

Treatments		Chlorophyll a		Chlorophyll b		Chlorophyll a +b	
Nano potassium	**Potassium levels**	**2021/2022**	**2022/2023**	**2021/2022**	**2022/2023**	**2021/2022**	**2022/2023**
0 (water)	**0.00**	3.200 h	3.220 f	1.000 e	1.000 e	4.200 h	4.220 g
	50 % RR	3.440 f	3.450 e	1.090 d	1.100 d	4.530 f	4.550 e
	75% RR	3.600 d	3.650 c	1.250 c	1.290 b	4.850 d	4.940 c
	100 % RR	3.790 b	3.850 ab	1.370 b	1.380 a	5.160 b	5.230 a
40 ppm	**0.00**	3.350 g	3.410 e	1.010 e	1.040 de	4.360 g	4.450 f
	50 % RR	3.520 e	3.550 d	1.150 d	1.200 c	4.670 e	4.750 d
	75% RR	3.710 c	3.780 b	1.300 bc	1.350 ab	5.010 c	5.130 b
	100 % RR	3.950 a	3.900 a	1.470 a	1.400 a	5.420 a	5.300 a

50 %RR= kg 23.70 K/ha, 75 % RR=35.56kg K/ha and 100 %RR= 47.43 kg K/ha

3.3. Yield and its components

3.3.1 Effect of Nano K as foliar application

Spraying wheat plants with Nano-K at 40 ppm increased plant height, 100 grain weight, grain straw and biological yield as well as and harvest index, expect straw yield in the 2nd season (Table 5). Nano-K at 40 ppm gave the tallest plants (114.50 and 115.50 cm) and increased 100 grain weight (5.00 and 5.24 g), grain yield /ha (6.562 and 6.628 ton) , straw yield/ha(8.782 and 8.782 ton) , biological yield /ha ((15.344 and 15.410 ton) and harvest index ((42.77 and 43.01 %) in the 1st and the 2nd seasons, respectively against without Nano K (105.50 and 112.00 cm), (4.72 and 4.85 g), (6.217 and 6.217 ton) , (8.497 and 8.542 ton) , (14.714 and 14.753 ton) and (42.25 and 42.10 %) for plant height , 100 grain weight , grain yield /ha , straw yield/ha, biological yield and harvest index in the 1st and the 2nd seasons, respectively .

In the first and second seasons, the relative increases in grain and biological yield over unsprayed plants were 5.54 and 6.71%, and 4.28 and 4.45%, respectively, as a result of spraying plants with Nano K at 40 ppm.

Applying Nano potassium fertilizer topically can help to reinforce and stimulate metabolic processes. The positive correlation between the rise in dry weight and the increased grain yield of wheat could be the cause of this (Naderi and Abedi, 2012).

Results obtained by Hamouda *et al*. (2015); Burhan, and Al-Hassan (2019); Al-Juthery *et al*., (2020); Noaema *et al*. (2020); Sheoran *et al*. (2021) and AL-Zubade and AL-Ubor (2024) on wheat they showed that yield and its components (100- grain weight, grain yield, straw yield and biological yield as well as harvest index significantly increased with potassium Nano fertilizer as foliar spray as compared to unsprayed plants.

Table 5: Effect of nano potassium as foliar spray on plant height and yield and its components of wheat in 2021/2022 and 2022/2023 seasons.

Treatments	Plant height (cm)	100 grain weight (g)	Grain yield (ton/ha)	Straw yield (ton/ha)	Biological yield (ton /ha)	Harvest index (%)
			2021/2022			
0 Water	109.50 b	4.72b	6.217 b	8.497b	14.714b	42.25b
40 ppm	114.50 a	5.00a	6.562 a	8.782a	15.344a	42.77a
			2022/2023			
0 Water	112.00 b	4.85b	6.211 b	8.542a	14.753b	42.10b
40 ppm	115.50 a	5.24a	6.628 a	8.782a	15.410a	43.01a

3.3.2 Effect of K levels as soil application

Data in Table 6 illustrated that plant height and grain yield and its components gradually increased with increasing K levels up to 100% of RR (47.43 kg /ha). The best treatments for enhancing plant height (126.0 and 127.5 cm), 100 grain weight (5.40 and 5.37 g), grain yield (7.592 and 7.413 ton/ha), straw yield (9.234 and 9.282 ton/ha), biological yield (16.826 and 16.695 ton/ha) and harvest index (45.12 and 44.40 %) when K f fertilizer at 100% from was added (47.43 kg/ha) in the 1st and the 2nd seasons, respectively, followed by K at 75 % of RR (35.56kg /ha) in both seasons.

For all treatments, grain yield ton/ha were ranged from 4.938 to 7.592 in the 1st season and from 5.117 to 7.413 in the second season (from 5.027 to 7.502 ton/ha as average of the two seasons).

