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Humic acid and potassium feldspar improve growth, yield and head quality of broccoli grown under saline water irrigation

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Abstract---An open field experiment was carried out during the two successive seasons of 2018/2019 and 2019/2020 respectively, at a private farm in Badr City, El-Beheira, Egypt to study the effect of saline irrigation water on growth, yield and quality of broccoli (*Brassica oleracea* L. var. *italica*) cultivar “Marathon” grown in sand soil. During soil preparation, soil was supplied with (2 ton/fed.) of gypsum and (7.8 ton/fed.) of compost, in combination with 2 levels of potassium feldspar (141- 424 kg K₂O/fed.), to supplement sand soil with 100 and 130 unites of K₂O. Three levels of humic acid (2, 4 and 6 L humic acid/fed.) were foliar sprayed after two weeks post transplanting for five times every 10 days. Plants were arranged in three replicates using a randomized complete block design. Control was supplied with full NPK mineral fertilizers, as recommended, and irrigated with saline irrigation water. Our results were showed that saline water decreased growth, yield and quality of control broccoli

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plants in the two growing seasons. On the other hand, foliar application of humic acid and organic soil amendments enhanced performance of broccoli plants grown under saline water. In this respect, gradual significant increases were recorded in fresh weight, plant height, stem length, head diameter and total yield of main head and secondary heads of broccoli plant at (6 L humic acid + 424 kg K₂O/fed.). In terms of heads quality, higher doses of foliar humic acid and potassium feldspar level led to significant improvement in dry matter, N, P, K, vitamin C, total chlorophyll, total soluble solids (TSS), and significant decrease in total phenols of broccoli heads in both growing seasons if compared to control. In conclusion, organic substances play a key role in enhancing soil fertility and minimize the negative impact of saline water on broccoli production in sand soil.

Keywords---broccoli, gypsum, compost, humic acid, yield, TSS, vitamin C, quality

Introduction

Broccoli (*Brassica oleracea*) is an important crucifer crop grown in many countries because of its considerable nutritional value and head quality traits Jeffery and Araya (2009). In addition, it is known as multiple harvesting crops with moderately tolerant to salt stress (Muries et al., 2013; Chevilly et al., 2021). Salinity is an important threat to food sustainability in arid regions that have limited resources for fresh irrigation water (Tripathi et al., 2016; Abdelaziz and Abdeldaym 2019). One-fifth of arable soils are suffering from salinity, either via salt accumulation in soil or through water salinization (Plaut et al., 2013). In connection, an excessive chemical fertilizers application has increased salt accumulation in soil and underground water. Indeed, irrigation with saline water is one of the major causes for soil salinization, especially in sand soils that have high rates of evapotranspiration Rozema and Flowers (2008). Saline water has been reported to decrease water uptake by the root due to the osmotic effect (Hoffmann et al., 2020), which inhibits plant growth and increase yield loss by interrupting cell metabolism and photosynthetic apparatus (Yang et al., 2020; Shahid et al., 2020). However, arable lands subjected to water salinization losses their productivity and quality, mainly in hot climate zones (De Pascale, et al., 2013; Machado and Serralheiro, 2017). To improve crop performance under saline conditions, different management strategies have been used (Hussain, et al., 2019; Ayub et al., 2020). However, classical breeding and continuing genetic engineering activities struggling success of commercial yield production because the physiological complexity of salt tolerance mechanism (Al-Harbi et al., 2017). Hence, a wide range of reports showed that organic soil amendments as a sustainable key in mitigating salt stress (Bello et al., 2021). Several articles indicated that maintaining optimal K⁺/Na⁺ ratios and soil organic matter such as compost, straw, organic manure, green manure, humic substances and biochar enhance plant growth against salt stress condition (Osman and Rady, 2012 ; Assaha, et al., 2017). Furthermore, potassium feldspar, as a natural and economic source for K⁺ Abou- el-Seoud and Abdel-Mageed (2012), who reported that alternate chemical K⁺ and provide plants with low releasing K⁺ additive that improve plant growth against salt stress.

