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Article

An Attempt to Reduce the Water Requirements of Potatoes Using Certain Agricultural Practices and the Impact on Productivity, Tuber Quality and Water Use Efficiency

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Abstract: This experiment was conducted on potato plants at a private farm at Sin El-Baharya – Badr District Center, Beheira Governorate, Egypt, over the winter season of 2024/2025 and 2025/2026, focusing on the effect of different irrigation water quantity (IWQ) (1000, 1250, 1500 and 1750 (m^3/fed.), K rates at 75, and 100 % of the recommended rate (RR) which equal 96 and 72 kg K_2O/fed. respectively, humic acid (HA) at 0 and 10 kg/fed. as soil application and their interactions on the growth, and productivity, potassium and water use efficiency (KUE and WUE) , and quality of the tubers in a sandy soil. The experiment was carried out in a split-split plot design, in which the irrigation water amounts was the main plot, the sub plot varied the K rates and the HA rate occupied in the sub sub plot. The triple interaction among IWQ at 1500 m^3/fed. and fertilizing potato plants with 75 % RR which equal 72 kg K_2O kg/ fed. and HA at 10 kg /fed. as soil application was the best treatment for enhancing plant growth and productivity and KUE. In addition, this treatment led to a relative increase in the total yield by 5.8% and saved 250 m^3/fed. water than the interaction among IWQ at 1750 m^3/fed. , with the same of K and HA amounts in both seasons. While, IWQ at 1750 m^3/fed. and fertilizing with K at 100 % (96 kg K2O/fed.) and HA at 10 kg /fed. produced the best tuber quality. On other side, the maximum WUE were obtained with the interaction among IWQ at 1000 m^3 water/fed., K at 100 % RR and HA at 10 kg /feddan in both seasons.

Key words: Potato, IWQ , K rates, HA, growth, yield and WUE .

1. Introduction

Overall, potato is among the most promising agricultural commodities grown worldwide. In Egypt, it is the leading vegetable crop. They are nutritious tubers, containing high amounts of carbohydrates, proteins, dietary fiber, some vitamins, and important minerals and trace elements. Furthermore, they are also the raw materials in various industries such as the manufacturing of French fries, potato chips, and alcohol, as well as starch. They are a good source of antioxidants. (**Chen *et.al.*, 2007**).

Nevertheless, excessive amounts of irrigation water can negatively impact crop yields due to leaching of nutrients, increasing prevalence of diseases, and/or not sufficiently encouraging the growth of the intended economic portions of the plants (**Solomon, 1993**). As stated by **Hanson and May (2004)** Because of the present shortage of water supply, the available water for irrigation is one of the natural resources that is currently under a lot of focus. It is important to find a balance between the water consumed and the water needed by the plants. Much of the irrigation water is lost to leaching and transpiration, making it clear that there is a reduction in the irrigation water requirement whenever possible, thereby reducing the water stress of the plants to some degree.

From the mentioned references, it is seen that the increased tuber quality, productivity and growth of potato plants were produced from the increased irrigation water supply to the potato plants (**Farhad *et al*., 2011; Eid *et al*., 2013; Abdel-Ati *et al*., 2014; Farrag *et al*., 2016; Dash *et al*., 2018; Badawy *et al*., 2019; Zahran *et al*., 2020; El- Metwaly and Mansour 2023**).

One of the most important plant nutrients that is crucial to plant growth is potassium (K). In addition to improving water use efficiency, K plays a crucial role in photosynthesis, enzyme activity, assimilate translocation, osmoregulation, and plant water status. It also increases water uptake, root permeability, and functions as a guard cell controller that controls stomatal opening and closing in plants (**Rengel *et al*., 2023**). Compared to many other vegetable crops, potato plants require more potassium; potassium fertilizers increase both the quantity and quality of tuber yield (**Westermann *et al*., 1994**).

Numerous scholars demonstrated that the best growth, yield, and tuber quality were achieved with fertilization of potato plants with K (**Ati *et al.,* 2012; Helal, and Abd Elhady, 2015; Elhakim *et al*., 2016; Abou Zeid and Abd El-Latif, 2017; Shunka *et al*., 2017; Abdel Naby *et al*., 2018; Elkhatib *et al*., 2018; Yakimenko and Naumova (2018); Bera *et al*., 2019; Alkharpotly and Abdelrasheed 2021; EL-Sayed *et al*., 2022 and Gabr *et al*., 2022 and Mansour and El- Metwaly,2023**).

Humic acids have been tested in agriculture for their ability to enhance soil fertility, promote in plant growth, and increase productivity. These naturally occuring organic compounds are produced by the decomposition of organic mater. To enhance plant growth and and development, the additions of humic acids improves ramification, facilitates metabolism, and helps increase the rate of nutrient absorption. Moreover, humic acids positively influence the aleration of the soil structure, moisture retention, and soil nutrient status, positively modifying the environment for plant growth (**Bera *et al*. 2024**).

As for humic acid **(Arafa and El-Howeity, 2017; Ali *et al*., 2019; El Komy *et al.*, 2021; Devi *et al*., 2023; Sanl *et al*., 2024, and El Damarawy *et al*., 2025)** showed that the treated potato plants achieved significantly the highest plant growth and its components, greatest yield, and tuber quality were superior unlike the plants without humic acid.

In the course of this study, an attempt was made to ascertain the effects of K fertilization, and humic soil application on growths quality and productivity of potato, with reducing the water requirements of potato under sandy soil condition.

2. Materials and Methods

This research experiment was implemented during the winter seasons of 2024/2025 and 2025/2026 in a private farm located at the Sin El-Baharya - Badr distract Center, Beheira Governorate, Egypt. The goal was to study the impact of irrigation water quantities, K rates and humic acid and how they interact to affect growth, productivity, potassium and water use efficiency as well as tuber quality under sandy soil conditions.

In both experimental seasons, the soil was sandy in texture and the physical and chemical properties of the experimental soil were as follows: 0.06, 0.06% organic matter, 8.11, 8.13 pH, 1.99, 2.03 mmhos/cm EC, 4.46, 4.75 ppm available N, 3.52, 3.56 ppm available P, and 8.22, 8.36 ppm available K in the 1^{st} and 2^{nd} seasons, respectively. The irrigation water was analyzed, and the results showed that its EC was 0.63 mmhos/cm, pH 7.84, and the following are notable: 1.52, 1.31, 1.53, 0.14, 1.26, 1.22, 2.23, and 1.51 mol/L for Ca, Mg, Na, K, SO4, Cl, HCO_3, and sodium adsorption ratio, respectively.

The experiment had a total of 16 treatments, which consisted of mixed combinations of the four quantities of irrigation water (1000, 1250, 1500 and 1750 m^3/fed. as drip irrigation), two levels of K (75 and 100% of the recommended rate (RR) which is 72 and 96 kg K_2O/fed. and two levels of humic acid (0 and 10 kg/fed as soil application) . The treatments were set up in a split split plot design in a fully randomized block design, which had 3 replications. The irrigation water quantities were applied in the main plot along with 16 mm diameter lateral lines at 15 cm soil surface depth with 2 l/hour flow rate at 1 bar pressure, K_2O rates were assigned in the sub plot, and the humic acid rate were assigned randomly in the sub sub plots.

Each experimental unit was 12.6 m^2. These units were made up of 3 dripper lines measuring 6 m in length with 70 cm spacing in between the dripper lines. One of the dripper line was assigned to measuring the morphological traits; the other two were designated for measuring the yields. In addition, an unused row was placed in between each pair of experimental units to function as a guard area to prevent the uncontrolled overlapping infiltration of irrigation water.

Over the course of the two year trial, on the 8th of October in both seasons, the Spunta potato cultivar was planted on the top third of the slope's ridges in 25cm distance intervals. Each of the experimental units was subsequently given 100 m^3 of water over the 20 days following the planting. On the 28th of October, the irrigation cycles began on a 3-day interval, until the irrigation was stopped on the 1st of February, which was 10 days before the harvesting of the tubers. Differentially, adjusted water inflows were conducted using a water flow and pressure management system.

The two potassium rates were divided into three parts: one-third was added during soil preparation, and the remaining two-thirds were applied via irrigation water starting 30 days after planting, distributed across 10 doses at four-day intervals. While, humic acid was applied before planting. Other than this, standard agronomic managements were applied.

