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Response of Onion Growth and Yield to Potassium Application in Alkaline Soils

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ABSTRACT

Onion (*Allium cepa* L.) is one of the most critical commercial vegetables, which, after tomatoes, ranks second in the world, especially in Afghanistan. It is a rich source of vitamins, protein, and amino acids, which are beneficial for human nutrition and traditional medicine. This experiment was conducted in 2022 at the research farm of the Faculty of Agriculture at Kabul University to investigate the response of onion to potassium application in alkaline soil. The different levels of potassium (0, 11.25, 22.5, 33.75, 45, 56.25, 67.5, 78.75, and 90 kg/ha) were used as treatments. The growth, quality, and yield attributes of onions were studied in this investigation. The research was designed using a Randomized Complete Block Design (RCBD), and the data were analyzed with the Statistical Tools for Agricultural Research (STAR) 2.0.1 software. The results show that applying 22.5 kg per hectare of potassium enhances both growth and yield attributes of onions. Farmers are advised to use this quantity of potassium, in the form of potassium sulfate, to produce a higher yield of onions.

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INTRODUCTION

Onion (*Allium cepa* L.) is regarded as one of the most important vegetables worldwide. It belongs to the genus Allium and the family Alliaceae. Onions are the second most commercially important vegetable crop worldwide, after tomatoes (Bekele, 2018; FAOSTAT, 2019; Cramer et al., 2021), and comprise around 24% of the vegetables produced worldwide (FAOSTAT, 2018).

Onion is a native crop of Afghanistan, and several varieties are grown throughout the country. The Safid e Paisaye is a native variety of onions that is cultivated in the Ghorband valley in Parwan province, located in the central agroecological zone of Afghanistan (Salari et al., 2020). Its medium-sized, flat, round, white bulb is referred to as *Safid e Paisaye* due to its white, coin-like appearance. It is highly desirable in Afghan restaurants throughout the region, owing to its long shelf life, and is commonly used in a Do Piazza dish in homes and restaurants (Salari et al., 2020).

Onions are commercially grown in Afghanistan. In 2023, five hundred and eighty-six thousand (586,000) metric tons of dry bulbs were produced for domestic and international markets (Commodities by Countries, 2023).

Onions contain bioactive substances along with their vitamins, amino acids, moisture content (88.65%), protein content (9.22-13.21 g 100gr-1 fresh weight), vitamin-C, carotenoids content (45.7 mg 100gFW-1), and (1.44 µg mL-1 FW), which make them useful for human food and traditional medicine (Sami et al., 2021). Among the many phytochemicals found in onions are polysaccharides, phenolic compounds, organosulfur compounds, and saponins. These chemicals, which include onionin A, cysteine sulfoxides, quercetin, and quercetin glucosides, serve as the main bioactive components of onions (Zhao et al., 2021)

Potassium is an important macro-element contributing to crop output and ecological stability (Srivastava et al., 2020). It is essential to regulate the movement of nutrients, metabolites, and water throughout plant tissues and organs, protect plants from oxidative stress, and support the preservation of osmotic balance (Srivastava et al., 2020). Potassium also plays a crucial role in several physiological processes, including regulation of cellular growth and wood development, xylem–phloem water content and transport, nutrition and metabolite translocation, and reactions to stress (Sardans & Peñuelas, 2021).

Potassium assists in diverse plant processes, highlighting plant-mediated reactions to environmental abiotic and biotic changes and stresses by regulating transmembrane potentials and transporting water, nutrients, and metabolites (Sardans & Peñuelas, 2021). The critical functions of K^+ justify its elevated concentrations in the most active plant organs, such as leaves, and align with the growing body of ecological and agricultural research that identifies K^+ as a vital element in the functionality and structure of terrestrial ecosystems, crop yield, and global food security (Sardans & Peñuelas, 2021). It governs various cellular and organ functions, and a shortage of K+ leads to diminished plant growth and productivity (Srivastava et al., 2020).

Considering that potassium is an important element in boosting plants' growth, yield, and quality, the current experiment was conducted to find out the optimum dose of potassium for producing a high-quality, increased yield of onions in alkaline soils.