In comparison to unfertilized wheat plants with K in the two seasons, the relative increases in grain, straw and biological yield as a result of fertilizing with K at 47.43 kg/ha were 53.7 and 44.9 %, 18.3 and 19.7 %, and 32.0 and 29.7%, respectively.

Potassium has a favorable effect on water and nutrient absorption, biosynthesis, and metabolite activities, which enhances growth and yield (Sharma and Singh 2020).

This finding was confirmed with Dincsoy and Sonmez, (2019); El-Hamdi *et al.* (2019); Kubar *et al.* (2019); Abido and El-Moursy (2020); Badawy *et al.* (2021); El-Saady *et al*. (2023); Abo Basha *et al.* (2024). They found that plant height and yield and its components (grain, straw and biological yield) gradually increased with increasing K levels.

Table 6: Effect of potassium levels as soil application on plant height and yield and its components of wheat in 2021/2022 and 2022/2023 seasons

Treatments	Plant height (cm)	100 grain weight (g)	Grain yield (ton/ha)	Straw yield (ton/ha)	Biological yield (ton /ha)	Harvest index (%)
			2021/2022			
0.00	94.00 d	4.24d	4.938 d	7.806d	12.744d	38.75d
50 % RR	109.50 c	4.65c	6.188 c	8.616c	14.804c	41.80c
75% RR	118.50 b	5.13b	6.842 b	8.902b	15.744b	43.46b
100 % RR	126.00 a	5.40a	7.592 a	9.234a	16.826a	45.12a
			2022/2023			
0.00	97.00 d	4.82d	5.117 d	7.754d	12.871d	39.76d
50 % RR	111.00 c	4.76c	6.307 c	8.616c	14.923c	42.26c
75% RR	119.50 b	5.21b	6.842 b	8.997b	15.839b	43.20b
100 % RR	127.50 a	5.37a	7.413 a	9.282a	16.695a	44.40a

50 %RR= kg 23.70 K/ha, 75 % RR=35.56kg K/ha and 100 %RR= 47.43 kg K/ha

3.3.3 Effect of the interaction

Fertilizing wheat plants with different levels of K (100, 75 and 50 % of RR as well as control (without K) and spraying with Nano –K at 40 ppm increased plant height and grain yield and its components compared to control treatment (without K) and spraying with water (without Nano-K) as shown in Table 7.

The interaction between Nano –K at 40 ppm and K at 100% of RR (47.43 kg /ha) recorded the tallest plants and gave the highest values of 100 grain weight, grain yield (Fig. 3), straw, biological yield (Fig.3) and harvest index, followed by The interaction between spraying with water (without Nano –K) and K at 100% of RR (47.43 kg /ha) and the interaction between Nano –K at 40 ppm and K at 75% of RR (35.56 kg /ha) in both seasons.

The increases in grain yield were 7.50 and 4.76%, 8.00 and 7.84 %, 1.75 and 5.36%, and 5.80 and 8.36 % for control (without K), 50, 75 and 100 % of RR K, respectively with Nano-K at 40 ppm compared to control (without K) 50, 75 and 100 % of RR K without Nano-K at 40 ppm in the 1st and 2nd seasons, respectively.

The stimulative effect of the interaction between Nano-K at 40 ppm and K at 100 % of RR on grain yield may be due to that this treatment increased shoot dry matter (Table 2) and leaf pigments (Table 4) and 100 grain weight (Table 6).

Table 7: Effect of the interaction between nano potassium as foliar spray and potassium levels as soil application on plant height and yield and its components of wheat in 2021/2022 and 2022/2023 seasons

Treatments		Plant height (cm)	100 grain weight (g)	Grain yield (ton/ha)	Straw yield (ton/ha)	Biological yield (ton /ha)	Harvest index (%)
Nano potassium	Potassium levels	2021/2022					
0 Water	0.00	90.00 f	4.08 g	4.760 h	7.616 f	12.376g	38.46h
	50 % RR	109.00 d	4.56 e	5.950 f	8.473 d	14.423e	41.25f
	75% RR	117.00 c	4.96 c	6.783 d	8.758 c	15.541cd	43.65c
	100 % RR	122.00 b	5.28 b	7.378 b	9.139 ab	16.517b	44.67b
40 ppm	0.00	98.00 e	4.4 f	5.117 g	7.997 e	13.114f	39.02g
	50 % RR	110.00 d	4.76 d	6.426 e	8.758 c	15.184d	42.32e
	75% RR	120.00 bc	5.32 b	6.902 c	9.044 b	15.946bc	43.28d
	100 % RR	130.00 a	5.52 a	7.806 a	9.330 a	17.136a	45.55a
		2022/2023					
0 Water	0.00	95.00 f	4.56 f	4.998 f	7.606 f	12.604f	39.65e
	50 % RR	110.00 d	4.60 f	6.069 d	8.568 e	14.637d	41.46d
	75% RR	118.00 c	5.04 de	6.664 c	8.854 cd	15.518c	42.94c
	100 % RR	125.00 b	5.20 c	7.116 b	9.139 ab	16.255b	43.78b
40 ppm	0.00	99.00 e	5.10 cd	5.236 e	7.902 f	13.138e	39.85e
	50 % RR	112.00 d	4.92 e	6.545 c	8.663 de	15.208c	43.04c
	75% RR	121.00 c	5.40 b	7.021 b	9.139 bc	16.16b	43.45b
	100 % RR	130.00 a	5.56 a	7.711 a	9.425 a	17.136a	45.00a