Data recorded

Plant growth: Morphological details; plant height, stem diameter, and leaf area were measured for five randomly selected plants from each experimental unit, 90 days after planting.

Total leaf chlorophyll: Chlorophyll value (SPAD relative) was measured using acore from a spade meter and processed as in **Picazo *et al*. 2013**, 90 days after planting in both seasons.

Yield and its compositions: Yield parameters (average tuber weight (g) was assessed by weighing tubers harvested from each plot after 120 days of planting and converted to derive the total yield and marketable yield per feddan (0.42 hectare).

Potassium Use Efficiency (KUE) was computed by dividing the yield/fed, according to **Clark (1982)** by the amount of potassium consumed. and given as kilogram tuber/kg K2O.

Water Use Efficiency (WUE): according to **Begg and Turner (1976**) the WUE was calculated by a study which water consumed per unit area was compared to the yield per area to derive a ratio of yield to water consumed, measured in tuber yield (kg) per water (m^3) consumed.

Tuber Quality: Alongside how much tuber was produced, specific tuber quality attributes were assessed. Each in particular was recorded and compared and / or measured in the following attributes, specific to each tuber, (g/cm^3) specific gravity, a percentage of the total mass which is dry matter (%), total sugar (%), starch, and the amount of vitamin C per hundred grams of tuber weight (mg/100 g FW) as well as potassium contents in tandem to the **AOAC (2018**).

Statistical Analysis: The captured and stored data in computerized format were subjected to the analysis of variance and statistical software ASREML was also implemented to undertake the statistical separation among the means which was described based on **Duncan (1958**) and also **Snedecor and Cochran (1980**).

3. Results and Discussion

1. Plant growth and total chlorophyll

1.1. Effect of irrigation water quantity (IWQ)

In the current study, the characteristics including plant height, stem diameter, leaf area, and total chlorophyll present in the leaves increased significantly with increasing irrigation water quantity (IWQ) up to 1500 m^3/fed. in both season (Table 1). No significant differences were noted between 1500 and 1750 m^3/fed. in stem diameter and total chlorophyll for both seasons, and in plant height for the 1st season. The total chlorophyll increases due to irrigation, with 1500 m^3/fed. were 14.82 and 13.18 % more than that of irrigation with 1000 m^3/fed. in both seasons.

To maintain more soil moisture, potato plants may have needed more water, which may have aided plant metabolism and increased the production of dry matter and other plant growth components. The absence of water may have reduced the absorption of nutrients, which could disrupt the physiological processes of the plant (**Salter and Goode, 1967**). The obtained results conform the findings **of Farhad *et al*. (2011), Eid *et al.* (2013), and Dash *et al*. (2018).**

1.2. Effect of K (RR%)

Data in Table 1 indicate that fertilizing of potato plants with 75 % recommended rate (RR) of K (72 kg K_2O) gave higher plant height, stem diameter, leaf area and total chlorophyll in leaf tissues, without significant differences with 100 % RR of K_2O (96 kg/fed.) at 90 days after planting (DAP) in both seasons. The increases in total chlorophyll due to fertilizing with 75 % RR of K was about 1.85 and 5.89 % over fertilizing with 100 % RR of K in both seasons.

Greater growth measures could be caused by expanded cellular division as well as elongation (**Krishnappa and Shivasankar, 1981**). Dry matter build up was remarked and documented significantly higher with the dominant patterns of K (**Patel, 2013**). Moreover, the nitrogen enhances the yield and the photosynthesis activity during tuber initiation, while the optimal limit is exceeded and tuber development is delayed foliage growth is increased at the cost of tuberization (**Sharma and Kumar 2014**).

Table (1). Effect of irrigation water quantity, K_2O rates and humic acid on potato growth 90 days after planting during 2024/2025 and 2025/2026 winter seasons

Treatments	Plant height (cm)		Stem diameter (mm)		Leaf area/ plant (m^2)		Total chlorophyll (SPAD)	
	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season
(IWQ)	**Effect of irrigation water quantity (m^3/fed.)**							
1000	49.97 c	51.60 d	11.40 c	11.60 c	0.496 d	0.524 d	44.17 c	44.00 c
1250	55.17 b	54.90 c	12.59 b	12.99 b	0.547 c	0.565 c	45.97 b	46.32 b
1500	60.82 a	59.30 a	13.72a	14.06 a	0.602 a	0.608 b	50.72a	49.80 a
1750	60.82 a	58.67 b	13.67a	14.09 a	0.594 b	0.618a	50.22a	50.05 a
	Effect of KO_2 rates (RR%)							
75	56.80 a	55.50 b	12.84 a	13.29 a	0.560 a	0.584 a	47.33 b	46.18 b
100	56.60 a	56.73 a	12.85 a	13.08 a	0.559 a	0.573 b	48.21 a	48.90 a
	Effect of humic acid rates (kg /fed.)							
0	54.87 b	54.47 b	12.62 b	12.84 b	0.548 b	0.560 b	45.73 b	45.97 b
10	58.52 a	57.76 a	13.07 a	13.53 a	0.571 a	0.597 a	49.81 a	49.11 a

RR= recommended rate , 75 % RR K_2O=72 kg K_2O/fed., 100 % RR K_2O=96 kg K_2O/fed.,

These outcomes are concordant with **Ati *et al. (*2012) , Helal, and Abd Elhady (2015), Elhakim *et al*. (2016), Abou Zeid and Abd El-Latif (2017)** all on potato. They showed that increasing K fertilization produced the highest plant growth and total chlorophyll.

1.3. Effect of humic acid (HA)

Soil amended with 10 kg/fed. HA increased plant height, stem diameter, leaf area and total chlorophyll in leaf tissues compared to control with no HA (Table 1). Total chlorophyll increases due to HA application were 8.92 and 6.83 % (over control) in the first and second growing season, respectively. Such increases can be attributed to greater vegetative growth of the plants, which enhances the synthesis and translocation of the photosynthates needed for tuber formation (**Yang *et al*., 2021**).

These findings are in concordance with those reported by **Arafa and EL- Howeity (2017), Ali *et al.* (2019), and EL Komy *et al.* (2021)** where potato plants treated with humic acid showed the highest growth attributes compered without humic acid. Humic acid application was also reported to improve leaf area index significantly by **Hassan *et al*. (2022**).

1.4. Effect of the double interaction between IWQ and K_2O (RR%)

With IWQ at 1500 m^3/fed. and fertilization with 100% K there was the highest results in the stems and leaves (both area and total chlorophyll of) and there was the tallest plants, followed by the combination of IWQ at 1750m^3/fed. and fertilizing with 100% K at 90 DAP during both seasons (Table 2). Otherwise, the combination of IWQ 1000 m^3/fed. and K at 75% RR produced the plant height, stem diameter, leaf area, and total chlorophyll in leaf tissues in both seasons.

1.5. Effect of the double interaction between IWQ and HA rates

The data in Table 2 show that the interaction of IWQ at 1500 m^3/fed. and treated soil with HA at 10 kg/fed. was the best for plant height, stem diameter, leaf area, and total chlorophyll in leaf tissues. This was then followed by the interaction of IWQ at 1750 m^3/fed. and HA at 10 kg/fed. at 90 DAP in both seasons. In contrast, the interaction of IWQ of 1000 m^3/fed. and without HA resulted in the lowest plant height, stem diameter, leaf area, and total chlorophyll in leaf tissues in both seasons.

In this regard, **Alenazi *et al*. (2016)** found that the tallest plants, as well as the highest number of branches and the heaviest tuber dry weight, were obtained by treating potato plants with irrigating at 75% ET and HA at 1.5 g/L during the tuber bulking period. In addition, **Ali *et al*. (2019)** found that the combination of irrigation at 100% ETc and HA at 2.5 g/l had the greatest positive effect on the parameters of vegetative growth.

1.6. Effect of the double interaction between K_2O (RR%) and HA rates

The combination of K at full 100% RR and HA at 10kg/fed. increased the growth of plants, including growth features like the stem diameter, and the leaf area, total chlorophyll, of the tissue leaves during the period of 90 days growing from the start of planting, (Table 2). The combination of K 75% RR without HA results in the least plant height, diameter of stem, area of leaves and total leaf chlorophyll in leaves in both seasons in study .

