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Reducing the Salt Effect on Maize Plant Through the External Addition of Melatonin and Soil Addition of Vermicompost and Potassium Humate

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ABSTRACT

Salinity stress poses a significant challenge in the Egyptian agricultural sector, contributing to physiological disorders in plants. To address this issue, two field trials were conducted over consecutive seasons (2022-2023) aiming to evaluate the impact of various soil amendments, including vermicompost and potassium humate, along with a control group, as the main factor. Additionally, external applications of melatonin hormone at different concentrations (0.0, 50, 100 mmol L^{-1}) were introduced as subplots, on maize grown on salt affected soil. The growth characteristics of the plants, such as fresh and dry weights and leaf area, were assessed. Additionally, the yield and its components, including the number of seeds per cob, the weight of 1000 seeds and seed yield, were also measured. Also, the soil fertility was assessed by determining the availability of nutrients, including nitrogen (N), phosphorus (P), and potassium (K). The results indicate that potassium humate was the most effective soil addition in terms of enhancing plant performance and productivity, followed by vermicompost, with the control treatment showing the least favorable outcomes. Additionally, as the concentration of melatonin increased, there was a corresponding increase in the values of all studied parameters related to plant performance and productivity, contrasting with the control group which exhibited the lowest values. Generally, the combined treatment of potassium humate and melatonin at rate of100 mmol L^{-1} resulted in the maximum values of growth parameters and productivity of maize plant. Finally, these findings provide valuable insights for sustainable agricultural practices in salinity-affected regions.

Keywords: Salinity, Vermicompost, Potassium-humate, Melatonin, Maize

INTRODUCTION

Salinity stress is a pervasive challenge in agricultural ecosystems, particularly in regions like Egypt, where it poses a substantial threat to plant health and productivity. This environmental condition arises when soil accumulates excessive salts, leading to physiological disturbances in plants. The detrimental effects of salinity include impaired nutrient absorption, water imbalance, and oxidative stress, ultimately hindering plant growth and yield (Jouyban, 2012).

In addressing the complex issue of salinity stress, researchers have explored alternative approaches to mitigate its impact on plants. This study focuses on the potential benefits of employing soil amendments, specifically vermicompost and potassium humate, along with the application of melatonin hormone. These amendments are considered potential strategies to enhance plant tolerance to salinity, promoting growth and productivity even in challenging soil conditions.

Vermicompost, a nutrient-rich organic fertilizer produced through the decomposition of organic matter by earthworms, is known for improving soil structure and nutrient availability (Lim *et al.* 2015). Potassium humate, a substance derived from humic acid and potassium, has shown promise in enhancing plant resilience to environmental stressors (Kadam *et al.* 2011). Melatonin, a hormone well-known for its role in regulating circadian rhythms in plants, is explored for its potential to alleviate salinity-induced stress (Nawaz *et al.* 2016).

Maize, *Zea mays* L., holds the position of the third most significant cereal crop globally, trailing only wheat and rice. This status extends to its importance in Egypt as well. The maize grain serves a multitude of purposes, being extensively utilized in the production of corn starch, corn oil, corn syrup, dextrose, corn flakes, gluten, lactic acid and grain cake (Awwad *et al.* 2015). These products find applications in diverse industries such as textiles, foundries, fermentation, and the food sector. The surge in the poultry and livestock industry has further led to a substantial increase in maize consumption in animal feeds. Recognized as a lucrative grain crop, maize stands out as one of the most versatile globally (El-Sherpiny *et al.* 2020).

The objective of this research work is to comprehensively evaluate the effectiveness of vermicompost, potassium humate, and melatonin in enhancing the tolerance of maize plants to salinity stress. By understanding how these amendments and hormone applications influence maize plant growth, nutrient uptake, and overall productivity, the study aims to contribute valuable insights for developing sustainable agricultural practices in salinity-affected regions.

MATERIALS AND METHODS

Two field trials were conducted over consecutive seasons (2022-2023) at the Experimental Farm, Agricultural Research Station (ARS), Tag El-Ezz village, Egypt (31°31' 47.64" N latitude and 30°56' 12.88" E longitude) aiming to evaluate the impact of various soil amendments, including vermicompost at rate of 1.5 ton fed^{-1} and potassium

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humate15 kg fed^{-1}, along with a control group, as the main factor. Additionally, external applications of melatonin hormone at different concentrations (0.0, 50, 100 mmol L^{-1}) were introduced as subplots, on maize grown on salt-affected soil having EC value of 6.25 dsm^{-1}. The attributes of the initial soil are outlined in Table 1, with the soil sample analysis conducted using standard methods as per the protocols derived from Smith and Mullins, (1991). The attributes of the examined vermicompost are presented in Table 2, whereas the properties of potassium humate are documented in Table 3.

