International Journal of Multiphysics
Volume 18, No. 2, 2024
ISSN: 1750-9548

Improving the Performance of Agronomic Traits of Barley (*Hordeum Vulgare*) By Salicylic Acid and Biofertilizers Application

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Abstract

The present study was conducted at the agricultural experimental farm, Fac. of Agric., Zagazig District, Sharkia Governorate, Egypt (Lat.30° 34'59.3" N ;31°31'03" E,9 m above the sea level). The trial was performed during the winter season of 2020/2021 and 2021/2022. The study aimed to find out the effect of salicylic acid (SA) foliar spray-applied in three rates (Check, 150 and 300 ppm) under seven bio-chemical NPK fertilization regimes (Check; chemical NPK 100% recommended dose "RD"; chemical NPK 50 % of the RD; chemical NPK 25 % of the RD; chemical NPK 50 % of the RD + NPK biofertilizers; chemical NPK 25 % of the RD + NPK biofertilizers and NPK biofertilizerson on growth and yield attributes of barley (Hordeum vulgare). The experiment was arranged in a split plot design in three replications with two factors. Results indicated that foliar application of salicylic acid at the rate of 150 ppm operatively increased leaf area, flag leaf area, number of tillers/ m2, as well as number of spikes/ m2 of barley plant comparable with the control and 300 ppm. Similarly, application of the F3 (chemical NPK 50 % of the RD) and F6 (chemical NPK 25% + Bio NPK) fertilization regime, tended to maximize the plant's leaf area. Fertilization at 50% (F3) or 100% (F2) of the recommended quantity of NPK produced the largest number of /tillers/m2 compared to the other fertilization. Eke, number of spikes under the NPK bio-fertilizer (F7) and under chemical NPK 100% chemical fertilizers (F2) were at par, this paves the way for replacing NPK chemical fertilizers entirely or partially with the NPK biofertilizers. It can be concluded that integration of biofertilizers with foliar application of SA is an effective strategy to improve barley performance under the conditions of clay soils in Egypt.

Keywords: Barley; Growth; Salicylic acid; Biofertilizers; K solubilizing bacteria (KSB); Sustainable agriculture.

1. Introduction

Barely (*Hordeum vulgare* L.) is a short season plant belongs to the family Poaceae (Gramineae), which is a large and nearly ubiquitous family of monocotyledonous flowering plants commonly known as true grasses (**Megahed *et al*., 2024**). Barely is the fourth most important cereal crop next to wheat, maize and rice worldwide (**El-Hashash and El-Absy, 2019, Shavanov, 2021 and Hanify *et al*., 2024).**

Eke, barely is a vital cereal crop in arid and semi-arid regions, assumes particular significance in North Africa countries. In Egypt, barely is the main cereal crop next to wheat grown in winter season on a large acrage in the Northern Costal and in the newly reclaimed soils. Barely is one of the four major feed grains (corn, barely, oats and wheat) and is widely used as a feed for livestock. Barely grains may be used as a major source of energy, protein and fiber for ruminants, the percentage of barely used for livestock feed in different countries varies from below 50% to as high as 90%. EU countries and Russia are the major feed barely consumers, followed by Canada, Turkey and Saudi Arabia (**Zhou, 2010; Mastanjevic *et al*., 2019 and El-Wakeel *et al*., 2024**). Barely can also be grown as a dual purpose crop for providing good quality fodder as well as grains, the cutting at early stage (50-55 days after sowing) provides good quality fodder for livestock feeding (**Singh *et al.*, 2017 and Abd El-Lattief *et al.*, 2021).**

Barely have ability to withstand difficult climatic conditions such as drought, heat and salt, thence it is grown prosperously in the rainy regions of Egypt (Northern Costal) and newly reclaimed sandy soils (**Hanif *et al.*, 2024 and El-Wakeel *et al.*, 2024)**

According to the list of countries by barely production in 2022 based on the Food and Agriculture Organization Corporate Statistical Database (https://en.wikipedia.org/wiki/Listof countries by barely production,2023) the total world barely production for 2022 was 154,877,140 metric tonnes, Egypt ranked 62 with barely production 96717 tonnes.

The largest acreage cultivated with barely worldwide was 51.9 million hectares in 2020, that acreage decreased in 2021 by 5.8% compared to 2020 and by 0.3% comparably with year 2015 (**soare *et al.,* 2023**). The outmost barely production worldwide (158.8 million tonnes) was recorded in 2019, at the opposite pole, the lowermost barely production (141.0 million tonnes) was observed in 2018, the drought that affected part of Europe that year hamper the world barely production (**Bindereif *et al.*, 2021 and Soare *et al.*, 2023**). For the next decade, a 2.9% increase in the value of barely production is estimated in 2023 comparably with 2023 (**Future Market insights, 2023**). The uppermost average productivity of barely (3101.3 kg/ha) was recorded in 2017, whilst the lowermost average productivity of barely worldwide (2934.1 kg/ha) was achieved in 2018 (**Soare *et al.*, 2023**). Worldwide, the human consumption of barely and barely products recorded the most significant consumption (152.869 thousand tonnes) in 2019, while the lowest one (136.128 thousand tonnes) was reported in 2018 (**Soare *et al.*, 2023**). The largest quantitave imports recorded worldwide (44.1 million tonnes) were made in 2021 and the lowest (32.8 million tonnes) were made in 2019 (**Soare *et al.*, 2023**). On marketing year (MY) 2024-2025 basis, European Union produced 35% of the global barely production with total production of 50.33 million metric tonnes and ranked first, whilst United States ranked 10th among the top ten producing countries with 2% of the global production and total production of 3.13 million metric tonnes in MY 2024-2025 (http://www.fas.usda.gov/data/production/commodity/0430000)

Salicylic acid (SA) is a phenolic compound commonly occurring in vascular plants, salicylic acid is a beta-hydroxy acid (BHA). SA was initially discovered from the bark of willow tree (*Salix alba*) in 1826 (**Dakhell *et al.*, 2022 and Hanif *et al.*, 2024).** SA protects plants against the oxidative damage, reduced growth, and impaired photosynthetic efficiency brought on by stress (**Dakhell *et al.*, 2022).** SA regulates plant development; it protects plants from environmental stress such as salinity (**Maruri-Lopez *et al.*, 2019**).

High agricultural yields can be attained by supplying salicylic acid, which improves plant growth and germination rates in both salt and stress-free conditions (**Jangra *et al.,* 2022**). SA supplying can have an effect on seed production, stomatal regulation, chlorophyll content and photosynthesis (**Moustakas *et al.*, 2022-2023**). Salicylic acid positively impacts a plant's capacity for withstanding biotic and abiotic stress as well as defensive responses (**Kandoudi and Nemeth-Zamborine, 2022**).

Salicylic acid (SA) as an endogenic phytohormone from phenolic compounds influence many physiological processes like seedling growth (**Ahmed *et al.*,2012**), maintenance of tissue water contents and reduced membrane permeability (**Faroog *et al.*, 2008**), responsive antioxidative system (**Afzal *et al.*, 2008, Guan *et al.,* 2009 and Carvalho *et al.*, 2011**).