Furthermore, (Saidmoradi et al., 2019) stated that humic acid plays inducing plant metabolism against abiotic stresses which led to improvement in plant growth and increased resistance under salinity. Earlier studies stated that application of compost sustained release of available nutrients to plants for salt-affected soils which promoting soil fertility and plant growth performance under salt stress condition (Ait-El-Mokhtar et al., 2020). Likewise, (Lastiri-Hernández et al., 2019) indicated that gypsum is the most effective amendment in saline soil since it can improve physical, chemical characteristics and increases soil microbial activity (Alcívar et al., 2018). In this respect, (Shaaban et al., 2013) and (Saqib et al., 2020) found that the combination between gypsum and humic acid improves soil chemical traits and biomass of grown crops.

This work aims to improve growth characteristics, yield and heads quality of broccoli plants grown in sand soil and irrigated with saline water under different levels of humic acid and potassium feldspar.

Materials and Methods

Two open filed experiments were carried out in sand soil at a private farm in Badr City, El-Beheira, Egypt. Seeds of broccoli (*Brassica oleracea* L. var. *italica*) cultivar Marathon (Sakata Co., Japan) were sown in trays filled with a mixture of peat moss and vermiculite (1:1 volume) on 2nd and 6th of September 2018 and 2019, respectively. One month later, seedlings were set in plots (10.5 m²) as 50 cm between plants and 70 cm between lines and each plot included 7 lines with 30 plants to each line. The total area of all replicates was 220.5 m² with 630 plants. The previous treatments were arranged in three replicates using a randomized complete block design.

Gypsum was added at rate of (2 ton gypsum/fed.) as a source for calcium (Ca) and sulfur(S) to sand soil Table (1). Gypsum was mixed with (7.8 ton/fed.) of compost Table (2) as a source for nitrogen (120 units N/fed.) + 134 kg rock phosphate, as a source for phosphorous (75 units P₂O₅/fed.), as one single dose. In addition, potassium feldspar, as a source for potassium (K₂O 10.6%), was applied in two levels (141 and 424 kg K₂O/fed.) to complete (100 and 130 unites of K₂O/fed.), respectively.

Table 1. Physiochemical characteristics of the soil

Soil characteristics	Values
Particle size distribution (%)	
Coarse sandy	49.5
Fine sandy	43.3
Silt	4.0
Clay	3.2
Texture	Sand
C.E.C (cmol/Kg)	4.8
pH	7.8
EC (dS/m)	2.9
CaCO ₃ (%)	3.8
O.M (%)	0.3

Table 2. Chemical analysis of compost

Properties	Values
pH	7.69
O.M %	40.10
O.C %	23.25
EC (dS/m)	7.60
Total Nitrogen (%)	1.53
Total phosphorus (%)	0.57
Total potassium (%)	1.09
Humidity %	37.0
C/N ratio	1:15.9
Ash (%)	59.90
Weight of m ³ (kg)	625
Weeds seeds	Nil

Humic acid and NPK mineralization

Three levels of foliar humic acid (2, 4 and 6 L/fed.) were sprayed after two weeks post transplanting, for five times every 10 days, in comparison to control. Regarding mineral fertilization, phosphorus and potassium were added during soil preparation in the form of superphosphate (P₂O₅ 15%), and potassium sulphate (K₂O 48%), while nitrogen amount was divided into equal doses. First dose was applied during soil preparation, while the second dose was applied 6 weeks after planting in the form of ammonium sulphate (N 20.5%). The recommended doses of N: P₂O₅: K₂O were added at (150:75:75 kg/fed.) respectively, according to good agriculture practice. Drip irrigation system and agricultural practices were followed as recommended. Saline water was used to irrigate grown plants as a source for salt stress as shown in Table (3).