This results match with studies done by **Abu- Zinada and Sekh-Eleid (2015)** which states that the potato plants with 100% of RR of NPK + 15 kg/ha HA had the highest plant height and number of main stems, leaf area, and the weight of fresh plant.

Table (2). Effect of the double interactions on plant growth at 90 days after planting of potato plants during 2024/2025 and 2025/2026 winter seasons

Treatment		Plant height (cm)		Stem diameter (mm)		Leaf area/ plant (m^2)		Total chlorophyll (SPAD)	
IWQ (m^3/fed.)	K_2O (RR%)	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season
		Effect of the interaction between IWQ and K_2O rates							
1000	**75**	50.45 c	51.85 f	11.38 c	11.58 c	0.495 d	0.517 f	43.85 e	42.95 e
	100	49.50 d	51.35 f	11.43 c	11.62 c	0.497 d	0.531 e	44.50 e	45.05 d
1250	**75**	55.15 b	54.45 e	12.62 b	13.11 b	0.549 c	0.570 d	46.00 d	45.30 d
	100	55.20 b	55.35 d	12.56 b	12.88 b	0.546 c	0.560 d	45.95 d	47.35 c
1500	**75**	60.80 a	57.85 c	13.67 a	14.28 a	0.601 ab	0.623 a	50.25 b	48.00 b
	100	60.85 a	60.75 a	13.77 a	13.84 a	0.603 a	0.593 c	51.20 a	51.60 a
1750	**75**	60.80 a	57.85 c	13.70 a	14.19 a	0.596 ab	0.627 a	49.25 c	48.50 b
	100	60.85 a	59.50 b	13.64 a	14.00 a	0.593 b	0.609 b	51.20 a	51.60 a
IWQ (m^3/fed.)	**HA (kg/fed.)**	**Effect of the interaction between IWQ and HA rates**							
1000	**0**	48.15 h	49.65 e	11.17 g	11.33 f	0.486 g	0.504 e	42.65 g	42.75 g
	10	51.80 g	53.55 d	11.64 f	11.87 e	0.506 f	0.544 d	45.70 e	45.25 f
1250	**0**	53.35 f	53.15 d	12.42 e	12.49 d	0.540 e	0.543 d	44.60 f	45.05 f
	10	57.00 e	56.65 c	12.76 d	13.50 c	0.555 d	0.587 c	47.35 d	47.60 d
1500	**0**	58.05 d	56.65 c	13.20 c	13.62 c	0.574 c	0.578 c	47.00 d	46.95 e
	10	63.60 a	61.95 a	14.24a	14.50a	0.630 a	0.638a	54.45 a	52.65a
1750	**0**	59.95 c	58.45 b	13.68 b	13.91 bc	0.595 b	0.615 b	48.70 c	49.15 c
	10	61.70 b	58.90 b	13.66 b	14.28ab	0.594 b	0.621 b	51.75 b	50.95 b
K_2O (RR %)	**HA (kg/fed.)**	**Effect of the interaction between K_2O and HA rates**							
75	**0**	56.40 c	56.15 b	12.83 b	13.43 b	0.558 b	0.591 b	46.77 c	48.25 b
	10	57.20 b	54.85 c	12.86 b	13.14 b	0.562 b	0.577 c	47.90 b	44.12 c
100	**0**	53.35 d	52.80 d	12.41 c	12.24 c	0.539 c	0.528 d	44.70 d	43.70 d
	10	59.85 a	60.67 a	13.29 a	13.93 a	0.580 a	0.618a	51.72 a	54.10 a

RR= recommended rate , 75 % RR K_2O=72 kg K_2O/fed., 100 % RR K_2O=96 kg K_2O/fed.,

1.7. Effect of triple interaction among IWQ, K_2O (RR%) and HA

The interaction among IWQ at 1500 m^3/fed , K at 100 % RR, HA at 10 kg/fed. as soil application resulted in the enhancement of plant growth and total chlorophyll in leaf tissues, followed by irrigation with 1750 m^3/fed. fertilizing potato plants with K at 100 % RR and HA at 10 kg/fed. (Table 3).

Under the interaction among IWQ at 1500 m^3/fed , K at 100 % RR, HA at 10 kg/fed. as soil application, results show that the tallest plants grew to heights of 64.80 and 65.80 cm and stems were 14.29 and 14.75 mm in diameter. Other attributes including leaf areas of 0.630 and 0.652 m^2 and total chlorophyll leaf compositions of 56.50 and 58.30 SPAD were also maximum. In both seasons, the second best treatments involved irrigation of 1750 m^3/fed. , 100 % RR of K and HA at 10 kg /fed. at 90 DAP. On the other hand, the lowest values of all attributes were recorded with irrigation with 1000 m^3/fed., fertilizing of K at 75 %RR without HA in both seasons.

The increases in total chlorophyll due to the interaction among irrigation with 1500 m^3/fed., K at 100 % RR and humic acid at 10 kg /fed. were about 29.88 and 20.35 than the interaction among irrigation with 1000 m^3/fed., K at 75 % RR and zero humic acid in the 1st and 2nd seasons respectively.

Table (3). Effect of the triple interaction among irrigation water quantity, K_2O and humic acid rates on plant growth at 90 days after planting of potato plants during 2024/2025 and 2025/2026 winter seasons

Treatments			Plant height cm	Stem diameter (mm)	Leaf area/ plant (m^2)	Total chlorophyll (SPAD)
IWQ (m^3/fed.)	K_2O (RR %)	HA (kg/fed.)	2024/2025 season			
1000	75	0	50.80 k	11.59 ij	0.504 g	43.50 j
		10	50.10 k	11.18 jk	0.486 h	44.20 j
	100	0	45.50 l	10.76 k	0.468 i	41.80 k
		10	53.50 i	12.10 h	0.526 f	47.20 gh
1250	75	0	54.50 h	12.83 fg	0.558 d	45.70 i
		10	55.80 g	12.42 gh	0.540 e	46.30 hi
	100	0	52.20 j	12.01 hi	0.522 f	43.50 j
		10	58.20 e	13.11 f	0.570 c	48.40 ef
1500	75	0	59.20 d	13.16 ef	0.572 c	48.10 efg
		10	62.40 b	14.19 ab	0.630a	52.40 c
	100	0	56.90 f	13.25 def	0.576 c	45.90 i
		10	64.80 a	14.29 a	0.630a	56.50a
1750	75	0	61.10 c	13.75 bc	0.598 b	49.80 d
		10	60.50 c	13.66 cd	0.594 b	48.70 e
	100	0	58.80 de	13.62 cde	0.592 b	47.60 fg
		10	62.90 b	13.66 cd	0.594 b	54.80 b
			2025/2026 season			
1000	75	0	52.50 h	11.78 fg	0.522 hi	44.70 g
		10	51.20 i	11.38 gh	0.512 i	41.20 i
	100	0	46.80 j	10.88 h	0.486 j	40.80 i
		10	55.90 e	12.36 ef	0.576 fg	49.30 d
1250	75	0	55.10 f	13.25 d	0.576 fg	47.60 e
		10	53.80 g	12.97 d	0.564 g	43.00 h
	100	0	51.20 i	11.73 g	0.510 i	42.50 h
		10	59.50 c	14.03 b	0.610 de	52.20 c
1500	75	0	57.60 d	14.31 ab	0.622 cde	49.00 d
		10	58.10 d	14.25 ab	0.624 cd	47.00 ef
	100	0	55.70 ef	12.94 de	0.534 h	44.90 g
		10	65.80 a	14.75 a	0.652a	58.30a
1750	75	0	59.40 c	14.40 ab	0.646ab	51.70 c
		10	56.30 e	13.98 bc	0.608 e	45.30 g
	100	0	57.50 d	13.43 cd	0.584 f	46.60 f
		10	61.50 b	14.58 ab	0.634 bc	56.60 b

RR= recommended rate , 75 % RR K_2O=72 kg K_2O/fed., 100 % RR K_2O=96 kg K_2O/fed.,

2. Yield and its components and water use efficiency

2.1. Effect of IWQ

Average tuber weight/plant, average number of tubers/plant, yield/plant, marketable yield and total yield as well as potassium use efficiency (KUE) in both seasons significantly increased with increasing IWQ up to 1500 m^3/fed. while, WUE decreased with increasing IWQ in both seasons (Tables 4 and 5). IWQ at 1500 m^3/fed. gave the highest averages of tuber weight (160.16 and 158.29 g, tuber weight/plant (628.47 and 594.61 g), marketable yield (17.065 and 16.190 tons), and total yield (18.754 and 17.729 tons) as well KUE (227.74 and 215.73 kg tuber/ unit of K_2O in both seasons, followed with IWQ at 1750 m^3/feddan.