Maintaining soil fertility and nutritive capacity in balanced ranges is one of the keystones to increase crop productivity (**Diacono *et al.*, 2013**). Mineral fertilizers are decisive and quick available source of macro nutrients like nitrogen, phosphorous and potassium; but it is of great moment noting the negative impacts of its intensive applications which affects seriously environmental and human health (**Gomaa.,2024**). Hence, all attempts to decrease the high levels of chemical fertilizers, which are frequently used and / or substitute it by the bio-fertilizers are appreciated.

Nitrogen (N) is one of the essential nutrients for field crops, it's practical management as the major element for intensive crop production is of great moment aspect. Among abiotic factors, nitrogen fertilizers are an alpha and omega factors that dominantly impacts barely productivity during early plant growth stages (**Hammad *et al.*, 2022**). Nitrogen deficiency causes stunted growth, pale yellow color as well as drastic reduction in both grain and straw yields. Excess chemical nitrogen appliance has led to the environmental pollution, suppress micro-organisms activity, making the plants more prone to diseases and reduced soil fertility (**Zhang *et al.*, 2022 and Wang *et al.,* 2024**). Field crops only able to use 30-40% of the added amount of nitrogen fertilizers (**Ju *et al.*, 2009 and Hammad *et al.*, 2016**).

Over supplying of nitrogenous fertilizers and the extremely low crop recoveries of fertilizer nutrients (For N, < 10%) caused significant deterioration of both groundwater and soil quality (**Jia *et al.*, 2014 and Islamzade *et al.*, 2023**). Increasing and extending the role of the bio- fertilizers can alleviate the need for the chemical fertilizers and lessen adverse environmental impacts. Bio-fertilizers which fix the atmospheric nitrogen can compensate about 30-50% of the recommended N level (**El-Khawaga *et al.*, 2013; Khattab,2016; Khattab *et al.*,2016; El-Sobky and Desoky; 2017; Abd El-Lattief *et al.*, 2021; Islamzade *et al.*, 2023 and Gomaa, 2024**).

Phosphorus (P) is one of the indispensable nutrients for growth and development of cereal crops including barely, cereal field crops will often take up to 75% of their phosphorus need within 40 days after plant's emergency (**Xin-Kai *et al.*, 2012; Ross and Allan, 2013**). It is estimated that 43% of 130 billion ha of soils worldwide is inadequate in phosphorus content (**Shen, 1998 and Xin-Kai *et al.*, 2012**). Next to N, P is the second most important nutrient in Egyptian agriculture (**Farid *et al.*, 2023**). Plants need P for growth, development, sugar and starch utilization, photosynthesis, nucleus formation and cell division. Phosphorus compounds are involved in both transfer and storage of energy within plants. Energy from photosynthesis and the metabolism of carbohydrates is stored in phosphate compounds for later use in growth and reproduction (**Ross and Allan, 2013; Ibrahim *et al.*, 2023**). An adequate apply of available P in soil is conjoined with increased root growth, that means root system can explore more soil for nutrients and moisture. Phosphorus stimulates root growth and development in seeding stage, thence helps to establish the seedling quickly. P increase the numbers of tillers in cereal crops, eke it improves the ratio of grains to straw (**Majeed *et al.*, 2014**). Movement of the nutrients within the plant and the transportation of energy as well as genetic characters transfer to the following generation are controlled by phosphorus (**Abdelsalam and El-Sanatawy, 2022).**

Sharma *et al.* (2013) attested that P fertilizer utilization is less than 30% because soluble phosphorus is rapidly fixed in the soil ascribed to reacting with free Al^{+3}, Ca^{+2} and Fe^{+3}. Soil microorganisms play a noteworthy role in availability of phosphorus to the plants supplied with organic and/or inorganic P sources (**Wani *et al.*, 2007**). Phosphate solubilizing bacteria (PSB) plays an important role in improving P efficiency of both natural and supplied phosphorus and enhanced field crops productivity (**Khan *et al.*, 2009**). Phosphate solubilizing bacteria inoculation lessen or may minimize the supply with chemical P fertilizers up to 100% depending on soil and climatic conditions (**Fazlullah *et al.*, 2018; Khattab,2019 and Ibrahim *et al.*,2023**). Phosphate solubilizing bacteria (PSB) produce some organic acids in the soil which lessen the soil pH, thence solubilize calcium phosphate complexes.

Potassium (K) ranks third among the three major nutrients, after N and P especially in Egyptian agriculture. K plays an important role in the biophysical and biochemical plant processes, at both the cellular and the whole plant levels (**Amtmann *et al.*, 2005; Hermans *et al.*, 2006 and Adams and Shin, 2014**). K operatively contributes and boost to each of enzyme activation, cell development, metabolism, protein synthesis, maintenance of membrane electric potential, ionic homeostasis, solute transport and cell turgor particularly in the rapidly growing cells (**Pettigrew, 2008; White and Karley, 2010 and Hawkesford *et al.*, 2011**). Continuous apply of K is demandable by plants to maintain higher growth and development (**Zorb *et al.*, 2014; Al Azzawi *et al.*, 2021**). Most of the agriculture soils globally are reportedly deficient in available K (**Lal, 2000 and Romheld *et al.*, 2010**). Crop plant's needs for potassium change throughout the growing seasons; Seedling uptake is low and increases during the late vegetative and flowering stages (**Moore *et al.*, 2015 and Al Azzawi *et al.*, 2021**). Deficit of potassium may result in poor root system growth, hamper leaf development, Fewer grains/spike as well as smaller grain size, thence both yield quantity and quality depress are expectant (**Rengel and Damon, 2008, Prajapati and Modi, 2012**). As the barely plant progressed from tillering to the full maturity stage, a noticeable reduction in soil exchangeable potassium content was observed (**Islamzade *et al*., 2023**). In the soil K is present in various forms, including mineral K, non-exchangeable K, exchangeable K, and solution K (**Rawat *et al*., 2017**), Potassium is absorbed by plants root system as a K^+ ion (**Rahuma *et al*., 2017**), There is a need to find an alternative indigenous source of K and maintain K level in soils for sustainable crop production. It has been reported that some beneficial soil microorganisms such as K solubilizing bacteria (KSB) have attracted the attention of agriculturists as soil inoculum to promote the plant growth and yield (**Kalayu, 2019**). The use of bio fertilizers is an effective approach to minimize the appliance of chemical fertilizers. Bacillus cereus is a potassium (K) solubilizing bacteria which enhances plant growth via increasing nutrient uptake and production of plant hormones (**Narula *et al*., 2005; Zhang *et al*., 2013 and Meena *et al*., 2016).**

Keeping in view the above discussion a field experiment was performed to study the efficacy of salicylic acid foliar rates and NPK fertilization regimes on barely growth and yield attributes.