Table 1. Characteristics of initial soil

Properties	Values
Sand	18.0
Silt	33.0
Clay	49.0
Textural class is clay	
EC dSm^{-1}	6.25
pH**	7.99
$CaCO_3$ %	2.130
Organic matter, %	1.35
Nitrogen , mgKg^{-1}	50.2
Phosphorus , mgKg^{-1}	11.5
Potassium , mgKg^{-1}	214

Table 2. Characteristics of the studied vermicompost

Properties	Values
pH	6.00
EC, dSm^{-1}	4.25
P , mg kg^{-1}	1.72
K, mg kg^{-1}	1.23
C:N ratio	10.8
Total C, %	17.3
Total N, %	1.60

Table 3. Characteristics of the studied potassium humate

Humic acid,%	Moisture,%	Water solubility,%	pH	Appearance
70	15	100	8.9	Black

Experimental set up

Maize seeds of the "Cv Single Hybrid 10" variety were planted on April 29th in both seasons using a split-split-plot design with three replicates. The sub-plot area for the experiment was 9.0 m². One month before cultivation, vermicompost was applied based on the aforementioned treatments. Additionally, potassium humate was introduced 30 days after sowing. All plots received calcium superphosphate (6.6%P) at a rate of 30 kg fed-1 during the preparation stage, which took place one month before sowing. Subsequently, ammonium nitrate (33.5% N) was incorporated at a rate of 120 kg fed-1 30 days after sowing. Finally, potassium sulfate (39.8% K) was administered at a rate of 50 kg fed-1 before the fourth irrigation. Melatonin was externally applied following the specified treatments, commencing from the third irrigation and administered three times at 10-day intervals. In addition to melatonin application, traditional agricultural practices were carried out in accordance with MASR recommendations. The harvest process took place on August 19th.

Measurement traits

At the 70-day mark from sowing, various parameters were measured, including plant height cm), fresh and dry weights (g plant^{-1}), leaf area (cm^2 plant^{-1}). Leaves' nitrogen (N), phosphorus (P), and potassium (K) percentages were determined following the methods described by Walinga *et al.* (2013), utilizing the Kjeldahl method for nitrogen, spectrophotometer for phosphorus, and flam photometer for potassium. Additionally, chlorophyll (a&b) and carotene content (mg g^{-1}) were determined simultaneously, following the protocol outlined by Val *et al.* (1986). Proline (µg.g^{-1} F.W) and malondialdehyde (MDA, µmol.g^{-1} F.W) levels were also assessed at the 70-day mark, following the methodologies of Ábrahám *et al.* (2010) and Draper and Hadley (1990), respectively. Superoxide dismutase (SOD, unit mg^{-1} protein^{-1}) and catalase enzyme (CAT, unit mg^{-1} protein^{-1}) activities were estimated after 70 days from sowing, utilizing the standard methods described by Alici and Arabaci (2016).

Upon reaching the harvest stage, various measurements were taken, including weight of cob (g), cob length and diameter (cm), number of seeds cob^{-1} and weight of 1000 seeds (g).The harvest index was calculated based on the specified equation.

$$\text{Harvest index} = \frac{\text{Economical yield (grain yield)}}{\text{Biological yield (grain + straw yields)}} \times 100$$

Nitrogen (N), phosphorus (P), and potassium (K) percentages were assessed in the seeds using the previously mentioned methods with leaves. Additionally, protein and total carbohydrates (%) in the grain were assessed following the standard methods outlined in AOAC (2000). Crude protein content was calculated by multiplying the nitrogen percentage in maize seeds by 5.75.

Post-harvest soil analyses, including the determination of available nitrogen, phosphorus, and potassium, were conducted using the Kjeldahl method for nitrogen, spectrophotometer for phosphorus, and flam photometer for potassium (Smith and Mullins, (1991).

Statistical analysis

The statistical analysis of the data was performed using CoStat version 6.303, copyrighted (1998-2004), in accordance with the methodology outlined by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Growth criteria and chemical constituents