50 %RR= kg 23.70 K/ha, 75 % RR=35.56kg K/ha and 100 %RR= 47.43 kg K/ha

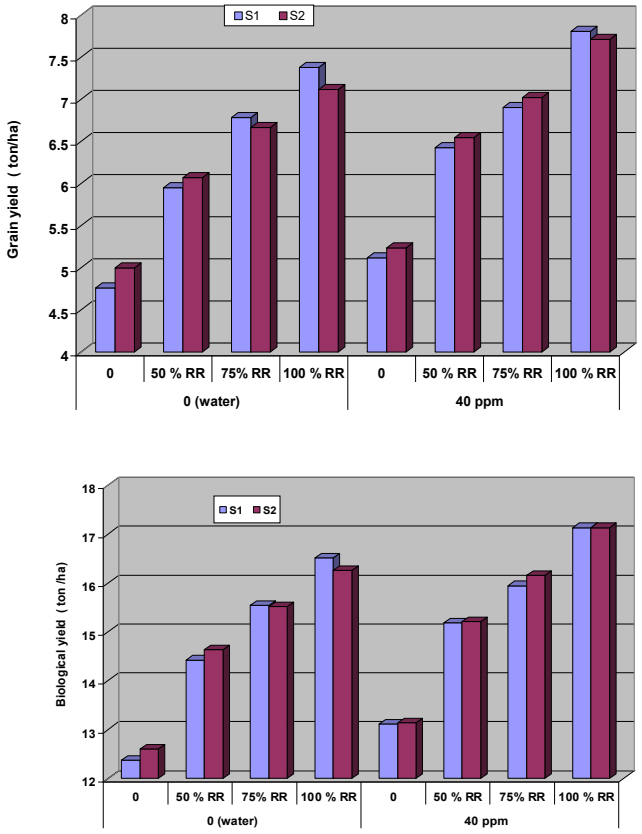

Fig. 3: Effect of interaction between Nano potassium as foliar spray and potassium levels as soil application on grain and biological yield of wheat in 2021/2022 and 2022/2023 seasons

3.4. Nitrogen, P and K concentration and uptake by grain and straw

3.4.1 Effect of Nano K as foliar application

Spraying wheat plants growing in clay soil with Nano-K twice, after 30 and 60 days from sowing increased N (2.15 and 2.18%), P (0.275 and 0.268%) and K (1.314 and 1.204 %) concentration and the uptakes by grain (kg /ha) of N (143.14 and 145.96), P (18.54 and 18.24) and K (75.33 and 76.57) agnist unsprayed plants which produced (2.02 and 2.06), (0.252 and 0.243%), (1.145 and 1.174%) for N, P and K concentration and (127.64 and 129.55), (16.12 and 15.44) and (73.03 and 74.48) for N, P and K uptake (kg /ha) in two seasons (Table 8).

As for N, P and K concentrations and its uptake by straw, data in Table 9 indicated that spraying plants with Nano-K at 40 ppm gave the same trend for N, P and K concentrations in grain and its uptake by grain in both seasons.

Similar results were found by Hamouda *et al*. (2015) on wheat. They showed that foliar application of potassium at 1000 ppm had significant effect on N, P and K contents and their uptake by grains and straw as compared with un-sprayed plants.