METHODS AND MATERIALS

The present investigation was conducted from March to September 2022 at the research farm of the Faculty of Agriculture at Kabul University. The research field is located at latitude 34.5184°N and longitude 69.1394°E. The study's objective was to determine the response of onions to potassium application in alkaline soil. A local variety of onions named Safid e

Paisaye was used in this investigation. The seeds of the mentioned variety were sown in the nursery on March 5, 2022, and the plants were transplanted to the field after 8 weeks on May 5, 2022.

The topsoil (0–30 cm) properties of the study field were tested. The soil was silty clay in texture with the following characteristics: organic matter – 3.04%, P2O5 – 45.05 ppm, K – 319 ppm, CaCo3 – 14.8 %, EC – 0.24 ms/cm, pH– 8.12, and cation exchange capacity – 21.4 meq/100 g (Sahbani et al., 2023).

Chemical fertilizers like nitrogen (90 kg per hectare) as urea, phosphorus (60 kg per hectare) as diammonium phosphate (DAP), and farm yard manure (15 Mt per hectare) were applied to all plots in common. According to the treatment details of the research, different potassium levels at rates of 0, 11.25, 22.5, 33.75, 45, 56.25, 67.5, 78.75, and 90 kg per hectare were applied to the plots as sulfate of potash. During soil preparation, DAP, sulfate of potash, half of the nitrogen, and all farm yard manure were added to the plots. The remaining half of the nitrogen as urea was added a month after transplanting. Each treatment was replicated three times.

The plots were kept free from weeds through hand-weeding. Based on climatic conditions, the irrigation interval was once every 7-10 days using the flood irrigation method. Plants were spaced 15 cm apart, and rows were laid out 20 cm apart.

Different growth parameters, including the number of leaves per plant, leaf length (in cm), leaf area, and leaf area index, were measured during the vegetative growth stage. After 50% of the onion leaves were dried, the plants were harvested. Pre-harvest observations were recorded on five randomly labeled plants from each treatment at 120 days after sowing, and the mean value was worked out across all treatments. The leaf area index (LAI) was calculated by dividing the actual leaf area per plant by the land area occupied by the same plant (spread of the plant) using the formula (1) and was measured 120 days after sowing.

$$LAI = \frac{\text{Leaf area per plant } (\text{cm}^2)}{\text{Land area occupied by each plant } (\text{cm}^2)} \qquad (1)$$

For the maturity period, the number of days from sowing to harvest for each treatment was counted and presented in days. Marketable and total yields were recorded in kg/plot and converted into metric tons per hectare.

Post-harvest observations were recorded on five randomly selected bulbs, and the mean value was calculated. A vernier caliper was used to measure the bulb width (largest equatorial diameter), length (polar diameter), thickness (smallest equatorial diameter), and neck diameter, all of which were recorded in centimeters. The geometric mean diameter (D_{gm}), arithmetic mean diameter (D_{am}), and neck-to-bulb ratio were calculated based on the formulas (2-4) given by (Kurniawan et al., 2020; Priya et al., 2015) (W, L, and T represent width, length, and thickness, respectively).

$$Dgm = \sqrt[3]{W * L * T} \qquad (2)$$

$$D_{am} = (W + L + T)/3 \quad (3)$$

$$Neck\ to\ bulb\ ratio = \frac{Neck\ diameter\ (cm)}{Largest\ equatorial\ bulb\ diameter\ (cm)} \quad (4)$$

The frontal surface area (AFS), cross-sectional area (ACS), and total area (AT) of the bulbs were calculated using the formulas (5-7) given by (Kurniawan et al., 2020; Priya et al., 2015). The letters W, L, and T represent width, length, and thickness, respectively.

$$A_{FS} = \frac{\pi}{4}(W * L) \quad (5)$$

$$A_{CS} = \left(\frac{\pi}{4}\right)((W + L + T)^2/9) \quad (6)$$

$$A_T = \pi(Dgm)^2 \quad (7)$$

Bulb quality and storage parameters, such as the fresh bulb weight in grams, were recorded using a digital weighing balance. Bulb volume in cubic centimeters was recorded using the water displacement method. A measuring jar was filled with water, and the bulbs were submerged. The amount of water displaced by each bulb was measured in milliliters, and the volume of each bulb was recorded in cubic centimeters. Using the following formula (12), the bulb density (g/cm^3) was calculated as the ratio of bulb weight to bulb volume.

$$Bulb\ density = \frac{Bulb\ weight\ (g)}{Bulb\ volume\ (cm^2)} \quad (8)$$

TSS (Brix) was recorded using a hand refractometer (0-32°B). Equatorial firmness (Kg/cm^2) and polar firmness (Kg/cm^2) were recorded with the help of a penetrometer (13 kg). A one cm in diameter probe was used to collect the firmness data, which was presented in kilograms per square centimeter.