Materials and Methods

The present study was conducted at the agricultural experimental farm, Fac. of Agric., Zagazig District, Sharkia Governorate, Egypt (Lat.30° 34'59.3" N ;31°31'03" E,9 m above the sea level), the trial was performed during the winter season of 2020/2021 and 2021/2022. The study aimed to find out the effect of salicylic acid (SA) foliar spray-applied in three rates under seven bio-chemical NPK fertilization regimes on growth, yield and yield attributes of barley (*Hordeum vulgare*). Barley sowing was made after sudan grass (*Sorghum sudanese*) as a preceding crop in both seasons. Sowing was done in rows, 15 cm apart and 3m length, each plot area (9m²) included 20 rows. Phosphorus as ordinary superphosphate (15.5 % P_2O_5) was added during seed bed preparation at rate of 15.5 kg P_2O_5/fad. Potassium fertilizer was applied at rate of 24 kg K_2O/ fad as potassium sulphate (48 % K_2O) before sowing. Also, N fertilizer at level of 60 kg N /fad was applied at two dosages before the first and second irrigations (30 and 55 days after sowing "DAS") as Urea (46.5%). The other culture practices were applied as recommended in the experimental area. On December 2nd and 12th in the first and the second seasons, the six rowed barley cultivar (Giza 134) was planted at a rate of 40 kg/ fad. Furrow flood irrigation was conducted at 30-days interval. The experimental site soil's physical and chemical analyses are publicized in Table 1. However, Table 2 display irrigation water chemical analyses in the two growing seasons, Table 3 display mean temperature and humidity during both the growing seasons.

The experiment included three factors. The first factor was foliar application of SA at three concentrations (Check "tap water", 150 and 300 ppm. The second factor was the NPK fertilization regimes. The NPK fertilization regimes included sole NPK chemical fertilization and sole NPK biological fertilization as well as bio-chemical fertilization. The NPK fertilization regimes included the following seven treatments: (F1): Check; without supply fertilizers; (F2): chemical NPK (recommended dose: RD").60, 15.5, 24 kg/fad (RD); (F3): chemical NPK 50 % of the RD; (F4): chemical NPK 25 % of the RD; (F5): chemical NPK 50 % of the RD + NPK biofertilizers; (F6): chemical NPK 25 % of the RD + NPK biofertilizers and (F7): NPK biofertilizers.

Barely plants were foliar sprayed using the aqueous solution of SA (250 L/fad/spray) using hand operated compressed air sprayers. Kinzo, the welting agent was added to the spraying solution in the rate of 100 cm³/20 L tap water. Salicylic acid foliar spray was applied at 30 and 60 DAS. Before sowing, the barley seeds were inoculated with a biofertilizer mixture (*e.g*., Nitrobein biofertilizer containing *Azotobacter* sp. and *Azospirillum* sp. as N_2-fixing bacteria, phosphorien biofertilizer containing *Bacillus megaterium* var. phosphaticum as phosphate-solubilizing bacteria (PSB), and potassiomage as K solubilizing bacteria (KSB). These biofertilizers were commercially produced by General Organization for the Agricultural Equalization Fund, Agriculture Research Center, Ministry of Agriculture, Egypt and were used at the recommended dose of 1 kg fad^{-1} for each biofertilizer.

Experimental design

A split plot design with three replications was used, where SA treatments were allocated in the main plots, whereas the fertilization regimes were assigned to the sub plots.

Recorded data

A. Barley growth attributes

At 50% heading,90 days after sowing (DAS) a plant sample from 1 "m" length (0.15 m^2) was taken from the third row where the following data were recorded:

1. Leaf area (cm^2/plant). Leaf area was determined according to **Lal and Subba Roa (1951)** by using the following equation: blade length x maximum blade width x 0.72 x (mean leaf number/plant).

2. Flag leaf area (cm^2). At 50% heading (90 DAS), 10 flag leaves were randomly chosen determine the area of the flag leaf according to the abovementioned equation.

B- Barley yield attributes

3. Number of tillers/ m^2: It was counted from one square meter using a wooden square.

4. Number of spikes/ m^2: It was counted from one square meter using a wooden square.

D. Statistical analysis

Data were statistically analyzed according to **Gomez and Gomez (1984)** by using **MSTAT-C (1991)** where statistical program Version 2.1 was used for analysis of variance (ANOVA). A combined analysis was undertaken for the data of the two seasons after testing the homogeneity of the experimental errors by Bartellet test **(Steel *et al.*, 1997)**. Treatment means were compared using least significant differences (LSD) test at 0.05 level of probability **(Wallar and Duncan, 1969).** In the interaction tables, capital and small alphabet were used for mean comparison in rows and columns, orderly.

Table 1. Soil mechanical and chemical analyses of the experimental site at 30 cm soil depth in the two seasons*

	Chemical analysis									
	Soluble cations (meq./ L)				Soluble anions (meq./ L)				pH	EC dS\m
	K^+	Na^+	Mg^{++}	Ca^{++}	CO_3^{--}	HCO_3^-	SO_4^{--}	Cl^-		
2020/2021	0.06	7.06	2	3	0	1	3.92	7.2	7.78	1.52
2021/2022	0.3	4.91	2	4	0	1	5.21	5	7.77	0.1

	Mechanical analysis			
	Sand (%)	Silt (%)	Clay (%)	Soil texture
2020/2021	52.50	33.65	13.85	Sandy loam
2021/2022	57.50	38.90	3.60	Sandy loam

Soil-water suspension 1;2.5 Soil water extract 1;5
* Source: Central Laboratory, Faculty of Agriculture, Zagazig University, Zagazig, Egypt

Table 2. Water chemical analyses in the two growing seasons

Water property	Chemical analyses									
	Soluble cations (meq./ L)				Soluble anions (meq./ L)				pH	EC dS\m
	K^+	Na^+	Mg^{++}	Ca^{++}	CO_3^{--}	HCO_3^-	SO_4^{--}	Cl^-		
2021/2020	0.34	26.86	6	10	0	2	23.2	18	8.3	4.18
2022/2021	0.72	15.53	7	8	0	2	4.25	25	7.1	3.51

* Source: Central Laboratory, Faculty of Agriculture, Zagazig University, Zagazig, Egypt

Table 3. Monthly mean minimum and maximum air temperatures, relative humidity and precipitation during the two barely growing seasons*

Month	Temperature (°C)			Relative humidity (%)	Precipitation (mm)
	Min.	Max.	Mean		
2020/2021 season					
November	14.90	22.70	18.30	65.26	4.00
December	12.90	21.70	17.30	59.66	12.00
January	111.50	20.60	16.10	63.33	13.00
February	11.10	20.90	16.00	83.31	8.00
March	13.50	24.10	18.80	51.91	7.00
April	14.10	29.60	21.90	44.39	3.00
May	21.30	38.00	29.70	24.40	2.00
2021/2022 season					
November	15.76	28.57	22.17	64.26	6.78
December	9.89	20.35	15.12	68.59	29.94
January	6.24	17.58	11.91	68.17	28.32
February	7.04	20.44	13.74	67.87	19.77
March	7.36	21.78	14.57	61.32	7.19
April	13.47	32.19	22.83	48.38	3.47
May	16.71	34.33	25.52	44.25	0.70

3. Results and Discussion

Leaf area (cm^2/plant)