Table 3. Chemical analysis of irrigation water

Properties	Values
pH	7.8
EC (mmhos/cm)	4.7
SO ₄ ²⁻ (meq/l)	13.5
Adsorb Na ⁺ (meq/l)	14.2
CO ₃ ²⁻ (meq/l)	4.9
Cl ⁻ (meq/l)	23.4
Na ⁺ (meq/l)	30.3
Ca ⁺⁺ (meq/l)	3.4
Mg ⁺⁺ (meq/l)	7.8

Agronomic growth and yield traits

Five plants were taken randomly at harvest to determine fresh weight (Fw), plant height, stem length and head diameter. For head biomass, total yield of main head weight, total yield of secondary heads and total yield (ton/fed.) were also calculated.

N, P and K content in broccoli heads

To determine N, P and K content in broccoli heads, 200g fresh samples were taken at harvest and oven dried at 72 °C for two days. Later, dried samples were re-weighted to calculate dry weight percentage (%). Nitrogen was analyzed by modified Kjeldahl while total phosphorus was determined by spectrophotometer, total potassium was determined by a flame photometer (Cottenie et al. 1982).

Head quality traits

At harvest, a random sample of 100g fresh weight was taken of broccoli heads from each replicate to determine heads quality. Ascorbic acid was evaluated by using 2,6-dichlorophenolindophenol (DCPIP) according to titration method as described in A.O.A.C. (1975). Total chlorophyll content of heads was evaluated by colorimetric determination as described in method was used by A.O.A.C. (1990). Total phenols were determined by reverse-phase high performance liquid chromatography (HPLC) according to method was used by Stanković (2011). Total soluble solids (TSS) were determined by a hand refractometer according to method was used by A.O.A.C. (1980).

Statistical analysis

All data were statistically analyzed by using a randomized complete block design across the two seasons, with three replications. The treatment means were compared by least significant difference (LSD) test at 0.05 level of variance according to Snedecor and Cochran (1994) and by using Assisat program according to Silva and Azevedo (2009).

Results and Discussion

Saline water could be used to irrigate plants in region with limited fresh water recourses, with an expecting decrease in crop yield, plant growth performance as well as deterioration in soil resources (Feizi et al., 2010). In this respect, improving soil fertility and plant growth might be a good tactic that minimize the negative impact of saline water on crop production and maximize the economic benefits of cultivated crops (Ayub et al., 2020). Here, this work drives to improve salt tolerance of broccoli, as moderate salt tolerant crops, grown in sand soil irrigated with saline water, using organic soil amendments or foliar stimulants.

Effect of humic acid and potassium feldspar on agronomic growth

According to the data in Table (4), our results show the positive effect of humic acid and potassium feldspar on agronomic growth parameters (i.e. fresh weight, plant height, stem length and head diameter) in the two growing seasons. In particular, clear increases in terms of growth characteristics were recorded when broccoli supplied with (6 L humic acid + 424 kg K₂O/fed.), in comparison with other levels and control. Broccoli plants treated with potassium application at (40 kg K₂O/fed.), and followed by (60 kg K₂O/fed.) had significantly increase in fresh weight and plant height (Zaki et al., 2015). Also, foliar humic acid was reported to improve plant growth, root and shoot of treated plants either in normal condition or against salt stress (Vetayasuporn 2006; Rose et al., 2014; Saidimoradi et al., 2019).

Table 4. Effect of different levels of humic acid and potassium feldspar on agronomic growth of broccoli in the two growing seasons