The data was analyzed statistically using the Statistical Tools for Agricultural Research (STAR 2.0.1) software. The least significant difference (LSD) method was applied to show the differences in the analyzed data results among treatments.

FINDINGS

In the present investigation, statistical analysis at the $P < 0.05$ level was performed on various growth and yield parameters collected throughout the experiment. Varying levels of potassium application significantly affected the growth and yield of onions.

Different levels of potassium significantly affected the number of leaves per plant. The 45 kg/ha of potassium produced higher numbers of leaves per plant (9.62). Leaf length, leaf area per plant, and leaf area index were not significantly influenced by different quantities of potassium (Table 1).

***Table 1**: Response of Onion growth observations to potassium application in alkaline soils*

Treatments	Number of Leaves per plant	Leaf length (cm)	Leaf area per plant (cm2)	Leaf area index
0 kg	8.62 d	49.38	785.06	2.62
11.25 kg	9.25 abc	41.94	702.49	2.34
22.5 kg	9.12 bc	42.81	768.96	2.56
33.75 kg	8.62 d	44.88	638.96	2.13
45 kg	9.62 a	39.25	660.09	2.20
56.25 kg	9.25 abc	44.81	773.84	2.58
67.5 kg	9.50 ab	42.94	674.50	2.25
78.75 kg	9.25 abc	43.06	709.79	2.37
90 kg	9.00 cd	42.50	645.47	2.15
F-Value	*	NS	NS	NS
LSD (0.05)	0.4899			
CV (%)	2.32			

CV (%) = Coefficient of variation, LSD = Least significant difference, * = Significant level at ($P<0.05$), NS = non-significant level. Different letters indicate the groups with significant differences.

According to the statistical analysis output, the marketable and total yield (Mt ha^{-1}) was affected by various levels of potassium application. The highest marketable and total yields (35.08 and 35.32 Mt ha-1) were achieved by applying 56.25 kg ha-1 of potassium, respectively (Table 2). The second highest yield was produced by applying 22.5 kg per hectare (Table 2).

***Table 2:** Response of onion yield attributes to potassium application in alkaline soils*

Treatments	Marketable yield (MT ha-1)	Total yield (MT ha-1)
0 kg	31.08 bc	31.37 bcd
11.25 kg	28.01 de	29.01 de
22.5 kg	30.58 bcd	30.58 bcd
33.75 kg	29.54 bcde	29.78 bcde
45 kg	30.37 bcd	32.20 b
56.25 kg	35.08 a	35.32 a
67.5 kg	26.99 e	26.99 e
78.75 kg	29.18 cde	29.18 cde
90 kg	32.11 b	32.11 bc
F-Value	*	*
LSD (0.05)	2.7234	2.9432
CV (%)	3.89	4.15

CV (%) = Coefficient of variation, LSD= Least significant difference, * = Significant level at ($P<0.05$). Different letters indicate the groups with significant differences.

The application of potassium significantly influenced the size of onion bulbs (Tables 3 and 4). The largest bulbs in terms of diameter and surface area were recorded under the treatment containing 22.5 kg of potassium per hectare.

Table 3: *Response of onion bulb diameter observations to different levels of potassium application*

Treatments	Polar bulb diameter (cm)	Largest equatorial bulb diameter (cm)	Smallest equatorial bulb diameter (cm)	Geometric mean diameter (cm)
0 kg	4.3 b	6.20 a	6.14 abc	5.47 bc
11.25 kg	4.36 ab	6.16 a	5.95 abcd	5.43 cd
22.5 kg	4.35 ab	6.44 a	6.18 a	5.57 a
33.75 kg	4.49 a	6.35 a	5.75 d	5.47 bc
45 kg	4.29 b	6.41 a	6.17 ab	5.54 ab
56.25 kg	4.10 c	5.85 b	5.91 cd	5.21 e
67.5 kg	4.24 bc	6.34 a	5.70 d	5.35 d
78.75 kg	4.35 ab	6.19 a	5.92 bcd	5.42 cd
90 kg	4.26 bc	6.23 a	5.95 abcd	5.41 cd
F-Value	*	*	*	*
LSD (0.05)	0.1838	0.3000	0.2535	0.0908
CV (%)	1.85	2.08	1.84	0.7252