Table 8: Effect of nano potassium as foliar spray on N, P and K concentration and its uptake by grain of wheat in 2021/2022 and 2022/2023 seasons

Treatments	Concentration (%)			Uptake (kg /ha)		
	N	P	K	N	P	K
			2021/2022			
0 Water	2.02 b	0.252 b	1.145b	127.64 b	16.12 b	73.035b
40 ppm	2.15 a	0.275 a	1.314a	143.14 a	18.54 a	75.339a
			2022/2023			
0 Water	2.06 b	0.243 b	1.174b	129.55 b	15.44 b	74.483b
40 ppm	2.18 a	0.268 a	1.204a	145.96 a	18.24 a	76.573a

Table 9: Effect of Nano potassium as foliar spray on N, P and K concentration and its uptake by straw of wheat in 2021/2022 and 2022/2023 seasons

Treatments	Concentration (%)			Uptake (kg /ha)		
	N	P	K	N	P	K
			2021/2022			
0 Water	0.315 b	0.130 b	1.378b	26.93b	11.17b	118.11b
40 ppm	0.329 a	0.142 a	1.459a	29.01a	12.59a	129.09a
			2022/2023			
0 Water	0.323 a	0.134 a	1.399b	27.70a	11.535b	120.69b
40 ppm	0.330 a	0.142 a	1.464a	29.14a	12.608a	129.69a

3.4.2 Effect of K levels as soil application

The concentrations and uptake of N, P and K by grain (Table 10) were significantly increased with increasing K levels up to 100% of RR (47.43 kg /ha) in both seasons. This means that 24.43 kg K/ha produced the highest concentrations of N (2.29 and 2.31%), P (0.330 and 0.318%) and K (1.513 and 1.533 %) and its uptake by grain (173.95 and 171.70), (25.09 and 23.66) and (115.08 and 113.90) for N, P and K uptake (kg/ha) in both seasons. Fertilizing with K at 75 % of RR (35.56 kg /ha) came in the second rank, while control treatment (0 K) produced the lowest values of N, P and K concentrations and its uptake by grain in both seasons.

In relation to the N, P, and K concentrations in straw and the uptake by straw, data in Table 11 demonstrated that applying 47.43 kg of K/ha of fertilizer to plants resulted in the same trend for the concentrations of N, P, and K in grain and the uptake by grain in both seasons.

Potassium improves leaf development by promoting N absorption and protein synthesis. Additionally, potassium acts as a guard cell by assisting plants in maintaining their osmotic potential, which enhances water uptake and root permeability. It also increases how well water is used (Marschner, 1995). Application of K boosted the absorption of macronutrients. Improvements in

solvent transport and water mobility are indicated by nutrient absorption enhanced with K. This discovery may stem from the trans-membrane potential and osmotic pressure in xylem tubes, which play a K-regulating role and are strongly impacted by the K status in roots (Abd El–Mageed *et al*. 2017).

Results agreement with those obtained by Gharib and Meleha (2016); Mosaad and Fouda (2016); Kumar *et al*. (2018); Sarhan and Abd El-Hamed, (2018) and Ali *et al.* (2019). They showed that N, P and K percentage and uptake by grain and straw of wheat was significantly enhancing by adding potassium fertilizer relative to control. In this concern, Kuber *et al*. 2019 indicated that the highest results of nitrogen, phosphorus and potassium content in grains and straw were recorded in plots fertilized with 100 kg K/ ha potassium.

Table 10: Effect of potassium levels as soil application on N, P and K concentration and its uptake by grain of wheat in 2021/2022 and 2022/2023 seasons

Treatments	Concentration (%)			Uptake (kg /ha)		
	N	P	K	N	P	K
			2021/2022			
0.00	1.85 d	0.200 d	0.936d	91.45 d	9.89 d	46.306d
50 % RR	2.02 c	0.245 c	1.155c	125.61 c	15.17 c	71.630c
75% RR	2.20 b	0.280 b	1.314b	150.57 b	19.16 b	89.924b
100 % RR	2.29 a	0.330 a	1.513a	173.95 a	25.09 a	115.085a
			2022/2023			
0.00	1.86 d	0.195 d	0.956d	95.49 d	10.01 d	48.964d
50 % RR	2.07 c	0.238 c	1.194c	131.17 c	15.03 c	75.496c
75% RR	2.23 b	0.272 b	1.354b	152.66 b	18.66 b	92.791b
100 % RR	2.31 a	0.318 a	1.533a	171.70 a	23.66 a	113.908a

50 %RR= kg 23.70 K/ha, 75 % RR=35.56kg K/ha and 100 %RR= 47.43 kg K/ha

Table 11: Effect of potassium levels as soil application on N, P and K concentration and its uptake by straw of wheat in 2021/2022 and 2022/2023 seasons

Treatments	Concentration (%)			Uptake (kg /ha)		
	N	P	K	N	P	K
			2021/2022			
0.00	0.294 d	0.121 d	1.131d	22.97d	9.49d	88.34d
50 % RR	0.315 c	0.131 c	1.378c	27.14c	11.29c	118.79c
75% RR	0.334 b	0.142 b	1.526b	29.73b	12.64b	135.98b
100 % RR	0.347 a	0.152 a	1.638a	32.04a	14.09a	151.29a
			2022/2023			
0.00	0.298 d	0.121 d	1.141d	23.11d	9.39d	88.63d
50 % RR	0.318 c	0.134 c	1.388c	27.44c	11.59c	119.76c
75% RR	0.339 b	0.144 b	1.573b	30.55b	12.96b	141.57b
100 % RR	0.351 a	0.154 a	1.625a	32.59a	14.35a	150.88a