Treatments	Fresh weight (kg)	Plant height (cm)	Stem length (cm)	Head diameter (cm)
First Season (2019)				
2 L HA + 141 kg K ₂ O	2.5d	60.7f	26.3f	17.7e
2 L HA + 424 kg K ₂ O	2.7c	64.7e	28.3e	18.7de
4 L HA + 141 kg K ₂ O	2.8c	73.3d	30.3d	19.7cd
4 L HA + 424 kg K ₂ O	3.2b	77.7c	31.7c	20.3bc
6 L HA + 141 kg K ₂ O	3.1b	81.7b	32.7b	21.3ab
6 L HA + 424 kg K ₂ O	3.5a	85.3a	34.3a	22.3a
Control	2.1e	53.3g	24.7g	15.3f
Second Season (2020)				
2 L HA + 141 kg K ₂ O	2.6f	61.3f	26.7e	18.3e
2 L HA + 424 kg K ₂ O	2.8e	65.3e	28.7d	19.3de
4 L HA + 141 kg K ₂ O	2.9d	74.7d	30.7c	20.3cd
4 L HA + 424 kg K ₂ O	3.3c	78.7c	32.3b	20.7bc
6 L HA + 141 kg K ₂ O	3.4b	82.7b	33.3b	21.7ab
6 L HA + 424 kg K ₂ O	3.7a	86.7a	34.7a	22.7a
Control	2.2g	55.7g	25.3f	16.3f

HA Humic Acid, Values in column sharing similar letters are not significant at $p < 0.05$

On the other hand, broccoli plants irrigated with saline water resulted a significant reduction in growth and yield in comparison to plants treated with different concentrations of humic acid and both levels of potassium feldspar. This result state the adverse effect of salt stress on plant growth and development (Al Kharusi et al., 2019). Several reports showed that salinity decreases root mass of plants subjected to salt stress which directly affect plant growth and metabolism (Munns et al., 2020).

Effect of humic acid and potassium feldspar on yield

Likewise, significant increase in yield components (i.e. main head weight, secondary heads weight, total yield of main head, total yield of secondary heads and total yield), was observed in plants treated with foliar humic acid and potassium feldspar at (6 L humic acid + 424 kg K₂O/fed.), if compared to other treatments and control Table (5). In this respect, it is important to mention that humic acid is an organically charged bio-stimulant that significantly affects plant growth and yield development (Nardi et. al., 2004). These results could be explained based on fact that humic acid stimulates growth and yield of broccoli through cell respiration, photosynthesis, protein synthesis, enzyme activities and nutrient uptake (Fahramand et al., 2014). Potassium feldspar contains approximately (11% K₂O), therefore it is a possible K-source for crop production Badr (2006). However, (Naher et al., 2014) recorded that application of different nutrients exhibited significant influence on yield of broccoli in term of marketable head yield compared with control.

Table 5. Effect of different levels of humic acid and potassium feldspar on yield traits of broccoli in the two growing seasons

Treatments	Main head weight (g)	Secondary heads weight (g)	Total yield of main head (ton/fed.)	Total yield of secondary heads (ton/fed.)	Total yield (ton/fed.)
First season (2019)					
2 L HA + 141 kg K ₂ O	420f	559f	4.8f	6.4f	11.2f
2 L HA + 424 kg K ₂ O	450e	581e	5.1e	6.6e	11.7e
4 L HA + 141 kg K ₂ O	475d	594d	5.4d	6.8d	12.2d
4 L HA + 424 kg K ₂ O	495c	626c	5.7c	7.2c	12.9c
6 L HA + 141 kg K ₂ O	513b	647b	5.9b	7.4b	13.3b
6 L HA + 424 kg K ₂ O	538a	678a	6.2a	7.8a	14.0a
Control	355g	475g	4.1g	5.4g	9.5g
Second season (2020)					
2 L HA + 141 kg K ₂ O	421f	561f	4.8f	6.4f	11.2f
2 L HA + 424 kg K ₂ O	451e	586e	5.2e	6.7e	11.9e
4 L HA + 141 kg K ₂ O	477d	604d	5.5d	6.9d	12.4d
4 L HA + 424 kg K ₂ O	495c	626c	5.7c	7.2c	12.9c
6 L HA + 141 kg K ₂ O	514b	663b	5.9b	7.6b	13.5b
6 L HA + 424 kg K ₂ O	540a	688a	6.2a	7.9a	14.1a
Control	356g	476g	4.1g	5.4g	9.5g