Leaf area (cm^2/plant) of barley measured at 90 days after sowing (DAS) as affected by SA rates foliar application and NPK fertilization regimes are compiled in Table (4). Foliar application of SA at the rate of 150 PPM (SA_2) operatively increased leaf area of barley plant (5557.6 cm^2/plant) comparable with the control (SA_1) (3942.2 cm$_2$/plant) and spraying SA at the rate of 300 ppm (SA_3) (3649.9 cm^2/plant) in the 2nd season. Based on the combined analysis results, barley leaf area (cm^2/plant) ranged from 4933.5 cm^2/ plant (SA_2) to 6332.2 cm^2/ plant (SA_1). Similar conclusion was previously drawn by **Shalaby *et al.* (2013)** who reported that the most effective concentration on increasing barley leaf area/plant was 100 mg/L compared with the other concentrations (75, 50, 25 and zero mg/L). The promoter effect of spraying SA on barley plant leaf area was also purported by **Pirasteh-Anosheh *et al.* (2014, 2015), Pan *et al.* (2019) and Jangra *et al.* (2022).**

Table 4. Leaf area/ plant (cm2) of barley as affected by salicylic acid foliar application rates and NPK fertilization regimes in the two seasons and combined analysis

Main effects and interaction	2020/2021	2021/2022	Combined
Salicylic acid rates (SA): Tap water (check) (SA_1)	8722.1	3942.2 b	6332.2
150 ppm (SA_2)	4309.4	5557.6 a	4933.5
300 ppm (SA_3)	7658.1	3649.9 b	5654.0
F .test	NS	**	NS
NPK Fertilization regimes (F):			

Without fertilization (F_1)	10862.0 a	3374.1 d	7118.1 ab
Chemical NPK 100% (F_2) (60: 15,5: 24 kg/fad)	5365 .0ab	4424.6 bc	4894.7 ab
Chemical NPK 50% (F_3)	5561.0 ab	6178.0 a	5869.7 ab
Chemical NPK 25% (F_4)	3990.0 b	3749.4 cd	3869.5 b
Chemical NPK 50% + Bio NPK (F_5)	8103.0ab	3947.7 cd	6052.3 ab
Chemical NPK 25% + Bio NPK (F_6)	8837.0 ab	5661.7 ab	7249.5 a
Biofertilizers (NPK) (F_7)	5558.0 ab	3347.3 d	4452.6 ab
F. test	*	**	*
Interaction SA x F	NS	**	NS

*,** and NS indicate significancy at 0.05 and 0.01 levels and insignificancy of differences, in respective order

Allusive to NPK fertilization regimes, barley leaf area/plant operatively affected by the NPK fertilization regimes. Given the limited amount of N, P and K added from the chemical sources (F_4) *e.g*. 25% of the recommended quantity, the plant's leaf area tended to decrease (3990.0, 3749.4 and 3869.5 cm^2/plant) in the 1st, the 2nd seasons and the meta-analysis.

Ironically, the same treatment combined with the biofertilization of the three nutrients *i.e.* application of the F_6 fertilization regime, tended to maximize the plant's leaf area (8837.0, 5661.7 and 7249.5 cm^2/plant) in the 1st, the 2nd seasons and the pooled analysis results. In the available literature, there is lake of studies about the efficacy of the NPK fertilization regimes on barley leaf area/plant. The interaction efficacy between the SA rates foliar application and the NPK fertilization regimes came to nothing.

Flag leaf area (cm^2)

Results presented in Table (5) testify the efficacy of spraying salicylic acid rates (SA) and the NPK bio-chemical fertilization regimes on barley flag leaf area (cm^2) recorded 90 days after sowing (DAS).

The three treatments of spraying salicylic acid, operatively influenced the barley flag leaf area, wherein the maximum flag leaf area in both growing seasons and their consolidated analysis was obtained ascribed to spraying SA at the rate of 150 ppm (SA_2). Allusive to the pooled analysis results, flag leaf area under (SA_2) treatment outbalanced the flag leaf area under both check treatment (SA_1) and spraying the highest rate at 300 ppm (SA_3) with relative increase amounted 18.30% and 10.46%, in the same order.

The flag leaf is the final leaf to emerge in barley, crucial for providing the majority of assimilates – often over 50% – for grain filling, directly influencing yield. Protecting this leaf from diseases and stress is vital for maximizing grain weight and overall productivity. The current results are in harmony with the findings reported by **Shalaby *et al.* (2013).**

Referring to the efficaciousness of NPK fertilization regimes on barley flag leaf area, results in Table (5) display that decreasing the chemical NPK fertilizer to 25% of the recommended levels (F_4), hampered the barley flag leaf area to the minimum value in each of the 1st, the 2nd seasons and the combined analysis (33.11, 39.33 and 36.22 cm^2) in the same respective order. It is noteworthy that the same fertilization treatment (F_4) when conjoined with bio-NPK fertilizers *e.g.* the fertilization treatment (F_6), the barley flag leaf area recorded the highest value in the 1st season and the meta-analysis, statistically equal with the supply of the three nutrients (NPK) in the form of chemical fertilizers at the recommended level (F_2) or at 50% of the recommended level (F_3). A similar trend was observed in barley plant leaf area (Table 4).

The enhancement role of nitrogen in increasing flag leaf area was also recorded by **Abd El-Maksoud (2002)** in wheat, **Zeidan *et. al* (2005)** in wheat, **Farag and El-Khawaga (2013)** in wheat, **El-Khawaga *et al*. (2013)** in barley, Eke, these findings resonate with the conclusions drawn by **Khattab (2016) and Saud Nouhan (2026)** on wheat.

Concerning the interactive influence between salicylic acid rates (SA) and the NPK fertilization regimes on barley flag leaf area (cm^2) (Table 5-A), it is difficult to determine a consistent trend in the effect of fertilization regimes on flag leaf area under the three salicylic acid rates, and *vice versa*. The largest and the smallest flag leaf area (66.17 viz 32.50 cm^2) was the resultant of the F_2 x SA_2 and F_7 x SA_3 interactions.