There were no considerable differences in IWQ of 1500 m^3/fed. and 1750 m^3/fed. regarding average weight of tubers, average quantity of tubers per plant, weight of tubers per plant, marketable yield (ton/fed.), and total yield (ton/fed.) in the second season.

With regards to WUE, at 1000 m^3 of water/fed, each one m^3 water produced 15.205 and 15.566 kg , while at 1500 m^3/fed., each m^3 water produced 12.503 and 11.819 kg of tubers in both seasons.

In this regard, **Suganya and Sivasamy (2006**) pointed out that the major problems in sandy soils are high permeability and the disability to retain both moisture and nutrients. Thus, the major challenge in ameliorating sandy soil is controlling irrigation water and nutrients in the plant. This is due to the fact that insufficient irrigation results in very high soil moisture tension which is stressful to the plants and reduces productivity.

The increase in the total yield of tubers is more due more to the increase in tubers/plant and average tuber weight and the weight of tubers/plant' and not to the increase in number of tubers/plant. The yield data and its components were also obtained in the same way for the data of growth of the plants. More water applied to soil will cause more soil moisture, which makes the nutrients more available to the plants. This will in turn enhance the physiological processes that is directly related to the yield and its components and to the physiological features of the plant. For sure, the plants that were given more water were able to retain more and produced heavier tubers than the ones under water stressed condition. The same findings confirm those of **Ati *et al*. (2012) Abdel-Ati *et al.* (2014), Farrag *et al.* (2016) and Zahran *et al*. (2020)** who showed that the increase in the irrigation water quantity to potato plants resulted in the heaviest tuber weights.

2.2. Effect of K_2O (RR%)

There were no significant differences between the two rates of K regarding yield and its components parameters in both seasons, except tuber weight/ plant, marketable and total yield and WUE in the 1st season. This means that fertilizing potato plants grown in sandy soil with K 75 % RR enhanced average tuber weight, tuber count per plant, tuber weight per plant, total and marketable yields and improved water use efficiency (WUE) (Tables 4 and 5) .

As for KUE, data in Table 5 reveal that fertilizing with 100 % RR of K produced the highest KUE (231.50 and 233.60 kg tuber/kg K_2O) against fertilizing with 75 % RR which produced (183.50 and 174.92 kg tubers/kg K_2O) in the both seasons.

Potassium deficiencies cause small and light tubers containing high amounts of sugar and low amounts of dry matter. The immature tubers are also more prone to disease infections **(Sharma and Arora ,1987)**. The more mature the crop, the more tubers produced per plant. On the other hand, nitrogen also promotes increased tuber initiation beyond the optimum levels and photoactivity which results in delayed tuber development. This increase was noted in foliage while also inhibiting tuberization (**Sharma and Kumar, 2014**).

These results are consistent with **Shunka *et al*. (2017), Abdel Naby *et al*. (2018), Elkhatib *et al*. (2018**), **Yakimenko and Naumova (2018)** and **Bera *et al*. (2019**) showing that potato yield and its components were significantly affected by K fertilization.

2.3. Effect of HA rates

Data presented in Table 4 indicated that HA at 10 kg/fed. as a soil application in comparison to the control (without HA) showed higher averages of tuber weight, the number of tubers/plant, total tuber weight/plant, marketable yield, total yield, and water use efficiency for both seasons (Tables 4 and 5). The increases in total yield in both seasons were 15.64 and 15.18% over control treatment (without HA).

As for KUE, data in Table 5 show that treated plants with humic acid at 10 kg /fed. gave the highest KUE (224.43 and 218.94 kg tuber/kg K_2O) against non fertilizing with humic acid which gave (190.81 and 189.58 kg tubers/kg K_2O) in the both seasons. The increases in WUE were, over control treatment (zero HA) were, 15.50% and 13.48% in the first and second seasons, respectively.

There might be an improvement in total tuber yield due to the positive influence of humic acid has on the physical and chemical attributes of the soil and the growth of the plants, as echoed by **El-Damarawy *et al*. (2022)** whose findings indicated the enhancement of total tuber yield with the application of humic acid compared to control.

The results obtained are in accordance with the findings of **Devi *et al*. (2023), Şanl *et al.* (2024)** as they reported that the yield and its components were superior with the application of humic acid to the potato plants compared to those without humic acid.

Table (4). Effect of irrigation water quantity, K_2O and humic acid rates on yield and its components of potato plants during 2024/2025 and 2025/2026 winter seasons

Treatments	Average tuber weight (g)		Tuber weight/plant (g)		Marketable yield (ton/fed.)		Total yield (ton/fed.)	
	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season
	Effect of irrigation water quantity (m^3/fed.)							
1000	145.47 c	148.17b	511.83d	522.42c	13.297 d	13.614 c	15.205 d	15.566 c
1250	152.16b	151.03b	548.23 c	541.39 b	14.563 c	14.418 b	16.336 c	16.156 b
1500	160.16 a	158.29 a	628.47 a	594.61 a	17.065 a	16.190 a	18.754 a	17.729 a
1750	157.82 a	157.41 a	613.85 b	596.43 a	16.629 b	16.161 a	18.308 b	17.770 a
	Effect of K_2O (RR %)							
75	153.92 a	152.62 a	591.28 a	562.76 a	15.658 a	15.043 a	17.616 a	16.792 a
100	153.89 a	154.82 a	559.91 b	564.66 a	15.119 b	15.149 a	16.685 b	16.819 a
	Effect of humic acid rate (kg/fed.)							
0	148.18b	146.82b	533.62 b	527.20 b	13.781 b	13.667 b	15.906 b	15.727 b
10	159.62 a	160.63 a	617.57 a	600.22 a	16.996 a	16.525 a	18.395 a	17.884 a

RR= recommended rate , 75 % RR K_2O=72 kg K_2O/fed., 100 % RR K_2O=96 kg K_2O/fed.,

Table (5). Effect of irrigation water quantity, K_2O and humic acid rates on potassium use efficiency (KUE) and water use efficiency (WUE) of potato plants during 2024/2025 and 2025/2026 winter seasons

Treatments	KUE (kg tubers/kg K_2O)		WUE (kg tubers/m^3 water)	
	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season
	Effect of irrigation water quantity (m^3/fed.)			
1000	183.35 d	188.78c	15.205 a	15.566 a
1250	197.53 c	196.43b	13.06 b	12.925 b
1500	227.74 a	215.73 a	12.503 c	11.819 c
1750	221.87 b	216.09 a	10.462 d	10.154d
	Effect of K_2O (RR %)			
75	183.50 b	174.92 b	13.199 a	12.626 a
100	231.74 a	233.60 a	12.420 b	12.606 a
	Effect of humic acid rate (kg/fed.)			
0	190.81 b	189.58 b	11.888 b	11.819 b
10	224.43 a	218.94 a	13.731 a	13.413 a

RR= recommended rate , 75 % RR K_2O=72 kg K_2O/fed., 100 % RR K_2O=96 kg K_2O/fed.,

2.4. Effect of the double interaction between IWQ and K_2O (RR%)

The interaction between irrigation water quantity at 1500 m^3/fed. and fertilizing with K at 100 % RR significantly increased total yield (18.652 and 17.884 ton/fed.) and its component parameters and KUE , followed by the interaction between irrigation water quantity at 1500 or 1750 m^3/fed. and fertilizing with K at 75 or 100 % RR, respectively, in both seasons (Tables 6 and 7) .

Potassium use efficiency was the higher with the interaction between irrigation with 1500 m^3/fed. and fertilizing with K at 100 % which recorded (259.05 and 248.39 kg tubers/Kg K_2O water) in both seasons respectively. However, WUE was the best with the interaction between irrigation with 1000 m^3/fed. and fertilizing with K at 75 % which recorded (16.029 and 15.793 kg tubers/m^3 water) in both seasons.