Data of Tables 4 and 5 illustrate the effect of vermicompost, potassium humate and melatonin on maize plant's growth criteria (Table 4) as well as chemical constituents in maize tissues and photosynthetic pigments (Table 5) after 70 days from sowing during two successive seasons (2022-2023). The data show that the potassium humate treatment led to the highest values of plant height cm), fresh and dry weights (g plant^{-1}), leaf area (cm^2 plant^{-1}), leaves N, P, K (%),chlorophyll (a&b) and carotene content (mg.g^{-1}) followed by vermicompost treatment and lately control treatment. Regarding foliar application, the plants sprayed with melatonin at rate of 100 mmol L^{-1} had the highest values of plant height cm), fresh and dry weights (g plant^{-1}), leaf area (cm^2 plant^{-1}), leaves N, P, K(%),chlorophyll (a&b) and carotene content (mg.g^{-1}) followed by those sprayed with melatonin at rate of 50 mmol L^{-1}, while the corresponding plants grown without melatonin (control) possessed the lowest values. Therefore, it can be noticed from the data in Tables 4 and 5 that the maximum values were recorded with the combined treatment of potassium humate x spraying melatonin at rate of 100 mmol L^{-1}. The observed effects on maize plant growth and chemical constituents, as illustrated in Tables 4 and 5, stem from the distinctive properties of potassium humate, vermicompost, and melatonin. Potassium humate enhances growth by improving nutrient uptake, resulting in elevated plant height, fresh and dry weights, and leaf area. Vermicompost, acting as a slow-release fertilizer, enriches the soil with essential nutrients, contributing to overall plant vigor. Melatonin, applied foliarly, serves as a growth regulator and facilitates nutrient absorption under salinity conditions. The combined treatment of potassium humate and melatonin at a rate of 100 mmol L^{-1} demonstrates superior outcomes, suggesting a potential synergistic effect between the substances, emphasizing the importance of integrated approaches for optimizing plant growth and productivity under salinity conditions. These results are in harmony with those of Ye *et al.* (2016); Akhtar *et al.* (2022).

Table 4. Effect of vermicompost, potassium humate and melatonin on maize plant's growth criteria after 70 days from sowing during two successive seasons (2022-2023)

Treatments		Plant height, cm		Fresh weight, g plant^{-1}		Dry weight, g plant^{-1}		Leaf area, cm^2	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Main									
Control		192.42c	198.44c	904.44c	924.67c	225.33c	231.33c	575.33a	584.44c
Vermicompost		208.53b	214.64b	953.67b	974.22b	246.67b	252.33b	605.67a	617.67b
Potassium humate		217.92a	224.30a	988.00a	1015.00a	262.56a	268.67as	619.44a	627.89a
LSD at 5%		2.47	4.33	12.55	12.54	2.95	3.05	N.S	6.76
Sub									
Control		204.36b	210.52b	937.78b	960.33b	241.67b	247.67b	593.89a	603.00b
Melatonin (50 mmol L^{-1})		205.78ab	211.96b	947.11b	969.33b	244.67b	250.33b	600.89a	611.00ab
Melatonin (100 mmol L^{-1})		208.73a	214.91a	961.22a	984.22a	248.22a	254.33a	605.67a	616.00a
LSD at 5%		3.28	2.77	13.05	13.23	3.45	3.39	N.S	10.09
Interaction									
Control	Control	191.46	197.34	894.67	915.33	220.67	226.67	570.00	579.33
	Melatonin (50 mmol L^{-1})	192.14	198.34	904.00	922.00	224.67	230.67	577.00	585.67
	Melatonin (100 mmol L^{-1})	193.67	199.65	914.67	936.67	230.67	236.67	579.00	588.33
Vermicompost	Control	204.17	210.05	934.33	953.33	243.67	249.67	596.00	606.67
	Melatonin (50 mmol L^{-1})	207.08	213.16	949.00	971.67	246.67	251.67	608.00	620.67
	Melatonin (100 mmol L^{-1})	214.35	220.72	977.67	997.67	249.67	255.67	613.00	625.67
Potassium humate	Control	217.46	224.16	984.33	1012.33	260.67	266.67	615.67	623.00
	Melatonin (50 mmol L^{-1})	218.12	224.39	988.33	1014.33	262.67	268.67	617.67	626.67
	Melatonin (100 mmol L^{-1})	218.18	224.35	991.33	1018.33	264.33	270.67	625.00	634.00
LSD at 5%		5.68	4.79	22.60	22.92	5.98	5.87	24.04	17.48

Means within a row followed by a different letter (s) are statistically different at a 0.05% level

Table 5. Effect of vermicompost, potassium humate and melatonin on chemical constituents in maize tissues and photosynthetic pigments after 70 days from sowing during two successive seasons (2022-2023)