Table 5. Flag leaf area (cm^2) of barley as affected by salicylic acid foliar application rates and NPK fertilization regimes in the two seasons and combined analysis

Main effects and interaction	2020/2021	2021/2022	Combined
Salicylic acid rates (SA): Tap water (check) (SA_1)	48.76 b	39.24 c	44.00 c
150 ppm (SA_2)	55.19 a	48.91 a	52.05 a
300 ppm (SA_3)	47.57 b	46.67 b	47.12 b
F .test	**	**	**
NPK Fertilization regimes (F): Without fertilization (F_1)	55.78 a	45.89 c	50.83 b
Chemical NPK 100% (F_2) (60: 15,5: 24 kg/fad)	58.11 a	44.78 c	51.44 ab
Chemical NPK 50% (F_3)	56.33 a	51.78 a	54.05 a
Chemical NPK 25% (F_4)	33.11 c	39.33 d	36.22 d
Chemical NPK 50% + Bio NPK (F_5)	48.33 b	49.11 ab	48.72 b
Chemical NPK 25% + Bio NPK (F_6)	57.33 a	46.00 bc	51.64 ab
Biofertilizers (NPK) (F_7)	44.56 b	37.67 d	41.11 c
F. test	**	**	**
Interaction SA x F	**	**	**

** indicate significancy at 0.01 levels

Table (5-A). Flag leaf area (cm^2) of barley as affected by salicylic acid foliar application rates and NPK fertilization regimes interaction

Salicylic acid rates	**NPK Fertilization regimes**						
	F_1	**F_2**	**F_3**	**F_4**	**F_5**	**F_6**	**F_7**
Control	C 43.17c	B 46.17b	A 62.33a	D 33.50a	D 34.83c	C 40.83c	B 47.17a
150 ppm	C 51.67b	A 66.17a	C 51.17b	E 37.00a	C 52.17b	B 62.50a	D 43.67a
300 ppm	A 57.67a	D 42.00b	C 48.67b	E 38.17a	A 59.17a	B 51.67b	F 32.50c

Number of tillers/m^2

Table (6) exposes the efficacy of salicylic acid foliar spraying rates (SA) and NPK fertilization regimes (F) on number of tillers/m^2 of the six-rowed barley cultivar Giza 134. Spraying barley plants with salicylic acid) SA) at rates of 150 ppm (SA_2) and 300 ppm (SA_3) encouraged the plants to produce more tillers per square meter compared to the control treatment SA_1, no spraying with SA). Based on the pooled analysis results, tillers/m^2 under spraying 150 (SA_2) and 300 ppm (SA_3) of salicylic acid outnumber tillers/m^2 under the control treatment (SA_1), the relative increase over the control amounted 26.34% and 21.59% due to application of SA_2 and SA_3, consecutively.

Table (6). Number of tillers/m2 of barley as affected by salicylic acid foliar application rates and NPK fertilization regimes in the two seasons and combined analysis

Main effects and interaction	2020/2021	2021/2022	Combined
Salicylic acid rates (SA): Tap water (check) (SA_1)	471.71 b	420.24 c	445.98 b
150 ppm (SA_2)	660.48 a	466.43 b	563.45 a
300 ppm (SA_3)	579.05 ab	505.48 a	542.26 a
F .test	*	**	**
Fertilization regimes (F): Without fertilization (F_1)	505.56	460.00 c	482.78 b
Chemical NPK 100% (F_2) (60: 15,5: 24 kg/fad)	550.00	513.33 b	531.67 ab
Chemical NPK 50% (F_3)	616.67	566.67 a	591.67 a
Chemical NPK 25% (F_4)	538.89	402.78 e	470.83 b
Chemical NPK 50% + Bio NPK (F_5)	618.89	439.44 cd	529.17 ab
Chemical NPK 25% + Bio NPK (F_6)	578.89	455.00 c	516.94 b
Biofertilizers NPK (F_7)	584.00	411.11 de	497.56 b
F. test	NS	**	**
Interaction SA x F	NS	**	NS

*,** and NS indicate significancy at 0.05 and 0.01 levels and insignificancy of differences, in respective order

Avail of spraying salicylic acid at 150 ppm and 300 ppm rates was also found in flag leaf area (Table 5). Obtained results go along **with Jafar *et al.* (2012) and Shalaby *et al.* (2013)**. Regarding to the efficacy of the fertilization regimes of NPK on number of tillers/m^2, results in Table (6) exhibit that the number of tillers/m^2 was operatively affected by the abundance or scarcity of the three fertilizer elements (NPK), as fertilization at 50% (F_3) or 100% (F_2) of the recommended quantity of NPK produced the largest number of /tillers/m^2 (591.67 and 531.67) compared to the other fertilization regimes (combined results). Trends in the current study are partially in harmony with those of **Rahuma *et al.* (2017)**.

The interplay between SA rates and the NPK fertilization regimes was not influential on number of barley tillers/m^2 in the 1st season and the meta-analysis.

Number of spikes/m^2

Table (7) encapsulates the variations in number of spikes/m^2 of barley, cultivar Giza 134 due to the spraying SA at three rates and the bio-chemical NPK fertilization regimes. Results of spraying SA rates disclosed that spraying SA at the rate 150 ppm (SA_2) operatively elevated barley spike number/m^2 over both the control treatment (SA_1) and spraying SA at the rate 300 ppm (SA_3) in the 1st season and the combined analysis. Based on the pooled analysis results, spraying salicylic acid at 150 ppm (SA_2) caused relative increase in number of barley spikes/m^2 valued as much as 14.93% and 10.42% over the check treatment (SA_1) and spraying SA at the rate 300 ppm (SA_3), in the same order. Spraying salicylic acid at 150 ppm enhanced also each of leaf area/plant 2nd season, Table 4) flag leaf area (Table 5) as well as number of tillers/m^2 (Table 6). **El-Wakeel *et al.* (2024)** in Egyptian study reported that spraying salicylic acid at 300 ppm produced the highest number of barley spikes/m^2.

Referring to the efficacy of the NPK fertilization regimes (F), results of both seasons and their pooled analysis declared that the reduction in the amount of the chemical NPK fertilizers to 25% of the recommended amounts (F_4) led to a noticeable and significant decrease in the number of spikes/m^2.

However, it is worth noting that the same fertilization treatment (F_4) when added in combination with NPK bio-fertilizers *i.e.* application of F_6 fertilization treatment, resulted in a confirmed increase in number of spikes/m^2 and these results were confirmed in both seasons and their meta-analysis. Eke, number of spikes under the NPK bio-fertilizer (F_7) and under chemical NPK 100% chemical fertilizers (F_2) were at par, this paves the way for replacing NPK chemical fertilizers entirely or partially with the NPK biofertilizers. These results run with the findings previously noted by **Ben Khaled *et al.* (2014), Ashmawy *et al.* (2016), Khattab (2016), Rahuma *et al.* (2017), Abd El-Lattief *et al.* (2021), Abdelsalam and Ashshormillesy (2022), Alotaibi et al. (2024) and Ahmed *et al.* (2025).**

The interactive between SA rates and the biochemical fertilization regimes have not affected the barley number of spikes/m^2, which indicates independent efficacy of the main factors on number of spikes/m^2.

Table (7). Number of spikes/ m^2 of barley as affected by salicylic acid foliar application rates and NPK fertilization regimes in the two seasons and combined analysis

Main effects and interaction	**2020/2021**	**2021/2022**	**Combined**
Salicylic acid rates (SA): Tap water (check) (SA_1)	248.10 b	399.52	323.81 b
150 ppm (SA_2)	302.38 a	441.90	372.14 a
300 ppm (SA_3)	240.95 b	433.10	337.02 b
F .test	**	NS	**
Fertilization regimes (F): Without fertilization (F_1)	250.00 ab	453.33 a	351.67 ab
Chemical NPK 100% (F_2) (60: 15,5: 24 kg/fad)	265.56 ab	402.22 ab	333.89 abc
Chemical NPK 50% (F_3)	291.11 a	418.33 ab	354.72 ab
Chemical NPK 25% (F_4)	218.89 b	398.33 b	308.61 c
Chemical NPK 50% + Bio NPK (F_5)	247.78 ab	442.22 ab	345.00 abc
Chemical NPK 25% + Bio NPK (F_6)	270.00 ab	423.33 ab	346.67 abc
Biofertilizers NPK (F_7)	303.33 a	436.11 ab	369.72 a
F. test	*	*	*
Interaction SA x F	NS	**	NS

*, ** and NS indicate significancy at 0.05 and 0.01 levels and insignificancy of differences, in respective order

References

[1] **Abd El-Lattief, E., Ali, M., Hmadi, H. (2021).** Effect of sowing dates and fertilization treatments on productivity of barley crop under Upper Egypt conditions. SVU-International Journal of Agricultural Sciences, 3(3), 192-204.