2. 5. Effect of the double interaction between IWQ and HA rates

The greatest average tuber masses/per plant, the average count of tubers/per plant, yield/per plant, marketable total yield, and overall total yield as well as KUE were reached from the combination of IWQ 1500 m^3/fed. and HA 10kg/fed., followed by HA 10 kg/fed. and IWQ 1750 m^3/fed (Tables 6 and 7). The total yield/fed. impact from the combination of IWQ at 1500 m^3/fed. and HA 10 kg/fed. showed a 41.38 and 30.53% increase from the combination of IWQ 1000 m^3/fed. and no HA for the first and second seasons, respectively.

Table (6). Effect of double interaction on yield and its components of potato plants during 2024/2025 and 2025/2026 winter seasons

Treatments		Average tuber weight (g)		Tuber weight/plant (g)		Marketable yield (ton/fed.)		Total yield (ton/fed.)	
		2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season
IWQ	**K_2O**	**Effect of the interaction between IWQ (m^3/fed.) and K_2O (RR%)**							
1000	**75**	145.37 c	148.12 d	539.21 e	529.63 d	13.849 e	13.809c	16.029 d	15.793 c
	100	145.59c	148.23d	484.45 g	515.20 e	12.745 f	13.419 c	14.380 e	15.340 d
1250	**75**	152.74 b	150.98 cd	567.31 d	539.68 cd	14.890 c	14.332 b	16.909 c	16.108bc
	100	151.58 b	151.09 bcd	529.16 f	543.10 c	14.236 d	14.505 b	15.762 d	16.206 b
1500	**75**	159.89 a	156.53 ab	633.19 a	588.55 b	17.088 a	16.015 a	18.857 a	17.575 a
	100	160.44 a	160.05 a	623.75 b	600.68 a	17.043 a	16.366 a	18.652 a	17.884 a
1750	**75**	157.69 a	154.88 abc	625.41 ab	593.20 ab	16.807a	16.016 a	18.668 a	17.693 a
	100	157.96 a	159.94 a	602.28 c	599.66 ab	16.451 b	16.307 a	17.949 b	17.848 a
IWQ	**HA**	**Effect of the interaction between IWQ (m^3/fed.) and HA (kg/fed.)**							
1000	**0**	139.70 e	140.64 e	482.05 g	494.29 g	11.961 g	12.517 e	14.337 g	14.713 g
	10	151.25 c	155.71 cd	541.61 e	550.55 de	14.633 e	14.711 c	16.072 e	16.419 de
1250	**0**	145.75 d	142.94 e	500.13 f	509.41 f	12.841 f	13.134 d	14.912 f	15.214 f
	10	158.57 b	159.12 bc	596.34 c	573.36 c	16.285 c	15.703 b	17.759 c	17.100 c
1500	**0**	154.61 bc	151.91 d	578.10 d	544.17 e	15.375 d	14.469 c	17.238 d	16.254 e
	10	165.72 a	164.67 a	678.85 a	645.06 a	18.755 a	17.912 a	20.271 a	19.205 a
1750	**0**	152.68 c	151.80 d	574.20 d	560.92 d	14.947 e	14.550 c	17.139 d	16.726 d
	10	162.96 a	163.02 ab	653.49 b	631.94 b	18.311 b	17.773 a	19.478 b	18.815 b
K_2O	**HA**	**Effect of the interaction between K2O (RR%) and humic acid rates (kg/fed.)**							
75	**0**	150.73c	149.22 c	582.17 c	556.18 c	15.233c	14.739c	17.344c	16.613 c
	10	157.11 b	156.04 b	600.39 b	569.34 b	16.084 b	15.347b	17.888 b	16.971 b
100	**0**	145.64 d	144.43 d	485.07 d	498.21 d	12.329 d	12.596 d	14.469 d	14.840 d
	10	162.14 a	165.22 a	634.74 a	631.11 a	17.909 a	17.702 a	18.902 a	18.799 a

RR= recommended rate , 75 % RR K_2O=72 kg K_2O/fed., 100 % RR K_2O=96 kg K_2O/fed.,

Table (7). Effect of double interaction on potassium use efficiency (KUE) and water use efficiency (WUE) of potato plants during 2024/2025 and 2025/2026 winter seasons

Treatments		KUE(kg tubers/kg K_2O)		WUE (kg tubers/m^3 water)	
IWQ (m^3/fed.)	K_2O (RR%)	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season
		Effect of the interaction between IWQ and K_2O			
1000	**75**	166.97f	164.51 e	16.029 a	15.793 a
	100	199.72 d	213.05c	14.380 b	15.340 b
1250	**75**	176.14 e	167.79 e	13.527 c	12.886c
	100	218.92 c	225.08 b	12.610 d	12.965 c
1500	**75**	196.44 d	183.07 d	12.572 d	11.716 d
	100	259.05 a	248.39 a	12.435 d	11.923d
1750	**75**	194.45 d	184.30 d	10.668 e	10.110 e
	100%	249.29 b	247.89 a	10.256 f	10.199e
IWQ (m^3/fed.)	**HA (kg/fed.)**	**Effect of the interaction between IWQ and HA**			
1000	**0**	170.53 g	177.13 g	14.337 b	14.713 b
	10	196.16 e	200.43 de	16.072 a	16.419 a
1250	**0**	178.31 f	182.99 f	11.930 d	12.171 e
	10	216.75 c	209.88 c	14.207 b	13.680 c
1500	**0**	207.59 d	196.08 e	11.492 e	10.836 f
	10	247.90 a	235.37 a	13.514 c	12.803 d
1750	**0**	206.81 d	202.13 d	9.794 f	9.557 g
	10	236.93 b	230.06 b	11.131 e	10.752 f
K_2O (%)	**HA (kg/fed.)**	**Effect of the interaction between K_2O and humic acid rates**			
75	**0**	180.67 d	173.05d	13.060 c	12.511b
	10	186.33 c	176.78c	13.338 b	12.741 b
100	**0**	200.95 b	206.11 b	10.716d	11.127c
	10	262.53 a	261.09 a	14.124 a	14.086 a

RR= recommended rate , 75 % RR K_2O=72 kg K_2O/fed., 100 % RR K_2O=96 kg K_2O/fed.,

Concerning WUE, irrigation at 1000 m^3/fed. with HA at 10 kg /fed. produced the highest values (16.072 and 16.419 kg tubers/m^3water) in both seasons respectively. The findings obtained are consistent with the findings of **Alenazi *et al.* (2016)**, who found that the interaction between 75 % ET water regime and HA at 1.5 g/l at tuber bulking stage can increase potato production. In addition, **Ali *et al*. (2019)** found that the combination of irrigation at 100 % ETc and HA at 2.5 g/L resulted in the highest yield/plant, the highest tubers/plant, average tuber weight, yield/fed and tuber diameter.

2.6. Effect of the double interaction between Effect of K_2O (RR%) and HA rates

Fertilizing potato plants with K at 100 % RR and treated plants with humic acid at 10 kg /fed. was the best treatment for increasing yield and its components as well as KUE and WUE compared to other treatments in both seasons (Tables 6 and 7). Theses results are in harmony with those obtained with **Abu-Zinada and Sekh-Eleid (2015)** who indicated that treated potato plants with 100% RR of NPK + 15 kg HA/ ha scored the highest values of tuber number plant and tubers weight per plant.

2. 7. Effect of triple interaction among IWQ, Effect of K_2O (RR%) and HA rates

The combination of IWQ at 1500 m^3/fed., K at 100 % RR, (96 kg K_2O/fed.) and HA at 10 kg/fed. as soil application was the most effective in increasing tuber weight, number tubers/plant, yield/plant, marketable yield and total yield as well as KUE in both seasons. This was followed by the interaction among IWQ at 1750 m^3/fed., K at 100 % RR and HA at 10 kg/fed. during both seasons (Tables 8 and

9). This shows that IWQ at 1500 m^3/fed. , K at 100% RR and HA at 10 kg / fed increased the yield and its components more than IWQ at 1500 m3/fed. , K at 100 % RR and without HA. The irrigation at 1500 m^3/fed. and application of K at 100% RR as well as humic acid at 10 kg /fed. generated higher total yield (20.211 and 19.578 ton) as compared to similar treatments without HA. in both seasons .