HA Humic Acid

Potassium is the most abundant inorganic chemical in plant that has several physiological functions, including controlling water, nutrient and metabolite transport and stress responses according to Sardans and Peñuelas (2021). This natural source for potassium in soil plays a main role to improve plant salt stress tolerance. In term of the effect of potassium on plant growth and development, Sarhan and Abd El-Gayed (2017) found that adding potassium at (400 kg feldspar/fed.) combined with (10 kg humic acid/fed.) had significant increase in plant height and seed cotton yield. This in harmony with (Zaki et al., 2015) who noticed that potassium application at (40 kg K₂O/fed.), and followed by (60 kg K₂O/fed.) had significant increase in yield of broccoli plants. In connection, (Islam et al., 2010) mentioned that potassium application had significant effect on broccoli yield with increasing K level up to (200 kg K/ha.). These reports present, the importance of potassium on tomato grown under salt stress condition through reducing Na⁺ accumulation in tomato tissues Abdelaziz and Abdeldaym (2019).

Effect of humic acid and potassium feldspar on nutrient uptake

As shown in Table (6), regarding the effective of foliar humic acid and potassium feldspar on macronutrient content of broccoli in the two growing seasons, humic acid and potassium feldspar were effected on macronutrient uptake (i.e. nitrogen, phosphorus and potassium), data were recorded that using foliar humic acid and potassium feldspar at (6 L humic acid + 424 kg K₂O/fed.) had significant increase in (N, P and K) content in broccoli heads among other treatments.

Table 6. Effect of different levels of humic acid and potassium feldspar on N, P and K content in broccoli heads in the two growing seasons

Treatments	Nitrogen (%)	Phosphorus (%)	Potassium (%)
	Frist season (2019)		
2 L HA + 141 kg K ₂ O	2.42f	0.41f	2.41c
2 L HA + 424 kg K ₂ O	2.83e	0.52e	2.87b
4 L HA + 141 kg K ₂ O	3.13d	0.65d	2.93b
4 L HA + 424 kg K ₂ O	3.35c	0.73c	3.03b
6 L HA + 141 kg K ₂ O	3.71b	0.83b	3.12ab
6 L HA + 424 kg K ₂ O	3.92a	0.95a	3.34a
Control	1.18g	0.36g	1.33d
Treatments	Second season (2020)		
2 L HA + 141 kg K ₂ O	2.65f	0.46f	2.67d
2 L HA + 424 kg K ₂ O	3.05e	0.59e	2.96c
4 L HA + 141 kg K ₂ O	3.26d	0.67d	3.08bc
4 L HA + 424 kg K ₂ O	3.42c	0.78c	3.15b
6 L HA + 141 kg K ₂ O	3.77b	0.85b	3.23b
6 L HA + 424 kg K ₂ O	3.95a	0.96a	3.45a
Control	1.22g	0.38g	1.38e

HA Humic Acid, Values in column sharing similar letters are not significant at $p < 0.05$

Foliar and soil applications of humic acid raised macro and micro-nutrient contents of plant organs Khaled and Fawzy (2011). Moreover, humic acid has been reported to stimulate plant enzymes/hormones and improve soil fertility in an ecologically and environmentally benign manner (Sarir et al., 2005) as well as reduction of phytotoxicity, deficit, and impact of physiological processes over the yield Abdelaziz and Abdeldaym (2019). Also, Selim and Mosa (2012) recorded that using humic substances application at (120 L/ha.) due to significant increase in (N, P and K) content in broccoli heads under sandy soil condition and enhanced soil fertility. (Zaki et al., 2015) said that potassium application had significant increase in (N, P and K) content in broccoli heads by (adding 40 kg K₂O/fed.) and followed by (60 kg K₂O/fed.) under sandy soil condition.

Effect of humic acid and potassium feldspar on heads quality

Data in Table (7), regarding the effect of humic acid and potassium feldspar on head quality traits (i.e. vitamin C, dry matter, total chlorophyll and TSS) were determined in broccoli heads in the two growing seasons, data were reported that foliar humic acid and potassium feldspar at (6 L humic acid + 424 kg K₂O/fed.) led to significant increase in (vitamin C, dry matter, total chlorophyll and TSS) among other treatments. On the other hand, un-treated broccoli plants (Control), presented higher total phenols concentration than those plants treated with humic acid and potassium feldspar. The lowest values of total phenols were observed with (6 L humic acid + 424 kg K₂O/fed.). This could be justified according to the beneficial effect of humic acid and potassium feldspar in improving physical, chemical, and biological properties of sandy soils Mikkelsen (2005).