Treatments		N, %		P, %		K, %		Chlorophyll a, mg.g^{-1}		Chlorophyll b, mg.g^{-1}		Carotene, mg.g^{-1}	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Main													
Control		2.72c	2.87c	0.315c	0.329c	2.49c	2.62c	0.869c	0.904c	0.590c	0.602c	0.532c	0.540c
Vermicompost		3.10b	3.26b	0.352b	0.367b	2.82b	2.97b	0.947b	0.988b	0.635b	0.647b	0.572b	0.583b
Potassium humate		3.28a	3.45a	0.372a	0.388a	3.19a	3.35a	1.032a	1.071a	0.705a	0.719a	0.619a	0.628a
LSD at 5%		0.11	0.01	0.010	0.004	0.04	0.04	0.023	0.020	0.016	0.017	0.007	0.011
Sub													
Control		2.96b	3.10b	0.338c	0.353c	2.75b	2.89b	0.927c	0.966c	0.632c	0.645c	0.560c	0.569c
Melatonin (50 mmol L^{-1})		3.06a	3.22ab	0.345b	0.359b	2.87a	3.01a	0.948b	0.986b	0.644b	0.655b	0.575b	0.584b
Melatonin (100 mmol L^{-1})		3.09a	3.25a	0.356a	0.372a	2.89a	3.03a	0.972a	1.011a	0.655a	0.668a	0.588a	0.597a
LSD at 5%		0.10	0.12	0.003	0.004	0.05	0.05	0.011	0.013	0.006	0.008	0.009	0.008
Interaction													
Control	Control	2.60	2.74	0.310	0.323	2.44	2.57	0.859	0.896	0.582	0.594	0.518	0.527
	Melatonin (50 mmol L^{-1})	2.78	2.92	0.312	0.326	2.51	2.64	0.867	0.902	0.591	0.601	0.531	0.538
	Melatonin(100 mmol L^{-1})	2.79	2.94	0.324	0.338	2.54	2.66	0.880	0.914	0.598	0.611	0.546	0.554
Vermicompost	Control	3.06	3.21	0.341	0.355	2.71	2.84	0.913	0.955	0.619	0.632	0.563	0.573
	Melatonin (50 mmol L^{-1})	3.11	3.27	0.355	0.369	2.87	3.02	0.952	0.993	0.638	0.648	0.572	0.583
	Melatonin (100 mmol L^{-1})	3.13	3.30	0.361	0.378	2.89	3.04	0.977	1.016	0.648	0.661	0.581	0.593
Potassium humate	Control	3.21	3.36	0.365	0.380	3.11	3.27	1.008	1.047	0.694	0.708	0.599	0.608
	Melatonin (50 mmol L^{-1})	3.29	3.47	0.368	0.383	3.22	3.38	1.025	1.064	0.702	0.716	0.621	0.630
	Melatonin (100 mmol L^{-1})	3.35	3.51	0.385	0.400	3.25	3.41	1.061	1.104	0.718	0.732	0.635	0.645
LSD at 5%		0.17	0.21	0.006	0.008	0.08	0.08	0.020	0.023	0.010	0.014	0.016	0.014

Means within a row followed by a different letter (s) are statistically different at a 0.05% level

Plant's self-production of antioxidants

Table 6 presents the impact of vermicompost, potassium humate, and melatonin on maize plants' synthesis of proline (µg.g^{-1} F.W) and malondialdehyde (MDA, µmol.g^{-1} F.W) as non-enzymatic antioxidants, along with enzymatic antioxidants, namely superoxide dismutase (SOD, unit mg^{-1} protein^{-1}) and catalase enzyme (CAT, unit mg^{-1} protein^{-1}) after a 70-day growth period in the 2022-2023 seasons. The results reveal a reduction in proline and MDA levels compared to control groups, indicating that both soil addition and foliar treatments mitigate the plant's self-production of these stress indicators. Conversely, SOD and CAT exhibited a different pattern, with potassium humate treatment yielding the highest values, followed by vermicompost, and control treatments. Melatonin foliar application at 100 mmol L^{-1} resulted in the highest SOD and CAT values, followed by the 50 mmol L^{-1} application, while untreated plants exhibited the lowest enzyme activity.

Overall, the most effective performance was observed with the combined treatment of potassium humate and melatonin sprayed at a rate of 100 mmol L^{-1}. These outcomes suggest that the studied substances play a crucial role in modulating antioxidant responses, with the combined treatment demonstrating superior efficacy in alleviating stress indicators and enhancing enzymatic antioxidant activity. Vermicompost, potassium humate, and melatonin collectively play pivotal roles in alleviating the detrimental effects of salinity on maize plants. Vermicompost, rich in organic matter, enhances soil structure and nutrient availability, mitigating salinity stress by promoting robust root development and nutrient uptake (Lim *et al*. 2015). Potassium humate contributes to salinity tolerance by improving water and nutrient retention in the soil, aiding in osmotic regulation and minimizing ion toxicity (Kadam *et al.* 2011). Melatonin, acting as a potent antioxidant and growth regulator, helps mitigate salinity-induced oxidative stress, promoting overall plant health (Nawaz *et al*. 2016).

The combined application of these substances synergistically addresses salinity challenges, fostering a more resilient and productive maize crop by enhancing nutrient utilization, regulating osmotic balance, and combating oxidative damage.