Table (8). Effect of triple the interaction among irrigation water quantity K_2O rate and humic acid on yield and its components of potato plants during 2024/2025 and 2025/2026 winter seasons

Treatment			Average tuber weight (g)	Tuber weight/plant (g)	Marketable yield ton/fed.	Total yield (ton/fed.)
IWQ (m^3/fed)	**K_2O RR (%)**	**HA Kg/fed.**	**2024/2025 season**			
1000	**75**	**0**	141.35 g	554.09 fg	13.911 g	16.469 e
		10	149.38 f	524.32 i	13.787 g	15.589 f
	100	**0**	138.05 g	410.01 k	10.011 i	12.205 h
		10	153.12 ef	558.89 f	15.479 e	16.555 e
1250	**75**	**0**	148.72 f	556.21 fg	14.432 f	16.590 e
		10	156.75 cde	578.41 e	15.347 e	17.228 d
	100	**0**	142.78 g	444.05 j	11.250 h	13.234 g
		10	160.38 bc	614.26 c	17.222 d	18.290 c
1500	**75**	**0**	159.39 bcd	616.84 c	16.875 d	18.332 c
		10	160.38 bc	649.54 b	17.300 d	19.383 b
	100	**0**	149.82 f	539.35 h	13.875 g	16.144 e
		10	171.05 a	708.15 a	20.211 a	21.159 a
1750	**75**	**0**	153.45 def	601.52 d	15.714 e	17.985 c
		10	161.92 bc	649.30 b	17.900 c	19.351 b
	100	**0**	151.91 ef	546.88 gh	14.179 fg	16.292 e
		10	164.01 b	657.68 b	18.722 b	19.605 b
			2025/2026 season			
1000	**75**	**0**	142.45 gh	525.64 fg	13.617 ij	15.676 fg
		10	153.78 de	533.62 ef	14.001 ghi	15.910 ef
	100	**0**	138.82 h	462.93 h	11.417 k	13.750 h
		10	157.63 cd	567.47 d	15.421 f	16.929 d
1250	**75**	**0**	145.86 fgh	545.52 e	14.242 gh	16.310 e
		10	156.09 cd	533.83 ef	14.421 g	15.905 efg
	100	**0**	140.03 gh	473.30 h	12.025 k	14.117 h
		10	162.14 bc	612.89 c	16.985 c	18.294 c
1500	**75**	**0**	156.64 cd	571.74 d	15.785 ef	17.087 d
		10	156.42 cd	605.35 c	16.245 de	18.062 c
	100	**0**	147.18 efg	516.60 g	13.153 j	15.420 g
		10	172.92 a	684.76 a	19.578 a	20.347 a
1750	**75**	**0**	151.91 def	581.82 d	15.311 f	17.380 d
		10	157.85 cd	604.57 c	16.721 cd	18.005 c
	100	**0**	151.69 def	540.02 ef	13.789 hi	16.072 ef
		10	168.19 ab	659.30 b	18.825 b	19.624 b

RR= recommended rate , 75 % RR K_2O=72 kg K_2O/fed., 100 % RR K_2O=96 kg K_2O/fed.,

Irrigated potato plants cv. Spunta with 1500 m^3 water/fed., 100 % RR of K_2O and 10 kg HA as soil application gave average tuber weight (171.05 and 172.92 g), yield / plant (708.15 and 684.76g), and KUE (293.88 and 282.60 kg tuber/kg K_2O) in both seasons, whereas the plants received 1750 m^3 water/fed. ,100 % RR of K without HA gave average tuber weight (151.92 and 151.69 g), yield/ plant (546.88.30 and 540.02 g), and KUE (226.28 and 223.22 kg tuber/ kg K_2O water) in both seasons. As for WUE, the triple interaction among 1000 m^3 water/fed. , 100 % RR of K and 10 kg HA scored the best water use efficiency (16.555 and 16.929 kg tubers/m^3 water) in both seasons.

For all the interaction treatments, average tuber weights ranged from141.35 to 171.05 g in the 1st season from 142.45 to 172.92 g in the 2nd season.

Table (9). Effect of the triple interaction among irrigation water quantity K_2O rate and humic acid on potassium use efficiency (KUE) and water use efficiency (WUE) of potato plants during 2024/2025 and 2025/2026 winter seasons

Treatment			KUE (kg tubers/kg K_2O)		WUE (kg tubers/m^3 water)	
IWQ (m^3/fed.)	K_2O RR (%)	HA Kg/fed.	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season
1000	**75**	**0**	171.55 hi	163.29 k	16.469 a	15.676 b
		10	162.39 j	165.73 k	15.589 b	15.910 b
	100	**0**	169.51 ij	190.97 gh	12.205 g	13.750 d
		10	229.93 d	235.13 d	16.555 a	16.929 a
1250	**75**	**0**	172.81 hi	169.90 k	13.272 ef	13.048 ef
		10	179.46 gh	165.68 k	13.782 de	12.724 f
	100	**0**	183.81 fg	196.07 g	10.587 ij	11.294 h
		10	254.03 c	254.08 c	14.632 c	14.635 c
1500	**75**	**0**	190.96 f	177.99 j	12.221 g	11.391 h
		10	201.91 e	188.15 hi	12.922 f	12.041 g
	100	**0**	224.22 d	214.17 f	10.763 hij	10.280 i
		10	293.88 a	282.60 a	14.106 cd	13.565de
1750	**75**	**0**	187.34 fg	181.04 ij	10.277 j	9.931 i
		10	201.57 e	187.55 hi	11.058 hi	10.289 i
	100	**0**	226.28 d	223.22 e	9.310 k	9.184 j
		10	272.29 b	272.56 b	11.203 h	11.214 h

RR= recommended rate , 75 % RR K_2O=72 kg K_2O/fed., 100 % RR K_2O=96 kg K_2O/fed.,

3. Tuber quality

3.1. Effect of IWQ

Irrigation water quantity at 1750 m^3/fed. significantly increased specific gravity, dry matter, total sugars, , starch and vitamin C as well as potassium content in tubers , followed by IWQ at 1500 m^3/fed. in both seasons (Table 10). These results are in the same trend with those reported by **Abdel-Ati *et al*. (2014) , Badawy *et al.* (2019) and El- Metwaly and Mansour (2023)** who indicated that sufficient irrigation water quantity gave the best potato tuber quality.

3.2. Effect of K_2O (RR%)

The highest values of specific gravity, dry matter, total sugars, starch, Vit C and potassium contents in tubers were obtained from K at 100 % RR compared to 75 % RR in both seasons (Table 10).

Therefore, use adequate amount of K fertilizers at optimal rates, resulting in well-shaped tubers with low sugar content and high dry matter content (**Sharma and Arora, 1987**). In addition, potassium is essential for translocation of sugars to the tubers and also to starch synthesis (**Reis and Monnerat, 2000**).

In the current study K treatments enhanced significant increases in potato tuber quality, i.e., specific gravity, dry matter and starch as was detected by **Pauletti and Menarin ,2004** and **Silva and**

Fontes, 2016. Also, K improved percentage dry matter and starch content by activating the starch synthase enzyme, furthermore, K application induced specific gravity of potato tubers **(Westermann *et al.*, 1994)**. These results are in harmony with those obtained by **Alkharpotly and Abdelrasheed (2021) , Gabr *et al*. (2022) and Mansour and El- Metwaly (2023).**

3.3. Effect of HA rates

Treating potato plants with 10 kg /fed. HA increased tuber quality (specific gravity, dry matter, total sugars, starch, Vit C and potassium contents in tubers) compared without HA (Table 10). The application of humic acid enhances potato tuber quality by increasing starch content (**Alenazi *et al.* , 2016**). Also, humic acid may also stimulate root growth and development, leading to better nutrient and water uptake. This could contribute to increased starch synthesis (**El-Damarawy *et al*., 2025**)

The findings are consistent with those published by **Ali *et al.* (2019) and Şanl *et al.* (2024)** indicating that treated potato plants with humic acid produced the best tuber quality as compared to the cheek (without humic acid).