50 %RR= kg 23.70 K/ha, 75 % RR=35.56kg K/ha and 100 %RR= 47.43 kg K/ha

3.4.3 Effect of the interaction

The interaction between foliar spray with Nano-K at 40 ppm and soil application with K at 100 % of RR (47.43 kg /ha) increased N, P and K concentrations and its uptake by grain (Table 12 and Fig 4), followed by the interaction between spraying with water (control) and K at 100% of RR (47.43 kg /ha) and the interaction between foliar spray with Nano-K at 40 ppm and soil application with K at 75 % of RR (35.56 kg /ha) in both seasons.

Table 12: Effect of the interaction between Nano potassium as foliar spray and potassium levels as soil application on N, P and K concentration and its uptake by grain of wheat in 2021/2022 and 2022/2023 seasons

Treatments		Concentration (%)			Uptake (kg /ha)		
		N	P	K	N	P	K
Nano potassium	Potassium levels	2021/2022 season					
0 Water	0.00	1.80 e	0.190 h	0.876f	85.68 h	9.04 h	41.698g
	50 % RR	1.90 d	0.240 f	1.075d	113.05 f	14.28 f	63.963e
	75% RR	2.15 c	0.270 d	1.234c	145.83 d	18.31 d	83.702d
	100 % RR	2.25 b	0.310 b	1.393b	166.01 b	22.87 b	102.776b
40 ppm	0.00	1.90 d	0.210 g	0.995e	97.22 g	10.75 g	50.914f
	50 % RR	2.15 c	0.250 e	1.234c	138.16 e	16.07 e	79.297d
	75% RR	2.25 b	0.290 c	1.393b	155.30 c	20.02 c	96.145c
	100 % RR	2.33 a	0.350 a	1.632a	181.88 a	27.32 a	127.394a
		2022/2023 season					
0 Water	0.00	1.82 e	0.190 f	0.896f	90.96 f	9.50 f	44.782f
	50 % RR	1.95 d	0.230 e	1.114d	118.35 d	13.96 e	67.609d
	75% RR	2.19 c	0.265 c	1.254c	145.94 c	17.66 c	83.567c
	100 % RR	2.29 ab	0.290 b	1.433b	162.96 b	20.64 b	101.972b
40 ppm	0.00	1.91 d	0.201 f	1.015e	100.01 e	10.52 f	53.145e
	50 % RR	2.20 c	0.246 d	1.274 c	143.99 c	16.10 d	83.383c
	75% RR	2.27 b	0.280 b	1.453 b	159.38 b	19.66 b	102.015b
	100 % RR	2.34 a	0.346 a	1.632 a	180.44 a	26.68 a	125.844a

50 %RR= kg 23.70 K/ha, 75 % RR=35.56kg K/ha and 100 %RR= 47.43 kg K/ha

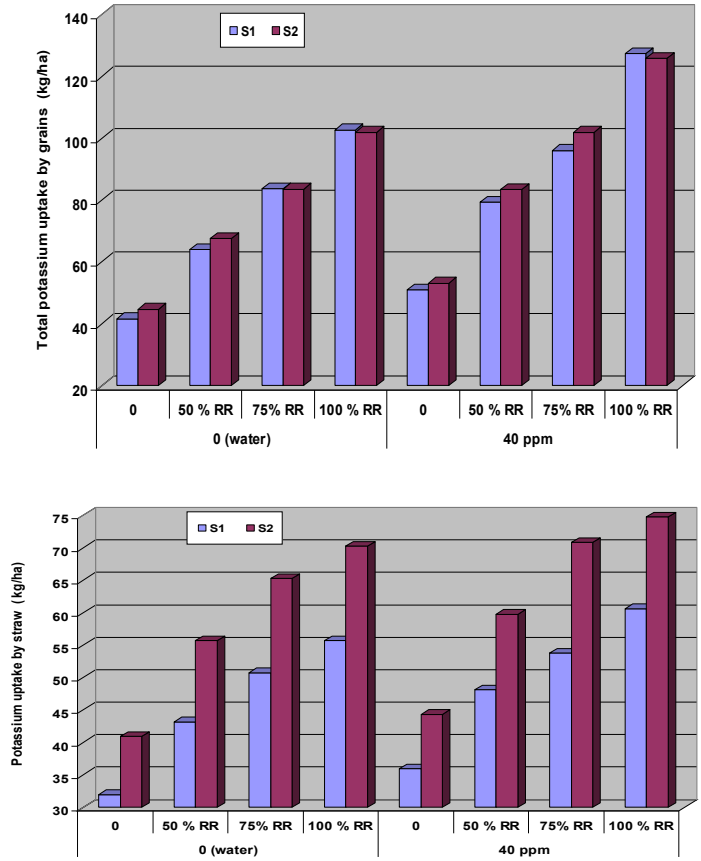

Fig. 4: Effect of the interaction between Nano potassium as foliar spray and potassium levels as soil application on potassium uptake by grains and straw of wheat in 2021/2022 and 2022/ 2023 seasons.