[2] **Abd El-Maksoud, M.F. (2002).** Response of some wheat cultivars to biofertilizer and nitrogen fertilizer levels. Zagazig J. Agric. Res., 29 (3): 891-905.

[3] **Abdelsalam, A. and Ash-Shormillesy. S. M. A. (2022).** Effect of mineral and bio-fertilization regimes on yield and grain viability of some barley cultivars. Sinai j of Appl Sci., 11(4): 625-642.

[4] **Abdelsalam, A., and El-Sanatawy, A. M. (2022).** Influence of some bio-chemical phosphorus fertilization regimes on yield and seed quality of some lentil varieties. Sinai Journal of Applied Sciences, 11(2), 195–212.

[5] **Adams, E.; Shin, R. Transport, signaling,(2014)** and homeostasis of potassium and sodium in plants. J. Integr. Plant Biol. , 56, 231–249.

[6] **Afzal I, Basra SMA, Farooq M, Nawaz A. (2008),.** Alleviation of salinity stress in spring wheat by hormonal priming with ABA, salicylic acid and ascorbic acid. Int. J. Agric. Bio.;80(1):23–28.

[7] **Ahmad I, I, Khaliq T, Ahmad A, Basra SMA, Hasnain Z, Ali A.(2012)** Effect of seed priming with ascorbic acid, salicylic acid and hydrogen peroxide on emergence, vigor and antioxidant activities of maize. Afr. J. Biotechnol.;11(5):1127–1132.

[8] **Alotaibi, M. M. A. Aljuaid. I. M. Alsudays, A. S. Aloufi. A. N. AlBalawi. A.and Alasmari (2024).** "Effect of bio-fertilizer application on agronomic traits, yield, and nutrient uptake of barley (*Hordeum vulgare*) in saline soil." Plants 13(7): 951.

[9] **Amtmann, A.; Hammond, J.P.; Armengaud, P.; White, P.J. (2005)** Nutrient sensing and signalling in plants: Potassium and phosphorus. Adv. Bot. Res., 43, 209–257.

[10] **Ashmawy, H. H. E. A. El-Nady, H. S. A. Fateh., M. R. and El-Mowafy (2018)**. Response of new barley cultivars to NPK fertilizers on sandy soil at Ismailia Conference paper, FCRI, ARC, Giza, Egypt,223-238.

[11] **Azzawi, W. A., Gill, M. B., Fatehi, F., Zhou, M., Acuña, T., Shabala, L., Yu, M., & Shabala, S. (2021).** Effects of potassium availability on growth and development of barley cultivars. Agronomy, 11(11), 2269.

[12] **Ben Khaled, A, T. Hayek, E. Mansour and A. Ferchichi. (2014).** "Comparing the interactive effects of NPK fertilization and saline water on tow genotypes of barley (*Hordeum vulgare* L.) grown in southern of Tunisia.

[13] **Bindereif, S. G., Rüll, F., Kolb, P., Köberle, L., Willms, H., Steidele, S., Schwarzinger, S. & Gebauer, G. (2021).** Impact of Global Climate Change on the European Barley Market Requires Novel Multi-Method Approaches to Preserve Crop Quality and Authenticity. Foods, 10, 1592.

[14] **Carvalho RF ,Piotto Fa, Schmidt D,Peters Lp, Monterio CC, Azevedo RA. (2011).** Seed priming with hormones dose not alleviate induced oxidative stress in maize seedling subjected to salt stress. Scientia Agricola (Piracicaba, Brazil).;68(5):598–602.

[15] **Dakheel MG, Ullah I, Doğan DE, Demirsoy L.(2022)** Potential role of salicylic acid ondrought stress tolerance of strawberry plants..

[16] **Diacono,M., P.Rubion and F. Montemurro. (2013).** Precision nitrogen management in wheat :a review . Agronomy for Sustainable Development .3(1):219-24

[17] **El-Khawaga, A.A.H., I.A. Farag and N.E. Liwa (2013).** Influence of both gamma radiation and nitrogenfertilization level on growth and productivity ofbarely. Isotope and Res., 45 (2): 385-400.

[18] **El-Wakeel, S. E., Mansour, M., El-Azeem, A. M., Aboulila, A. A. (2024).** Regulation of Physiological and Biochemical Mechanisms Related to Water Stress Tolerance in Barley and Improvement of Growth and Productivity Using Salicylic Acid and Chitosan. ASIAN JOURNAL OF ADVANCES IN AGRICULTURAL RESEARCH Учредители: Sciencedomain International, 24(10), 17-33.

[19] **Farag, I.A.A. and A.A.H. El-Khawaga (2013).** Influence of gamma irradiation and nitrogen fertilizer levels on Gammeza -9 wheat cultivar yield and its attridutes. J. sci and applications, 46 (2): 363-371.

[20] **Farid, I. M., Abbas, M. H., El-Ghozoli, A. (2023).** Wheat productivity as influenced by integrated mineral, organic and biofertilization. Egyptian Journal of Soil Science, 63(3), 287–299.

[21] **Farooq M, . M, Aziz T, Basra SMA, Cheema A, Rehman MH.(2008)** Chilling tolerance in hybrid maize induced by seed priming with salicylic acid. J. Agron. Crop Sci.;194:161–168.

[22] **Fazlullah, M. A., Shah, F., Iqbal, S., Arshad, M., Muhammad, F., Wahid, A., Hussain, M., Roman, D., Perveez, R., Noor, M. (2018).** Integrated application of phosphorus (P) and phosphate solubilizing bacteria (PSB) improve maize yield. Pure and Applied Biology, 7(2), 494–499.

[23] **FutureMarketInsights. (2023). Barley** Market. https://www. futuremarketinsights. com/reports/barley-market, accessed on 5.08.

[24] **Gomaa, F. (2024).** Impact of combining mineral and biofertilizers on bread wheat (Triticum aestivum vulgare L.) yield and its economic viability. Journal of Plant Production, 15(9), 485-494.

[25] **Gomez, K.H. and A.A. Gomez (1984).** Statistical procedures for agriculture research. John Willy and Sons. Inc., New York.

[26] **Guan YJ, YJ, Hu J, Wang XJ, Shao CX .(2009)**Seed priming with chitosan improves maize germination and seedling growth in relation to physiological changes under low temperature stress. J. Zhejiang Uni. Sci.;10:427–433.