Table (10). Effect of irrigation water quantity, K_2O and humic acid rates on tuber quality at harvest of potato plants during 2024/2025 and 2025/2026 winter seasons

Treatments	Specific gravity (g/cm^3)		Dry matter (%)		Total sugars (%)		Starch (%)		Vitamin C mg/100g FW		Potassium content (%)	
	2024/25 season	2025/26 season	2024/25 season	2025/26 season	2024/25 season	2025/26 season	2024/25 season	2025/26 season	2024/25 season	2025/26 season	2024/25 season	2025/26 season
	Effect of irrigation water quantity (m^3/fed.)											
1000	1.034 d	1.030 d	17.81 d	17.74 d	1.65 d	1.51 d	12.42 c	13.62 b	19.45 d	18.60 c	1.08 d	1.05 c
1250	1.045 c	1.046 c	19.01 c	19.66 c	1.73 c	1.62 c	13.27 b	14.33 a	20.42 c	20.35 b	1.34 c	1.40 b
1500	1.073 a	1.065 b	19.90 b	20.38 b	1.85 b	1.78 b	13.85 a	14.33 a	21.27 b	21.05 a	1.41 b	1.49 a
1750	1.069 b	1.074 a	20.88 a	21.74 a	1.92 a	1.89a	13.81 a	14.51 a	21.67 a	21.15 a	1.46 a	1.49 a
	Effect of K_2O rate (RR%)											
75	1.046 b	1.049 b	18.54 b	19.49 b	1.71 b	1.65 b	12.99 b	13.75 b	20.03 b	19.91 b	1.27 b	1.32 b
100	1.064 a	1.058 a	20.26 a	20.28 a	1.86 a	1.75 a	13.68 a	14.64 a	21.37a	20.66 a	1.38 a	1.39 a
	Effect of humic acid rate (kg/fed.)											
0	1.050 b	1.049 b	18.99 b	19.72 b	1.74 b	1.67 b	13.16 b	13.80 b	20.26 b	20.01 b	1.26 b	1.34 b
10	1.060 a	1.058 a	19.81 a	20.04 a	1.83 a	1.73 a	13.51 a	14.59 a	21.15 a	20.56 a	1.38 a	1.37 a

RR= recommended rate , 75 % RR K_2O=72 kg K_2O/fed., 100 % RR K_2O=96 kg K_2O/fed.,

3.4. Effect of the double interaction between IWQ and Effect of K_2O (RR%)

The interaction between IWQ at 1750 m^3/fed. and K at 100 %RR gave the highest specific gravity, dry matter total sugars, , starch, vitamin C and potassium contents in tubers followed by the interaction between IWQ at 1500 m^3/fed. and the same rate of potassium in both seasons (Table 11).

3.5. Effect of the double interaction between IWQ and HA rates

The best interaction treatment for enhancing specific gravity, total sugars, dry matter, starch, vit C and potassium contents in tubers were obtained with the interaction between IWQ at 1750 m^3/fed. and HA at 10 kg /fed. as soil application , followed by the interaction between IWQ at 1500 m3/fed. and HA at 10 kg /fed. in both seasons. (Table 11). Theses results are harmony with those obtained by **Alenazi *et al.* (2016)** showed that irrigation at 75 % ET water regime and applying 1.5 g/ l HA can increase specific gravity in potato tuber .In addition , **Ali *et al.* (2019)** showed that the interaction between irrigation at 100% ETc and HA at 2.5 g/l recorded the maximum tuber content of starch .

3.6. Effect of the double interaction between Effect of K_2O (RR%) and HA rates

The interaction between K at 100 %RR and HA at 10 kg /fed. as soil application gave the highest values of specific gravity , dry matter, total sugars, starch, vitamin C and potassium contents in tubers (Table 11).

Table (11). Effect of dual interaction on tuber quality at harvest of potato plants during 2023/2024 and 2024/2025 winter seasons

Treatment		Specific gravity (g/cm^3)		Dry matter (%)		Total sugars (%)		Starch (%)		Vitamin C mg/100g FW		Potassium content (%)	
		2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season	2024/2025 season	2025/2026 season
IWQ	**K_2O**	**Effect of the interaction between IWQ (m^3/fed.) and K_2O (RR %)**											
1000	**75**	1.022 g	1.024 e	16.60 f	17.14 f	1.57 f	1.46 e	11.90 e	13.18 e	18.20 g	17.55 d	1.05 e	1.01 f
	100	1.046 e	1.037 d	19.03 d	18.35 e	1.73 d	1.57 d	12.95 d	14.06 bc	20.70 e	19.65 c	1.11 d	1.09 e
1250	**75**	1.039 f	1.037 d	18.02 e	19.25 d	1.65 e	1.52 de	12.85 d	13.61 d	19.65 f	20.05 c	1.31 c	1.38 d
	100	1.051 d	1.054 c	20.01 b	20.07 c	1.81 c	1.73 c	13.70 bc	15.05a	21.20 cd	20.65 b	1.38 b	1.41 c
1500	**75**	1.066 b	1.065 b	19.46 c	20.62 b	1.77 d	1.78 bc	13.57 c	14.30 b	20.85 de	21.00 ab	1.32 c	1.46 b
	100	1.079 a	1.066 b	20.33 b	20.15 c	1.94a	1.78 bc	14.14 a	14.71a	21.70 ab	21.10 ab	1.50a	1.52 a
1750	**75**	1.057 c	1.070 b	20.10 b	20.94 b	1.86 b	1.84 b	13.66 c	13.92 cd	21.45 bc	21.05 ab	1.42 b	1.44 bc
	100	1.080 a	1.077 a	21.67 a	22.55 a	1.98a	1.94 a	13.96 ab	14.75a	21.90 a	21.26 a	1.51a	1.53 a
IWQ	**HA**	**Effect of the interaction between IWQ (m^3/fed.) and HA (kg/fed.)**											
1000	**0**	1.023 g	1.025 e	17.20 e	17.59 f	1.60 e	1.46 e	12.25 e	13.35 d	18.80 d	17.85 e	1.02 f	1.04 d
	10	1.046 e	1.036 d	18.43 d	17.89 f	1.70 d	1.56 d	12.60 d	13.89 c	20.10 c	19.35 d	1.14 e	1.06 d
1250	**0**	1.040 f	1.043 c	18.59 d	19.30 e	1.69 d	1.59 cd	12.90 c	13.83 c	19.75 c	20.35 c	1.28 d	1.40 c
	10	1.050 d	1.048 c	19.44 c	20.02 d	1.78 c	1.65 bc	13.65 b	14.83ab	21.10 b	20.35 c	1.41 b	1.39 c
1500	**0**	1.071 ab	1.059 b	19.51 c	20.52 c	1.80 c	1.73 b	13.76 ab	13.94 c	20.95 b	20.75 bc	1.34 c	1.45 b
	10	1.074 a	1.071 a	20.28 b	20.25 cd	1.91 b	1.84 a	13.95 a	15.07a	21.60 a	21.35 a	1.48 a	1.52 a
1750	**0**	1.067 c	1.071 a	20.67 b	21.49 b	1.88 b	1.89 a	13.76 ab	14.09 c	21.55 a	21.10 ab	1.41 b	1.46 b
	10	1.070 bc	1.076 a	21.10 a	22.00a	1.96 a	1.89 a	13.86 ab	14.58 b	21.80 a	21.21 a	1.52 a	1.51 a
K_2O	**HA**	**Effect of the interaction between K_2O (RR %) and humic acid rates (kg/fed.)**											
75	**0**	1.041 d	1.042 b	18.11 d	19.30 c	1.66 d	1.61 c	12.76 d	13.20 c	19.32 d	19.55 c	1.20 c	1.29 c
	10	1.051 c	1.056 a	18.98 c	19.67 b	1.76 c	1.69 b	13.23 c	14.31 b	20.75 c	20.27 b	1.34 b	1.35 b
100	**0**	1.059 b	1.057 a	19.88 b	20.15 a	1.82 b	1.73 ab	13.57 b	14.41 b	21.20 b	20.47 b	1.32 b	1.39 a
	10	1.069a	1.060 a	20.64 a	20.41 a	1.91 a	1.78 a	13.80 a	14.88 a	21.55 a	20.85 a	1.43a	1.39 a

RR= recommended rate , 75 % RR K_2O=72 kg K_2O/fed., 100 % RR K_2O=96 kg K_2O/fed.,

3.7. Effect of triple interaction among IWQ, K and HA

The interaction among IWQ at 1750 m^3/fed., K at 100 % RR and HA at 10 kg /fed. as soil application highly enhancing specific gravity, dry matter, total sugars, starch, vit C and potassium contents in tubers, followed by the interaction among IWQ at 1500 m^3/fed. , K at 100 % RR and HA at 10 kg /fed. in both seasons (Table 12). The interaction among IWQ at 1000 m^3/fed. , K at 75 % RR, without HA gave the lowest values of nitrate content in tubers in both seasons.