This means that spraying plants with Nano-K at 40 ppm and fertilizing with 47.43 kg K/ha produced the highest concentrations of N (2.33 and 2.34%), P (0.350 and 0.346%), and K (1.632 and 1.632%) and its uptake by grain (181.88 and 180.44), (27.32 and 26.68), and (127.39 and 125.84) for N, P, and K uptake (kg/ha) in both seasons, while control treatment (0 K) produced the lowest values of all grain nutrients and its uptake in both seasons.

Regarding the straw nutrients, i.e., N, P, and K concentrations and their uptake by straw, the data tabulated in Table 13 and Fig 4 showed that the maximum concentrations of N, P, and K, and its uptake by straw, were produced with wheat plants that were sprayed with Nano-K at 40 ppm and fertilized with 47.43 kg/ha K in both seasons (Table 13).

Table 13: Effect of the interaction between Nano potassium as foliar spray and potassium levels as soil application on N, P and K concentration and its uptake by straw of wheat in 2021/2022 and 2022/2023 seasons

Treatments		Concentration (%)			Uptake (kg /ha)		
		N	P	K	N	P	K
Nano potassium	Potassium levels	2021/2022					
0 Water	0.00	0.280 f	0.115 e	1.092g	21.32 f	8.75 e	83.148g
	50 % RR	0.310 de	0.125 d	1.326e	26.26 de	10.59 d	112.346e
	75% RR	0.328 bc	0.138 bc	1.508c	28.72 c	12.08 c	132.054cd
	100 % RR	0.344 a	0.145 b	1.586b	31.43 ab	13.25 b	144.924b
40 ppm	0.00	0.308 e	0.128 cd	1.170f	24.63 e	10.23 d	93.548f
	50 % RR	0.320 cd	0.137 bc	1.430d	28.02 cd	11.99 c	125.216d
	75% RR	0.340 ab	0.146 b	1.547bc	30.75 b	13.20 b	139.906bc
	100 % RR	0.350 a	0.160 a	1.690a	32.65 a	14.92 a	157.664a
		2022/2023					
0 Water	0.00	0.295 e	0.117 e	1.118e	28.08 f	11.14 f	106.444f
	50 % RR	0.315 d	0.130 cd	1.352d	33.74 e	13.92 d	144.794e
	75% RR	0.335 c	0.140 bc	1.534b	37.07 cd	15.49 c	169.780c
	100 % RR	0.347 ab	0.150 ab	1.599a	39.64 ab	17.14 b	182.676b
40 ppm	0.00	0.301 e	0.125 de	1.167e	29.73 f	12.35 e	115.310f
	50 % RR	0.322 d	0.139 bc	1.427c	34.87 de	15.05 cd	155.428d
	75% RR	0.344 bc	0.148 b	1.612a	39.30 bc	16.91 b	184.158b
	100 % RR	0.355 a	0.159 a	1.651a	41.82 a	18.73 a	194.506a

50 %RR= kg 23.70 K/ha, 75 % RR=35.56kg K/ha and 100 %RR= 47.43 kg K/ha

3.5. Grains quality

3.5.1 Effect of Nano K as foliar application

Foliar spray with Nano-K at 40 ppm significantly increased and produced the highest values of total protein (12.29 and 12.46%) and total carbohydrates (67.59 and 67.80%) in grain of wheat agnist spraying with water (control) which produced (11.54 and 11.75 %) and (66.67 and 66.80%) for total protein and total carbohydrates, respectively in two seasons (Table 14).

These results are harmony with those reported with Sheoran *et al.* (2021) indicated that spraying wheat plants with Nano potassium at 60 ppm produced the highest total protein content in wheat grains. Moreover, AL-Zubade and AL-Ubor (2024). They showed that the highest value of total protein in grains of wheat was recorded with foliar application of 2g/L Nano-potassium as compared to zero Nano potassium.

3.5.2 Effect of K levels as soil application

Total protein (13.05 and 13.28 %) and total carbohydrates (68.40 and 68.60%) in wheat grains significantly increased with increasing K levels up to 100% of RR (47.43 kg K/ha), followed by fertilizing with 75 % of RR (35.56 kg /ha) in both seasons (Table 14). On the other hand, unfertilized

plants with K produced the lowest values of total protein (10.54 and 10.63%) and total carbohydrates (65.97 and 66.11 %) in grains in both seasons.