Table 7. Effect of different levels of humic acid and potassium feldspar on quality traits of broccoli heads in the two growing seasons

Treatments	Vitamin C (mg/100g Fw)	Dry matter (%)	Total chlorophyll (mg/100g Fw)	Total phenols (mg/100g Fw)	TSS (°Brix)
First season (2019)					
2 L HA + 141 kg K ₂ O	96.5f	13.5f	68.7f	62.3b	5.8d
2 L HA + 424 kg K ₂ O	103.0e	15.1e	74.8e	59.6c	6.2cd
4 L HA + 141 kg K ₂ O	110.6d	16.3d	80.8d	55.6d	6.8c
4 L HA + 424 kg K ₂ O	116.6c	17.1c	86.7c	52.5e	7.6b
6 L HA + 141 kg K ₂ O	120.5b	18.7b	89.9b	47.7f	8.3ab
6 L HA + 424 kg K ₂ O	125.6a	19.9a	92.2a	41.6g	8.8a
Control	75.5g	12.2g	60.6g	103.3a	5.0e
Second season (2020)					
2 L HA + 141 kg K ₂ O	97.9f	13.6f	70.9f	61.2b	6.0d
2 L HA + 424 kg K ₂ O	103.4e	15.3e	75.2e	58.4c	6.3d
4 L HA + 141 kg K ₂ O	111.4d	16.5d	81.2d	54.3d	6.9c
4 L HA + 424 kg K ₂ O	117.3c	17.3c	87.3c	51.2e	7.8b
6 L HA + 141 kg K ₂ O	121.4b	19.3b	90.2b	46.3f	8.3b
6 L HA + 424 kg K ₂ O	126.1a	20.4a	92.8a	40.2g	8.9a
Control	73.8g	12.4g	61.3g	105.6a	5.3e

HA Humic Acid, Fw Fresh weight, TSS Total Soluble Solids, Values in column sharing similar letters are not significant at $p < 0.05$

Humic acid was proved to reduce toxic effects of salts on many plants i.e. soybean, wheat, rapeseed, forage, turnip and mustard (Masciandaro et al., 2002; Albayrak and Camas, 2005; Ozkutlu et al., 2006). Earlier, (Lützwow et al., 2006) mentioned that humate is most conventional material increasing nutrient elements, in plant organs. In this respect, it could be expected that these improvement in plant nutritional status reflected positively on enhancing quality of broccoli heads. Also, Yildirim (2007) recorded that foliar application of humic acid led to significant increase in (total yield and TSS) of tomato plants and chlorophyll in pepper according to (Karakurt et al., 2009). Moreover, Selim and Mosa (2012) mentioned that using humic substances application at (120 L/ha.) had significant increase in broccoli heads quality such as (vitamin C and TSS) under sandy soil condition. In term of the effect of potassium on plant quality, (Zaki et al., 2015) reported that increasing potassium at (40 kg K₂O/fed.), and followed had significant effect on broccoli heads quality (weight, diameter and dry matter) and chemical broccoli head composition (vitamin C and TSS). Also, Sarhan and Abd El-Gayed (2017) found that using potassium application at (400 kg feldspar/fed.) combined with (10 kg humic acid/fed.) had significant increase in total chlorophyll of cotton plant and improving soil fertility.

Conclusion

Foliar application of humic acid improved agronomic growth, total yield and heads quality of broccoli plants under saline water irrigation condition. However, soil organic application such as potassium feldspar could be a good alternative for mineral fertilizers in sand soils. These effects could be related to the beneficial effects of organic amendments to improve soil fertility and decreasing the damage of saline irrigation water.

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