[27] **Hammad, H.M., M.S. Chawla, R. Jawad, A. Alhuqail, H.F. Bakhat, W. Farhad, F. Khan, M. Mubeen, A.N. Shah, K. Liu and M.T. Harrison (2022).** Evaluating the impact of nitrogen application on growth and productivity of maize under control conditions. Front. in Plant Sci., 13: 885479.

[28] **Hammad, H.M., W. Farhad, F. Abbas, S. Fahad, S. Saeed, W. Nasim and Ha. F. Bakhat (2016).** Maize plant nitrogen uptake dynamics at limited irrigation water and nitrogen. Environ. Sci. and Pollut. Res., 24: 2549-2557.

[29] **Hanif, S., Mahmood, A., Javed, T., Bibi, S., Zia, M. A., Asghar, S., Naeem, Z., Ercisli, S., Rahimi, M., & Ali, B. (2024).** Exogenous application of salicylic acid ameliorates salinity stress in barley (Hordeum vulgare L.). BMC Plant Biology, 24(1), 270.

[30] **Hawkesford, M.; Horst, W.; Kichey, T.; Lambers, H.; Schjoerring, J.; Møller, I.S.; White, P(2011).** Functions of macronutrients. In Marschner's Mineral Nutritionof Higher Plants, 3rd ed.; Marschner, P., Ed.; Academic Press: Walthan, MA, USA, 2011; pp. 135–151.

[31] **Hermans, C.; Hammond, J.P.;White, P.J.;Verbruggen,N(2006).** How do plants respond to nutrient shortage by biomass allocation? Trends Plant Sci., 11, 610–617.

[32] **Ibrahim, H. H., Ramadan, I., Abdelsalam, A., Hassan, H., & El-Khawaga, A. (2023).** Impact Of Bio-Chemical Phosphorus Fertilization And Lithovit Regimes On Some Qualitative Traits Of Various Berseem Varieties. Zagazig Journal of Agricultural Research, 50(2), 149-166.

[33] **İslamzade, İ., Hasanova, G., & Asadova, S. (2023).** Impact of varied NPK fertilizer application rates and seed quantities on barley yield and soil nutrient availability in chestnut soil of Azerbaijan. Eurasian Journal of Soil Science, 12(4), 371-381.

[34] **Jafar, M.Z. M. Farooq . M.A. Cheema. I. Afzal, S.M.A. Basra. Wahid. M.A. T. Aziz. M.and Shahid, (2012).** Improving the performance of wheat by seed priming under saline conditions. J. Agron. Crop Sci. 198, 38-45.

[35] **Jangra, M.S.Devi,.Satpal.N.Kumar.,V.Goyal,S.and.Mehrotra(2022).** Amelioration effect of salicylic acid under salt stress in *Sorghum bicolor* L. Appl Biochem Biotechnol;194(10):4400–23.

[36] **Jia, X., L. Shao, P. Liu, B. Zhao, L. Gu, S. Dong, SH. Bing, J. Zhang and B.Zhao (2014).** Effect of different nitrogen and irrigation treatments on yield and nitrate leaching of summer maize (Zea mays L.) under lysimeter conditions. Agric. Water Manag., 137:92–103

[37] **Ju, X.T., G. X. Xing, X.P. Chen, S.L. Zhang, L.J. Zhang, X.J. Liu, Z.L. Cui, B.Yin, P. Christie, Z.L. Zhu and F. S. Zhang (2009).** Reducing environmental risby improving N management in intensive Chinese agricultural systems. Proc Natl Acad Sci., U S A 106:3041-3046

[38] **Kalayu, G. (2019)** Phosphate Solubilizing Microorganisms: Promising Approach as Biofertilizers.International.Journal.ofAgronomy. https://doi.org/10.1155/2019/4917256

[39] **Kandoudi, W. and Nemeth-Zamborine, E. (2022)**Stimulatingsecondarycompound accumulatio accumulatio by elicitation: is it a realistic tool in medicinal plants in vivo Phytochem Rev:1–19

[40] **Khan, A. A., Jilani, G., Akhtar, M. S., Naqvi, S. M. S., Rasheed, M. (2009).** Phosphorus solubilizing bacteria: Occurrence, mechanisms and their role in crop production. Journal of Agricultural and Biological Science, 1(1), 48–58.

[41] Khattab, A. W. M., El-Khawaga, A. A. H., Ramadan, I. E., Saleh, M. E. (2019). Traits of maize primary and secondary ears under some integrated nitrogen and phosphorus fertilization regimes. Bioscience Research, 16(3), 2655–2664.

[42] **Khattab, A. W., A., El-Khawaga, M.,Saleh, I.and Ramadan, (2016)**. Some bio-chemical nitrogen and phosphorus fertilization regimes impacts on wheat (*Triticum aestivum* L.) productivity. Zagazig J. Agri, Res, 43(1): 11-28.

[43] **Lal, R. (2000)** Soil management in the developing countries. Soil Sci. 2000, 165, 57–72.

[44] **Maruri-López I, Aviles-Baltazar NY, Buchala A, Serrano M.(2019)** Intra and extracellular journey of the phytohormone salicylic acid. Front Plant Sci. ;10:423.

[45] **Mastanjević K, Lukinac J, Jukić M, Šarkanj B, Krstanović V, Mastanjević K. (2019)**Multi-(myco) toxins in malting and brewing by-products. Toxins.;11(1):30.

[46] Meena, V.S.; Maurya, B.R.; Verma, J.P.; Meena, R.S.(2016) Potassium Solubilizing Microorganisms for Sustainable Sgriculture; Springer: Uttar Pradesh, India**,.**

[47] **Megahed FMA, El-Khawaga AA, Hassan AIA, Ali MMA.(2024) Assessment** of Barley Genotypes to Drought Tolerance Under Different Levels of Irrigation. Ann Agric Crop Sci.;9(3):1158.

[48] **Moore, L.V.; Dodd, K.W.; Thompson, F.E.; Grimm, K.A.; Kim, S.A.; Scanlon, K.S.(2015)** Using behavioral risk factor surveillance system data to estimate the percentage of the population meeting US Department of Agriculture food patterns fruit and vegetable intake recommendations. Am. J. Epidemiol. 2015, 181, 979–988.

[49] **Moustakas M, Sperdouli I, Adamakis I-DS, Moustaka J,(2022);**23 İşgören S, Şaş B. Harnessing the role of foliar applied salicylic acid in decreasing chlorophyll content to reassess photosystem II photoprotection in crop plants. Int J Mol Sci. (13):7038.

[50] **MSTAT, C. (1989).** Statistical Program Version 2.10. Crop and Soil Sci. Dept., Michigan State Univ., USA.

[51] **Narula, N., Saharan, B.S., Kumar, V., Bhatia, R., Bishnoi, L.K. and Lather, B.P. (2005).** Lakshminarayana, K. Impact of the use of biofertilizers on cotton (Gossypium hirsutum) crop under irrigated agro-ecosystem. Arch. Agron. Soil Sci. , 51, 69–77.