Table 14: Effect of Nano potassium as foliar spray and potassium levels as soil application on total protein and total carbohydrates in grain of wheat in 2021/2022 and 2022/2023 seasons

	Total protein (%)		Total carbohydrates (%)	
	2021/2022	2022/2023	2021/2022	2022/2023
	Effect of Nano potassium as foliar spray			
0 Water	11.54 b	11.75 b	66.67 b	66.80 b
40 ppm	12.29 a	12.46 a	67.59 a	67.80 a
	Effect of potassium levels as soil application			
0.00	10.54 d	10.63 d	65.97 d	66.11 d
50 % RR	11.54 c	11.82 c	66.65 c	66.80 c
75% RR	12.54 b	12.71 b	67.52 b	67.70 b
100 % RR	13.05 a	13.28 a	68.40 a	68.60 a

50 %RR= kg 23.70 K/ha, 75 % RR=35.56kg K/ha and 100 %RR= 47.43 kg K/ha

These findings may have been caused by the fact that potassium levels in plant tissue are essential for the correct operation of a number of significant physiological and biochemical processes that directly improve assimilate translocation, particularly the translocation of nitrogen compounds to the grains, which raises the protein content (Khaled and Hammad,2014).

Similar results were obtained by Tabatabaei *et al*. (2014) and Mohamed (2017). Who showed that the highest protein content in the wheat grains produced with potassium, especially the highest level.

3.5.3 Effect of the interaction

The interaction between spraying with Nano-K at 40 ppm and K level at 100 % of RR (47.43 kg /ha) increased total protein (13.28 and 13.50) and total carbohydrates (68.90 and 69.10%) in grains in both seasons, followed by the interaction between Nano-K at 40 ppm and K at 75 % of RR (35.56 kg/ha) and the interaction between 0 Nano-K and K level at 100 % of RR (47.43 kg /ha) while, the plants which subjected under 0 Nano-K and 0 K produced the lowest values of total protein (10.26 and 10.37%) and total carbohydrates (65.50 and 65.62%) in grains in both seasons (Table 15 and Fig.5).

Table 15: Effect of the interaction between Nano potassium as foliar spray and potassium levels as soil application on total protein and total carbohydrates in grain of wheat in 2021/2022 and 2022/2023 seasons

Treatments		Total protein (%)		Total carbohydrates (%)	
Nano potassium	Potassium levels	2021/2022	2022/2023	2021/2022	2022/2023
0 Water	**0.00**	10.26 e	10.37 e	65.50 e	65.62 f
	50 % RR	10.83 d	11.11 d	66.20 d	66.30 ef
	75% RR	12.25 c	12.48 c	67.10 c	67.20 d
	100 % RR	12.82 b	13.05 b	67.90 b	68.10 bc
40 ppm	**0.00**	10.83 d	10.88 d	66.44 cd	66.60 de
	50 % RR	12.25 c	12.54 c	67.10 c	67.30 cd
	75% RR	12.82 b	12.93 b	67.95 b	68.20 b
	100 % RR	13.28 a	13.50 a	68.90 a	69.10 a