For all the interaction treatments , dry matter of spunta cv ranged from 16.0 to 22.04 % in the 1st season and from 17.89 to 20.60 % in the 2nd season and achieved starch of the same cultivar from 11.70 to 14.20 in the 1st season and from 12.63 to 15.95 in the 2nd season.

Table (12). Effect triple interaction among irrigation water quantity, K_2O and humic acid rates on tuber quality at harvest of potato plants during 2024/2025 and 2025/2026 winter seasons

Treatments			Specific gravity (g/cm^3)	Dry matter (%)	Total sugars (%)	Starch (%)	Vitamin C mg/100g FW	Potassium content (%)
IWQ (m^3/fed.)	K_2O (RR%)	HA (kg/fed.)						
			2024/2025 season					
1000	**75**	**0**	1.011 f	16.00 i	1.52 k	11.70 h	17.10 k	1.00 i
		10	1.034 e	17.21 h	1.62 j	12.10 g	19.30 i	1.10 gh
	100	**0**	1.035 e	18.41 g	1.68 hi	12.80 f	20.50 gh	1.05 hi
		10	1.058 c	19.65 e	1.79 ef	13.10 ef	20.90 e-h	1.18 fg
1250	**75**	**0**	1.033 e	17.46 h	1.63 ij	12.30 g	18.50 j	1.25 ef
		10	1.046	18.58 fg	1.68 hi	13.40 de	20.80 fgh	1.37 cd
	100	**0**	1.047 d	19.72 e	1.75 fg	13.50 d	21.00 d-g	1.32 de
		10	1.055 c	20.30 cd	1.88 cd	13.90 abc	21.40 b-e	1.45 bc
1500	**75**	**0**	1.065 b	18.94 f	1.71 gh	13.45 d	20.40 h	1.20 f
		10	1.068 b	19.99 de	1.83 de	13.70 bcd	21.30 c-f	1.44 bc
	100	**0**	1.078a	20.09 cde	1.89 bc	14.08 a	21.50 a-d	1.49 b
		10	1.081a	20.58 c	1.99 a	14.20 a	21.90 ab	1.52 ab
1750	**75**	**0**	1.056 c	20.04 de	1.78 ef	13.60 cd	21.30 c-f	1.38 cd
		10	1.059 c	20.16 cde	1.94 ab	13.72 bcd	21.60 abc	1.46 b
	100	**0**	1.079a	21.30 b	1.98 a	13.92 abc	21.80 abc	1.45 bc
		10	1.082a	22.04 a	1.98 a	14.01 ab	22.00 a	1.58 a
			2025/2026 season					
1000	**75**	**0**	1.017 f	16.89 i	1.41 f	12.63 j	16.50 i	0.99 h
		10	1.031 e	17.39 i	1.51 def	13.73 gh	18.60 h	1.03 g
	100	**0**	1.033 e	18.30 h	1.52 def	14.07 fg	19.20 g	1.10 f
		10	1.042 d	18.40 gh	1.62 cd	14.06 fg	20.10 ef	1.09 f
1250	**75**	**0**	1.032 e	18.91 g	1.46 ef	13.06 ij	20.00 f	1.38 e
		10	1.043 d	19.60 f	1.58 de	14.17 efg	20.10 ef	1.39 de
	100	**0**	1.055 c	19.70 ef	1.73 bc	14.61 cde	20.70 cd	1.43 d
		10	1.054 c	20.44 cd	1.73 bc	15.50 a	20.60 de	1.40 de
1500	**75**	**0**	1.054 c	20.95 bc	1.73 bc	13.39 hi	20.70 cd	1.40 de
		10	1.076 a	20.30 de	1.84 ab	15.22 ab	21.30 ab	1.52ab
	100	**0**	1.065 b	20.10 def	1.73 bc	14.50 def	20.80 bcd	1.51 bc
		10	1.067 b	20.20 def	1.84 ab	14.93 bcd	21.40 a	1.53ab
1750	**75**	**0**	1.065 b	20.48 cd	1.84 ab	13.72 gh	21.00 a-d	1.41 de
		10	1.076 a	21.40 b	1.84 ab	14.12 fg	21.10 a-d	1.48 c
	100	**0**	1.078 a	22.50 a	1.94 a	14.46 ef	21.20 abc	1.52abc
		10	1.077 a	22.60 a	1.94 a	15.05 abc	21.32 ab	1.55a

RR= recommended rate , 75 % RR K_2O=72 kg K_2O/fed., 100 % RR K_2O=96 kg K_2O/fed.,

4. Conclusion

Under the conditions of sandy soil and during winter plantation, irrigation water quantity at 1500 m^3/fed. and fertilizing potato plants with 75 % of the recommended rate (72 kg K_2O kg/ fed. and humic acid at 10 kg /fed. as soil application) was the best treatment for enhancing plant growth and productivity and KUE. In addition, this treatment led to a relative increase in the total yield by 5.8% and saved water by 250 m^3/fed. compared to the interaction among irrigation with 1750 m^3/fed , with the same amount of K and humic acid in both seasons. However, irrigation at 1750 m^3/fed. and fertilizing with K at 100 % (96 kg K_2O/fed.) and humic acid at 10 kg /fed. produced the best tuber quality. On other side, the maximum water use efficiency was obtained with the interaction among irrigation at 1000 m^3 water/fed., K at 100 % RR and humic acid at 10 kg /feddan in both seasons.

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محاوله لتقليل الإحتياجات المائية للبطاطس بإستخدام بعض الممارسات الزراعية وأثر ذلك على الإنتاجية وجودة الدرنات وكفاءة إستخدام مياه الرى

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أُجريت هذه التجربة في مزرعة خاصة بمنطقة "سين البحرية" (مركز بدر، محافظة البحيرة، مصر) خلال موسمى شتاء 2025/2024، 2026/2025 . وقد ركزت الدراسة على تأثير كميات مياه الري (1000، 1250، 1500، و1750 مترًا مكعبًا/فدان)، ومعدلات البوتاسيوم (بنسبة 75% و100% من المعدل الموصى به، أي ما يعادل 72 و96 كجم بو$_{2}$أ/فدان على التوالي)، وحمض الهيوميك بمعدل صفر ، 10 كجم/ فدان اضافه ارضيه ، وتأثير التفاعلات المشتركة بين هذه العوامل على النمو والإنتاجية، وكفاءة استخدام البوتاسيوم والمياه، وجودة الدرنات للبطاطس الناميه فى الارض الرمليه .وقد صممت التجربة وفق تصميم القطع المنشقة مرتين ، حيث خُصصت كميات مياه الري للقطع الرئيسية، ومعدلات البوتاسيوم للقطع الفرعيه ، ومعدلات حمض الهيوميك للقطع تحت الفرعيه. كان التفاعل الثلاثى بين استخدام مياه الري (بمعدل 1500 متر مكعب/فدان)، وتسميد نباتات البطاطس بنسبة 75% من المعدل الموصى به (أي ما يعادل 72 كجم بو$_{2}$أ/فدان)، وإضافة حمض الهيوميك بمعدل 10 كجم/فدان (إضافة أرضية)، هى المعاملة الأفضل لتعزيز نمو النبات وإنتاجيته وكفاءة استخدام البوتاسيوم.بالإضافة إلى ذلك، أدت هذه المعاملة إلى زيادة نسبية في المحصول الكلى بنسبة 5.8% ووفرت 250 مترًا مكعبًا/فدانًا من المياه مقارنةً بمعاملة التفاعل التي استخدمت مياه ري بمعدل 1750 مترًا مكعبًا/فدانً، مع استخدام نفس معدلات البوتاسيوم وحمض الهيوميك في كلا الموسمين. في حين أدى استخدام كمية مياه ري 1750 م^{3}/فدان، مع التسميد بالبوتاسيوم بمعدل 100% (96 كجم بو$_{2}$أ/فدان) وحمض الهيوميك بمعدل 10 كجم/فدان، إلى الحصول على أفضل جودة للدرنات؛ وقد تم الحصول على أقصى كفاءة لاستخدام المياه بمعامله التفاعل بين كمية مياه الري 1000 م^{3}/فدان، والتسميد بالبوتاسيوم بمعدل 100% من المعدل الموصى به ، وحمض الهيوميك بمعدل 10 كجم/فدان في كلا الموسمين.

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