[52] **Nourhan, A. E. Saoud. A.A.H. El-Khawaga. S.M.I. Ash-shormillesy. E. Abdallah. F.S.M. and Gomaa (2024)** Impact of phosphorus fertilization regimes and a weed aqueous extract on wheat productivity. Zagazig. J. Agri. Res., 9(3):1158

[53] **Pakar, N., H., Pirasteh-Anosheh, Y.and Emam (2015).** Barley growth, yield, antioxidant enzymes and ion accumulation as affected by PGRs under salinity stress conditions. J. Plant. Nut. In Press.

[54] **Pan R, He D, Xu L, Zhou M, Li C, Wu C, Xu Y, Zhang W.(2019).** Proteomic analysis reveals response of differential wheat (*Triticum aestivum* L.) genotypes to oxygen deficiency stress. BMC Genomics.;20(1):1–13.

[55] **Pettigrew, W.T. (2008)** Potassium influences on yield and quality production for maize, wheat, soybean and cotton. Physiol. Plant. , 133, 670–681.

[56] **Pirasteh-Anosheh, H. G. Ranjbar. Y. Emam. M. and Ashraf (2014).** Salicylic-acid–induced recovery ability in salt-stressed Hordeum vulgare plants. Turk. J. Bot. 37, 112-121.

[57] **Pirasteh-Anosheh, H., Emam, Y., Sepaskhah, A. (2015).** Improving barley performance by proper foliar applied salicylic-acid under saline conditions. International Journal of Plant Production, 9(3), 467-486.

[58] **Prajapati, K.; Modi, H.(2012)** The importance of potassium in plant growth—A review. Indian J. Plant Sci. 2012, 1, 177–186.

[59] **Rahuma, M. F. I. Radwan. M. I. and Gomaa (2016).** Effect of potassium, phosphorus and bio-fertilization on barley productivity. J. the Advances in Agri.Res.,22(1) :136-147

[60] **Rawat J, Sanwal P, Saxena J.(2017)**Potassium and Its Role in Sustainable Agriculture.

[61] **Rengel, Z.; Damon, P.M(2008).** Crops and genotypes differ in efficiency of potassium uptake and use. Physiol. Plant. 2008, 133, 624–636.

[62] **Römheld, V.; Kirkby, E.A.(2010)** Research on potassium in agriculture: Needs and prospects. Plant Soil 2010, 335, 155–180.

[63] **Ross H. M .,and Allan M. (2013).** Phosphorus Fertilizer Application in Crop Production. AGRI-FACTS, Practical Information for Alberta's Agriculture Industry: 1-11.

[64] **Shalaby, M. A. F. M. A. Ahmed. M. S. A. Abdallah. E. A. and El-Housini (2013).** "Physiological role of salicylic acid in improving growth and productivity of barley (*Hordeum vulgare* L.) under sandy soil conditions." Middle East J. Agri. Res., 2(2): 68-75.

[65] **Sharma, S. B., Sayyed, R. Z., Trivedi and Th. A Gobi, (2013).** Phosphate solubilizing microbes: Sustainable approach for managing phosphorus deficiency in agricultural soils. Springer Plus, 2(1), 587.

[66] **Shavanov M.(2021)** The role of food crops within the Poaceae and Fabaceae families as nutritional plants. In: IOP Conference Series: Earth and Environmental Science:. IOP Publishing: 012111.

[67] **Shen, S. M. (1998).** Soil Fertility in China. China Agriculture Press, Beijing, pp. 120-145.

[68] **Singh, M.; A. Chauhan; R. Kumar; D. Joshi; P. G. Soni and V. K.Meena,(2017)** Dual purpose barley as affected by date of sowing, varieties and stage of harvesting-A review. Agricultural Reviews, 38 (2): 159-164. (18)

[69] **Soare, E., Bold, N., Stoicea, P., David, L., Dobre, C.-A., Firățoiu, A.-R. (2023).** Survey on the worldwide barley production and trade. Bulg. J. Agric. Sci, 29(Suppl 1), 119-124.

[70] **Steel, R.G.D., J.H. Torrie and D.A. Dickey (1997).** Principles and procedures of Statistics. A Biometrical Approach. 3 rd Ed. Mc Graw Hill Book Co. New York.

[71] **Waller, R. A., and Duncan, D. B. (1969).** A Bayes rule for the symmetric multiple comparisons problem. Journal of the American Statistical Association, 64(328), 1484–1503.

[72] **Wang, G.Y, K.Khan,L.Yang,Y.Wang,Y.X.Chi and X.Zhou (2024) .** Irrigation combines with nitrogen application to optimize soil carbon and nitrogen ,increased maize yield , and nitrogen use efficiency . Plant and soil at https: doi. Org/10.1007/s 11104-024-06480-6.

[73] **Wani, P.A., Khan, M.S. and Zaidi, A.,(2007).** Synergistic effects of the inoculation with nitrogen-fixing and phosphate-solubilizing rhizobacteria on the performanofield-grown chickpea. Journal of Plant Nutrition and Soil Science, 170(2), pp.283-287.

[74] **White, P.; Karley, A. (2010)** Potassium. In Cell Biology of Metals and Nutrients; Hell, R., Mendel, R.R., Eds.; Springer: Berlin/Heidelberg, Germany; pp. 199–224.

[75] Zeidan, E.M., A.A. El-Khawaga, H.A. Basha and I.M. Abd El-Hammeed (2005). Improvement of wheat productivity in newly reclaimed soil in Egypt. Annals universitatis. Mariaecurie Sklodowska, Lublin-Polonia Sec. E, (60) 113-121. Agron. Dep., Fac. Agric., Zagazig Univ., Egypte.

[76] **Zhang, A.M.; Zhao, G.Y.; Gao, T.G.; Wang, W.; Li, J.; Zhang, S.F. and Zhu, B.C. (2013).** Solubilization of insoluble potassium and phosphate by Paenibacillus kribensis CX-7, A soil microorganism with biological control potential. Afr. J. Microbiol. Res. , 7: 41–47.

[77] **Zhang, Y. C.Ye., Y.Su, W. Peng, R. Lu, Y.Liu, H.Huang, X. He, M.Yang and S. Zhu (2022 a) .**Soil acidification caused by excessive application of nitrogen fertilizer aggravates soil-borne diseases: Evidence from literature review and field trials, 340. Agric., Ecosystems Environ., p 108176

[78] **Zhou, M. (2010).** Barley production and consumption. In Genetics and improvement of barley malt quality (pp. 1-17). Springer.

[79] **Zhu XinKai, Z. X., Li ChunYan, L. C., Jiang ZongQing, J. Z., Huang LianLian, H. L., Feng ChaoNian, F. C., Guo WenShan, G. W. and Xin, P. Y. (2012).** Responses of phosphorus use efficiency, grain yield, and quality to phosphorus application amount of weak-gluten wheat.

[80] **Zörb, C.; Senbayram, M. and Peiter, E. (2014)** Potassium in agriculture–status and perspectives. J. Plant Physiol. 2014, 171, 656–669.