CV (%) = Coefficient of variation, LSD= Least significant difference, * = Significant level at ($P<0.05$). Different letters indicate the groups with significant differences.

Table 4: *Response of onion bulb area to different levels of potassium application*

Treatments	Frontal surface area	Cross-sectional area	Total area
0 kg	20.93 c	24.15 bc	93.93 bc
11.25 kg	21.08 bc	23.66 cd	92.46 cd
22.5 kg	21.99 ab	25.12 a	97.54 a
33.75 kg	22.38 a	24.01 c	94.05 bc
45 kg	21.59 abc	24.83 ab	96.24 ab
56.25 kg	18.83 d	21.94 e	85.36 e
67.5 kg	21.08 bc	23.12 d	89.84 d
78.75 kg	21.14 bc	23.63 cd	92.32 cd
90 kg	20.83 c	23.57 cd	91.74 cd
F-Value	*	*	*
LSD (0.05)	0.9984	0.7899	3.1135
CV (%)	2.05	1.44	1.46

CV (%) = Coefficient of variation, LSD= Least significant difference, * = Significant level at ($P<0.05$). Different letters indicate the groups with significant differences.

The application of 22.5 kg of potassium per hectare also improved bulb quality (Table 5). The application of potassium at a rate of 22.5 kg per hectare resulted in heavier bulbs with higher volume, density, and firmness. However, TSS was higher in the lower dose of 11.25 kg per hectare.

Table 5: *Response of onion bulb quality to different levels of potassium application*

Treatments	Bulb volume (cm3)	Fresh bulb weight (g)	Bulb density (g cm^{-3})	TSS (oBrix)	Polar firmness (Kg cm^{-2})
0 kg	106.00 ab	108.80 a	0.99 bc	10.62 ab	12.08 ab
11.25 kg	96.00 cd	98.00 d	0.98 bc	10.80 a	10.28 c
22.5 kg	101.00 bc	106.20 ab	1.05 a	9.68 c	11.89 ab
33.75 kg	105.00 ab	101.40 bcd	0.97 bc	10.70 a	13.15 a
45 kg	112.00 a	105.50 abc	0.94 c	9.92 bc	12.33 ab
56.25 kg	102.50 bc	103.50 abcd	1.01 ab	11.24 a	11.27 bc
67.5 kg	90.00 d	91.00 e	1.01 ab	10.61 ab	13.07 a
78.75 kg	99.00 bc	99.30 d	1.00 ab	9.70 c	12.09 ab
90 kg	103.00 bc	99.90 cd	0.99 bc	9.80 c	11.00 bc
F-Value	*	*	*	*	*
LSD (0.05)	8.9970	5.9684	0.0525	0.7561	1.4767
CV (%)	3.84	2.55	2.29	3.17	5.38

CV (%) = Coefficient of variation, LSD= Least significant difference, * = Significant level at ($P<0.05$). Different letters indicate the groups with significant differences.

DISCUSSION

Based on our investigation, potassium has the key rule for regulating the movement of nutrients, metabolites, and water throughout plant tissues and organs, protect plants from oxidative stress, and support the preservation of osmotic balance. So, through this the optimum amount of potassium enhance both growth and yield attributes.

In agreement with our investigation, Bekele's (2018) indicated that the application of potassium fertilizer at 120 kg per hectare significantly influenced growth, yield, and quality parameters, including plant height, leaf length, leaf count, sheath length, mean bulb weight, bulb length, bulb diameter, total soluble solids (°Brix), dry matter content (%), and bulb shape index.