Table 6. Effect of vermicompost, potassium humate and melatonin on plant's self-production of antioxidants and MDA bio-indicator after 70 days from sowing during two successive seasons (2022-2023)

Treatments		Proline, µg.g^{-1} F.W		MDA, µmol.g^{-1} F.W		SOD, unit mg^{-1} protein^{-1}		CAT, unit mg^{-1} protein^{-1}	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Main									
Control		10.54a	10.72a	11.56a	11.79a	52.18c	53.40c	67.45c	68.50c
Vermicompost		9.55b	9.72b	10.65b	10.85b	57.11b	58.34b	72.05b	73.41b
Humate K		8.45c	8.61c	9.81c	10.01c	62.53a	63.49a	83.71a	84.87a
LSD at 5%		0.01	0.11	0.12	0.21	0.72	1.25	0.59	1.29
Sub									
Control		9.81a	9.97a	10.99a	11.21a	55.72c	56.96c	73.54b	74.60c
Melatonin (50 mmol L^{-1})		9.52b	9.70b	10.64b	10.84b	57.02b	58.09b	74.25b	75.48b
Melatonin (100 mmol L^{-1})		9.21c	9.37c	10.39c	10.60c	59.08a	60.19a	75.42a	76.70a
LSD at 5%		0.05	0.15	0.17	0.15	0.71	0.72	1.13	0.76
Interaction									
Control	Control	10.77	10.94	11.84	12.07	50.92	52.17	66.01	67.01
	Melatonin (50 mmol L^{-1})	10.54	10.73	11.55	11.76	52.16	53.37	66.87	67.95
	Melatonin (100 mmol L^{-1})	10.32	10.50	11.30	11.54	53.46	54.67	69.46	70.54
Vermicompost	Control	9.91	10.07	11.11	11.32	55.15	56.42	71.16	72.35
	Melatonin (50 mmol L^{-1})	9.47	9.65	10.56	10.75	56.36	57.53	72.14	73.51
	Melatonin (100 mmol L^{-1})	9.26	9.43	10.28	10.48	59.81	61.08	72.84	74.36
Potassium humate	Control	8.75	8.91	10.02	10.23	61.09	62.30	83.45	84.45
	Melatonin (50 mmol L^{-1})	8.55	8.73	9.81	10.01	62.53	63.37	83.72	84.98
	Melatonin (100 mmol L^{-1})	8.04	8.18	9.60	9.77	63.96	64.80	83.98	85.20
LSD at 5%		0.08	0.27	0.29	0.26	1.23	1.24	1.97	1.31

Means within a row followed by a different letter (s) are statistically different at a 0.05% level.

Yield and its components at harvest stage

Tables 7, 8, and 9 delineate the impact of vermicompost, potassium humate, and melatonin on grain and biological yield (ton ha^{-1}), as well as harvest index (%), as presented in Table 7. Maize yield components, including the weight of cob (g), cob length and diameter (cm), number of seeds cob^{-1} and weight of 1000 seeds (g), are detailed in Table 8. Additionally, grain chemical and biochemical traits such as N, P, K, protein, and total carbohydrates (%) are outlined in Table 9. The results indicate that potassium humate was the most effective soil addition in terms of enhancing maize productivity, followed by vermicompost, with the control treatment showing the least favorable outcomes. Additionally, as the concentration of melatonin increased, there was a corresponding increase in the values of all studied parameters related to plant productivity, contrasting with the control group which exhibited the lowest values. Generally, the combined treatment of potassium humate and melatonin at rate of100 mmol L^{-1} resulted in the maximum values of parameters related to maize plant productivity. The scientific reasons for the observed results were as follows. Potassium is a vital macronutrient for plant growth and development. Humic substances in potassium humate enhance soil structure, nutrient availability, and water retention. The positive effects observed in grain and biological yield and harvest index may be attributed to improved nutrient uptake and utilization by maize plants. Vermicompost is rich in organic matter, essential nutrients, and beneficial microorganisms. Its application enhances soil fertility, promotes nutrient cycling, and provides a favorable environment for plant growth. The positive impact on maize productivity observed in the study aligns with the role of vermicompost in improving soil health and nutrient availability. Melatonin is a multifunctional molecule with roles in plant growth, stress response, and defense mechanisms. Its presence in plant systems can contribute to improved photosynthesis, nutrient uptake, and overall plant vigor. The study's results, indicating increased values with higher melatonin concentrations, suggest a positive correlation between melatonin application and maize productivity. The observed synergistic effect of combining potassium humate and melatonin at a rate of 100 mmol L^{-1} may be attributed to complementary mechanisms. Potassium humate improves soil conditions and nutrient availability, while melatonin contributes to enhanced physiological processes within the plant. Together, they likely create an optimal environment for maize growth and productivity.

The observed trends align with established scientific principles related to nutrient availability, soil fertility, and the physiological effects of melatonin on plant growth (El-Beltagi *et al.* 2023). The combined application of potassium humate and melatonin appears particularly promising for maximizing maize plant productivity under salinity conditions. These results are in agreement with those of Ibrahim and Ali (2018).