50 %RR= kg 23.70 K/ha, 75 % RR=35.56kg K/ha and 100 %RR= 47.40 kg K/ha

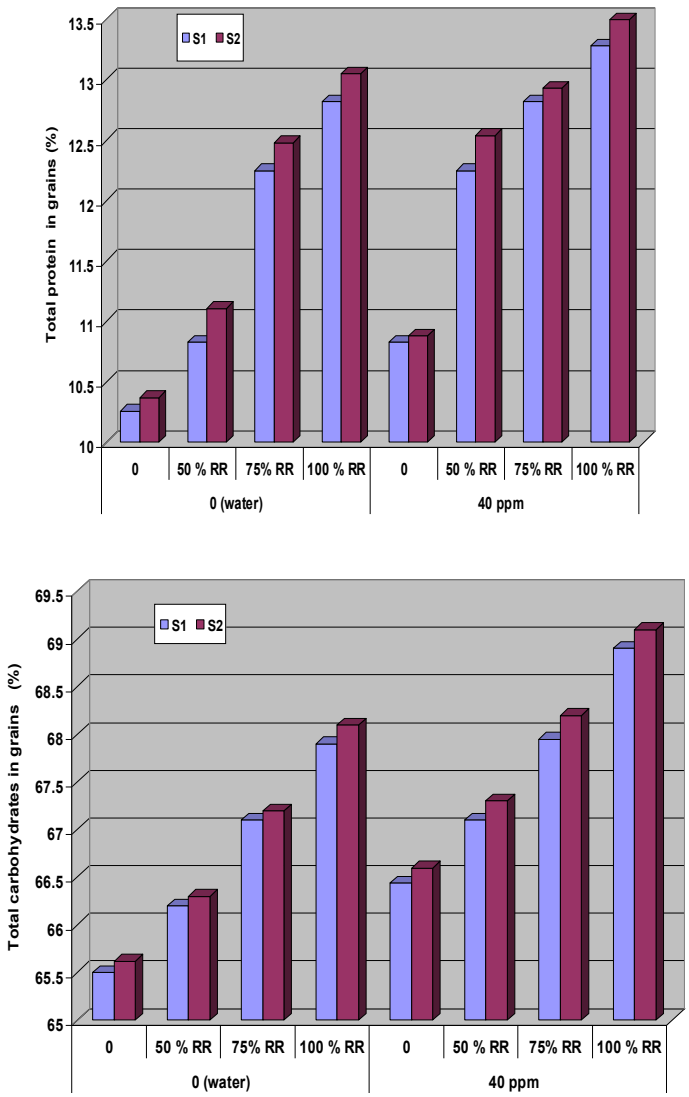

Fig. 5: Effect of the interaction between Nano potassium as foliar spray and potassium levels as soil application on total protein and total carbohydrates in grain of wheat in 2021/2022 and 2022/2023 seasons

3.6. Available K in soil after harvesting

3.6.1 Effect of Nano potassium

Available K in soil after harvesting of wheat was significantly increased by Nano potassium as a foliar spray as compared to control treatment (Table 16). However, sprayed wheat plants with Nano potassium at 40 ppm during the growing season scored the highest value of available K in soil (367.27 and 358.01 mg kg^{-1}) compared to untreated soil, which produced (279.50 and 277.74 mg kg^{-1}) for K in the 1st and the 2nd seasons, respectively**.**

3.6.2. Effect of potassium fertilization rate

Different rates of potassium as soil application had significantly affected available K in soil after harvesting wheat plants grown in clay soil as compared to zero potassium in both seasons (Table 16). The highest value of available K in soil after harvesting wheat plants (356.89 and 352.39 mg kg^{-1}), was obtained from the highest, which fertilized with K at 100% RR, followed by 75% RR (equals 47.43 kg/ha and 35.56 kg K/ha) in both growing seasons.

3.6.3. Effect of the interaction

Results in Table 16 showed that available K in soil after harvesting the wheat plants was significantly affected by the interaction between Nano potassium as foliar spray and K fertilizer application rate as soil application in both growing seasons. The best results for increasing K (395.23 and 391.23 mg kg^{-1}), were produced with the interaction between Nano potassium at 40 ppm and K at 100% RR in the 1st and the 2nd growing seasons, with no significant differences with the interaction between Nano potassium at 40 ppm and K fertilizer at 75% RR in the 2nd season. While the lowest value of soil available K content after harvesting of plants was produced from control treatment (no Nano potassium and no K) in both growing seasons.

Table 16: Effect of Nano potassium as foliar spray and potassium levels as soil application and their interactions on available K mg/kg soil of wheat after harvesting in 2021/2022 and 2022/2023 seasons.

Nano K asfoliar spray	K levels (kg/ha)				Mean (Nano K) A
	0	50% RR	75% RR	100 % RR	
			2021/2022 season		
Without	248.67 h	265.60 g	285.16 f	318.55 e	**279.50 B**
40 ppm	335.20 d	358.40 c	380.23 b	395.23 a	**367.27 A**
Mean (K) B	**291.94 D**	**312.00 C**	**332.70 B**	**356.89 A**	--
			2022/2023 season		
Without	252.67 d	268.60 d	276.16 d	313.55 c	**277.74 B**
40 ppm	322.20 c	346.40 bc	372.23 ab	391.23 a	**358.01 A**
Mean (K)	**287.44 C**	**307.50 BC**	**324.20 B**	**352.39 A**	--

50 %RR= kg 23.70 K/ha, 75 % RR=35.56kg K/ha and 100 %RR= 47.43 kg K/ha

From the foregoing results, it could be concluded that foliar spray of wheat plants which grown in clay soil twice after 30 and 60 days from sowing with Nano-K at 40 ppm and soil application of K at 100 % of RR (47.43 kg /ha) increased shoot dry matter percentage, leaf pigments, plant height, 100 grain weight, grain and straw yield, N, P and K uptake by grain and straw, total protein and total carbohydrates in grain, followed by foliar spray with water (control) and K at 100 of RR (47.43 kg/ ha).

4. Conclusion

Fertilizing of wheat plants with K at 47.43 kg /ha (100% of RR) and foliar spray with Nano-K at 40 ppm followed by K at 47.43 kg /ha without Nano-K were the best treatments for enchanting growth, grain yield and available K in soil after harvesting.

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