Table 7. Effect of vermicompost, potassium humate and melatonin on maize yield during two successive seasons (2022-2023) at harvest stage

Treatments		Grain yield, ton/hectare		Biological yield, ton/hectare		Harvest index, %	
		1st	2nd	1st	2nd	1st	2nd
Main							
Control		5.67c	5.79c	11.56c	11.78c	49.08c	49.12b
Vermicompost		6.11b	6.22b	12.20b	12.43b	50.07b	50.10b
Humate K		6.66a	6.79a	12.72a	13.00a	52.32a	52.22a
LSD at 5%		0.08	0.13	0.25	0.28	0.57	1.40
Sub							
Control		5.98b	6.12b	12.05b	12.28b	49.62b	49.76b
Melatonin (50 mmol L^{-1})		6.20a	6.31a	12.21ab	12.45a	50.76a	50.66a
Melatonin (100 mmol L^{-1})		6.25a	6.37a	12.22a	12.47a	51.08a	51.02a
LSD at 5%		0.08	0.08	0.16	0.11	0.91	0.64
Interaction							
Control	Control	5.49	5.61	11.28	11.47	48.65	48.87
	Melatonin (50 mmol L^{-1})	5.74	5.84	11.68	11.92	49.18	49.02
	Melatonin (100 mmol L^{-1})	5.78	5.91	11.71	11.95	49.40	49.47
Vermicompost	Control	6.00	6.14	12.18	12.42	49.29	49.44
	Melatonin (50 mmol L^{-1})	6.12	6.22	12.20	12.42	50.18	50.10
	Melatonin (100 mmol L^{-1})	6.19	6.31	12.20	12.44	50.75	50.76
Potassium humate	Control	6.46	6.60	12.69	12.95	50.93	50.98
	Melatonin (50 mmol L^{-1})	6.74	6.87	12.73	13.01	52.93	52.85
	Melatonin (100 mmol L^{-1})	6.76	6.89	12.74	13.03	53.09	52.84
LSD at 5%		0.13	0.14	0.27	0.19	1.57	1.11

Means within a row followed by a different letter (s) are statistically different at a 0.05% level

Table 8. Effect of vermicompost, potassium humate and melatonin on maize yield components during two successive seasons (2022-2023) at harvest stage

Treatments		Weight of cob, g		Cob length, cm		Cob diameter, cm		No. seeds per cob		Weight of 100 grain, g	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Main											
Control		164.57c	167.70c	17.59c	18.53c	2.93c	3.12a	295.33c	302.11c	38.32c	39.21c
Vermicompost		220.14b	224.51b	19.92b	20.86b	3.40b	3.54a	342.11b	349.44b	41.68b	42.71b
Humate K		245.91a	251.02a	22.38a	23.49a	3.94a	3.47a	384.33a	390.33a	43.85a	44.87a
LSD at 5%		2.60	2.50	0.22	0.44	0.14	N.S	6.15	3.94	1.38	0.10
Sub											
Control		204.74c	209.19c	19.27c	20.12c	3.28b	3.12c	335.44b	342.67b	40.35b	41.26b
Melatonin (50 mmol L^{-1})		210.44b	214.49b	19.85b	20.94b	3.43a	3.38b	339.78b	346.44b	41.57ab	42.60ab
Melatonin (100 mmol L^{-1})		215.44a	219.55a	20.77a	21.81a	3.57a	3.63a	346.56a	352.78a	41.93a	42.93a
LSD at 5%		3.64	3.46	0.34	0.26	0.14	0.18	5.76	5.83	1.35	1.59
Interaction											
Control	Control	161.42	164.96	17.07	17.99	2.70	2.80	293.00	300.00	38.04	38.91
	Melatonin (50 mmol L^{-1})	163.54	166.10	17.49	18.61	3.00	3.17	295.00	301.67	38.35	39.16
	Melatonin (100 mmol L^{-1})	168.75	172.05	18.21	18.98	3.10	3.40	298.00	304.67	38.58	39.55
Vermicompost	Control	215.95	220.59	19.17	19.88	3.30	3.33	336.00	342.67	39.35	40.07
	Melatonin (50 mmol L^{-1})	219.18	223.39	19.89	20.81	3.40	3.50	340.67	349.00	42.72	43.95
	Melatonin (100 mmol L^{-1})	225.28	229.54	20.71	21.88	3.50	3.80	349.67	356.67	42.96	44.12
Potassium humate	Control	236.86	242.04	21.57	22.48	3.83	3.23	377.33	385.33	43.66	44.80
	Melatonin (50 mmol L^{-1})	248.60	253.98	22.16	23.40	3.90	3.47	383.67	388.67	43.66	44.69
	Melatonin (100 mmol L^{-1})	252.28	257.05	23.40	24.58	4.10	3.70	392.00	397.00	44.24	45.13
LSD at 5%		6.30	5.99	0.58	0.45	0.24	0.31	9.98	10.09	2.33	2.76

Means within a row followed by a different letter (s) are statistically different at a 0.05% level

Table 9. Effect of vermicompost, potassium humate and melatonin on seed quality of maize during two successive seasons (2022-2023) at harvest stage

Treatments		N %		P %		K %		Protein %		Carbohydrates %	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Main											
Control		1.62c	1.70c	0.221c	0.231c	1.33c	1.39c	9.30c	9.78c	64.01c	65.01c
Vermicompost		1.85b	1.95b	0.246b	0.258b	1.81b	1.90b	10.66b	11.19b	67.12b	68.37b
Humate K		2.09a	2.19a	0.268a	0.281a	1.97a	2.04a	12.00a	12.59a	68.71a	69.68a
LSD at 5%		0.07	0.20	0.003	0.005	0.10	0.10	0.38	1.14	1.45	0.76
Sub											
Control		1.78b	1.87b	0.240c	0.252b	1.65a	1.72b	10.24b	10.73b	66.04b	67.02b
Melatonin (50 mmol L^{-1})		1.85b	1.94b	0.245b	0.258a	1.71a	1.79ab	10.61b	11.15b	66.79ab	67.87ab
Melatonin (100 mmol L^{-1})		1.93a	2.03a	0.249a	0.261a	1.76a	1.83a	11.12a	11.69a	67.01a	68.18a
LSD at 5%		0.08	0.08	0.003	0.004	n.s	0.11	0.43	0.47	0.82	0.86
Interaction											
Control	Control	1.52	1.60	0.217	0.227	1.28	1.34	8.76	9.20	63.87	64.87
	Melatonin (50 mmol L^{-1})	1.63	1.72	0.221	0.232	1.34	1.41	9.37	9.87	63.92	64.92
	Melatonin (100 mmol L^{-1})	1.70	1.79	0.224	0.235	1.38	1.42	9.78	10.27	64.24	65.26
Vermicompost	Control	1.80	1.88	0.244	0.255	1.78	1.87	10.33	10.79	66.63	67.69
	Melatonin (50 mmol L^{-1})	1.83	1.92	0.247	0.259	1.81	1.88	10.52	11.06	67.26	68.54
	Melatonin (100 mmol L^{-1})	1.94	2.04	0.248	0.261	1.85	1.94	11.14	11.73	67.46	68.88
Potassium humate	Control	2.02	2.12	0.260	0.274	1.89	1.94	11.63	12.21	67.61	68.50
	Melatonin (50 mmol L^{-1})	2.08	2.18	0.269	0.282	1.98	2.07	11.94	12.52	69.20	70.15
	Melatonin (100 mmol L^{-1})	2.16	2.27	0.275	0.288	2.04	2.12	12.44	13.05	69.32	70.38
LSD at 5%		0.13	0.14	0.006	0.006	0.19	0.19	0.75	0.81	1.41	1.50

Means within a row followed by a different letter (s) are statistically different at a 0.05% level

Post-harvest soil properties

The data presented in Table 10 delineates the influence of vermicompost, potassium humate, and melatonin on the availability of soil nutrients, namely nitrogen (N), phosphorus (P), and potassium (K) (mg kg^{-1}), during two consecutive seasons (2022-2023) at the harvest stage. Both vermicompost and potassium humate demonstrated a capacity to enhance the availability of the studied soil nutrients in comparison to the control treatment, which exhibited the lowest values for soil nutrients (N, P, K, mg kg^{-1}). Notably, the vermicompost treatment resulted in the highest levels of soil available nitrogen and phosphorus (mg kg^{-1}), followed by the potassium humate treatment, with the control treatment registering the lowest values.

Conversely, the potassium humate treatment led to the highest levels of soil available potassium (mg kg^{-1}), followed by the vermicompost treatment, with the control treatment exhibiting the least favorable outcomes. Intriguingly, the application of melatonin through spraying did not exert a significant impact on the availability of soil nutrients, including N, P, and K (mg kg^{-1}). This indicates that, in the context of this study, melatonin did not play a substantial role in altering the soil nutrient dynamics at the harvest stage.

The observed variations in soil nutrient availability among the treatments can be attributed to the distinct characteristics of vermicompost and potassium humate. Vermicompost, rich in organic matter and microbial activity, likely contributed to increased nitrogen and phosphorus availability, enhancing soil fertility (Moradi *et al.* 2014). On the other hand, potassium humate, being a source of organic potassium, had a pronounced effect on elevating soil available potassium levels. The control treatment, lacking these amendments, displayed lower nutrient availability (Shujrah *et al.* 2010). Notably, the application of melatonin through spraying did not yield significant changes in soil nutrient levels, suggesting that, in the specific context of this study, melatonin did not exert a discernible influence on soil nutrient dynamics at the harvest stage. The results emphasize the importance of soil amendments in influencing soil nutrient status, with vermicompost and potassium humate showing efficacy in enhancing nutrient availability, while melatonin exhibited no significant impact in this regard.

Table 10. Effect of vermicompost, potassium humate and melatonin on soil available nitrogen, phosphorus and potassium after harvest during two successive seasons (2022-2023) at harvest stage

Treatments		Available N mg.kg^{-1}		Available P mg.kg^{-1}		Available K mg.kg^{-1}	
		1st	2nd	1st	2nd	1st	2nd
Main							
Control		42.29c	42.95c	10.05c	10.35c	223.20c	227.56c
Vermicompost		46.19a	47.04a	11.16a	11.48a	244.09b	247.10b
Humate K		44.74b	45.34b	10.50b	10.81b	249.81a	252.53a
LSD at 5%		0.52	0.46	0.12	0.15	3.16	3.10
Sub							
Control		44.85a	45.46a	10.70a	11.03a	240.24a	243.43a
Melatonin (50 mmol L^{-1})		44.41a	45.12a	10.56a	10.86b	239.26a	243.11a
Melatonin (100 mmol L^{-1})		43.96	44.75a	10.45a	10.75b	237.61a	240.65a
LSD at 5%		N.S	N.S	N.S	N.S	N.S	N.S
Interaction							
Control	Control	42.81	43.39	10.22	10.54	224.83	229.61
	Melatonin (50 mmol L^{-1})	42.37	43.07	10.01	10.31	223.28	227.83
	Melatonin (100 mmol L^{-1})	41.70	42.39	9.91	10.20	221.50	225.26
Vermicompost	Control	46.74	47.43	11.27	11.60	244.83	247.23
	Melatonin (50 mmol L^{-1})	46.06	46.95	11.15	11.46	244.55	248.09
	Melatonin (100 mmol L^{-1})	45.76	46.73	11.05	11.38	242.90	245.97
Potassium humate	Control	45.00	45.57	10.60	10.94	251.04	253.46
	Melatonin (50 mmol L^{-1})	44.80	45.33	10.51	10.82	249.96	253.41
	Melatonin (100 mmol L^{-1})	44.41	45.13	10.38	10.68	248.44	250.71
LSD at 5%		1.22	1.33	0.31	0.25	5.65	6.57

Means within a row followed by a different letter (s) are statistically different at a 0.05% level

CONCLUSION

In conclusion, the study underscores the detrimental impact of salinity stress on Egyptian agriculture and highlights the potential mitigating effects of soil amendments and melatonin hormone application on maize growth and productivity. The superior performance of potassium humate and vermicompost, with potassium humate leading in enhancing soil fertility, suggests their promising role in alleviating salinity-induced physiological disorders. The positive correlation between increasing melatonin concentrations and improved plant parameters further supports the hormone's potential as a stress alleviator. These findings provide valuable insights for sustainable agricultural practices in salinity-affected regions. Moving forward, it is recommended to explore the long-term effects of these interventions.

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تخفيف التأثير الملحي على نباتات الذرة بالإضافة الخارجية للميلاتونين والأرضية للفيرمكمبوست وهيومات البوتاسيوم

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الملخص

إن الإجهاد الملحي يشكل تحديًا كبيرًا في قطاع الزراعة في مصر، اذ انه يساهم في اضطرابات فسيولوجية في النباتات. من أجل معالجة هذه المشكلة، تم إجراء تجربة حقلية في موسمين متتاليين (2022-2023) بهدف تقييم تأثير اضافات التربة المختلفة، مثل مكمورة السماد الدودي (فيرميكمبوست) وهيومات البوتاسيوم، بالإضافة الي معاملة الكنترول، كعامل رئيسي. بالإضافة إلى ذلك، تم تقييم الرش الخارجي لهرمون الميلاتونين بتراكيز مختلفة (0.0، 50، 100 ممول/لتر) كعامل منشق، على نبات الذرة النامية بتربة ملحية. تم تقييم خصائص نمو النباتات مثل الأوزان الطازجة والجافة والمساحة الورقية. بالإضافة إلى ذلك تم قياس المحصول ومكوناته بما في ذلك عدد البذور لكل كوز ووزن 1000 بذرة ومحصول البذور. كما تم تقييم خصوبة التربة عن طريق تحديد مدي صلاحية المغذيات مثل النيتروجين والفوسفور والبوتاسيوم. تشير النتائج إلى أن هيومات البوتاسيوم كانت التعديل الفعّال الأكثر في تحسين أداء النبات وإنتاجيته، يليه السماد الدودي، في حين أظهرت مجموعة الكنترول أقل النتائج. بالإضافة إلى ذلك، وجد انه مع زيادة تركيز الميلاتونين، زادت قيم جميع المعلمات المدروسة المتعلقة بأداء النبات وإنتاجيته، حيث ان مجموعة الكنترول أظهرت أقل القيم. وبشكل عام، أدت المعاملة المشتركة لهيومات البوتاسيوم والميلاتونين بمعدل 100 ممول/لتر إلى الحصول على أعلى قيم لمؤشرات النمو والإنتاجية لنبات الذرة. وفي النهاية، توفر هذه النتائج رؤى قيمة لممارسات زراعية مستدامة في المناطق المتأثرة بالملوحة .