Hasan (2021) observed that the application of 90 kg per hectare of potassium had a significant impact on plant height (cm), the number of leaves per plant, and leaf length (cm). He further noticed that the injection of potassium had a significant impact on the quality of onion bulbs. The onion bulb weight (65.67 g), maximum bulb width (5.05 cm), and maximum bulb production (19.83 t ha^{-1}) were achieved using 90 kg K ha^{-1}.

In addition to the recommended dosage of potassium fertilizer application, EL-Desuki et al. (2006) found that adding potassium fertilizer through spraying or soil dressing up to 4.76

L./ha of potassium oxide or 178.5 kg potassium sulfate/ha, respectively, increased the vegetative growth of onion plants and mineral uptake.

The findings of Zaidan et al. (2022) demonstrated that the addition of potassium to gypsiferous soil resulted in a reaction and that potassium fertilizer significantly increased the growth and yield indicators examined. After harvest, the amount of available potassium (dissolved and exchanged) increased significantly due to the salinity of the irrigation water used.

Shar et al. (2023) reported the same outcome, indicating that 100 kg (K) ha-1 yielded superior outcomes for all growth and yield metrics compared to other potassium levels. The same result that Hasan (2021) reported showed that the injection of potassium significantly impacted growth metrics, particularly Yield (t ha^{-1}). In contrast, the plot that did not receive potassium fertilizer had the lowest bulb production at 13.07 t ha^{-1}.

Based on the (Kumara et al., 2018) experiment result, potassium levels at 90 kg per hectare were comparable to 67.5 kg and 78.75 kg per hectare and had a substantial impact on the bulb's polar and equatorial diameters (53.80 and 60.63 mm, respectively), single bulb weight (105.18 g), and bulb yield (20.54 kg/plot and 48.91 t ha^{-1}).

Marrocos et al. (2018) suggested that potassium fertilization increased the maximum commercial and overall yields were 47.39 and 46.39 t ha^{-1} in the April to July 2013 experiment and 54.69 and 54.12 t ha^{-1} in the September to December 2012 experiment.

Based on the (Kumara et al., 2018) investigation result, potassium levels at 200 percent RDK were comparable to 67.5 kg and 78.75 kg per hectare and had a substantial impact on the bulb's polar and equatorial diameters (53.80 and 60.63 mm, respectively), single bulb weight (105.18 g), and bulb yield (20.54 kg/plot and 48.91 t ha-1).

Sable et al. (2024) observed that the application of potash and sulfur, alongside the appropriate dosage of nitrogen and phosphorus (NPKS 100:50:60:20 kg ha-1), yielded the best results in terms of production, quality measures such as physiological weight loss, and net return in onion cultivation. Additionally, total bulb yield and bulb quality increased gradually as potassium application increased up to 4.76 L/ha of potassium oxide as a foliar application or 178.5 kg of potassium sulfate/ha as a soil dressing.

According to Haftu et al. (2020), using NPSZn and KCl could be an effective way to promote the use of chemical fertilizers in conjunction with compost. Based on all factors, the optimal dosage for onion yield under experimental conditions was determined to be 90 kg K ha^{-1}. Additionally, Marrocos et al. (2018) suggested that potassium fertilization increased the amount of K in the leaf, commercial, and total yield, with the highest K2O content being achieved at a dose of 180 kg ha^{-1}.

CONCLUSION

Onion (*Allium cepa* L.) is one of the most critical commercial vegetables, which, after tomatoes, ranks second in the world, especially in Afghanistan. Potassium is essential to regulate the movement of nutrients, metabolites, and water throughout plant tissues and organs, protect plants from oxidative stress, and support the preservation of osmotic balance. The results of the present experiment suggest that applying 22.5 kg per hectare of potassium enhances both growth and yield attributes. Farmers are advised to apply this quantity of potassium through potassium sulfate to produce a higher yield of onions. Considering the limitations of laboratory equipment and reagents, we were unable to test the effect of potassium application on the sulfur content and pungency of onions. Future research may include the impact of potassium application on the nutritional quality and chemical composition of onions.

AUTHORS CONTRIBUTIONS

- H. Salari conceptualized and supervised the study.
- M.K. Rashidi, A.R. Shinwari and M.Z. Rashidi conducted the study in the field and collected the raw data
- M.K. Rashidi, H. Salari, and A.J. Zamany processed and analyzed data (equally).
- M. K. Rashidi, H. Salari, A. R. Shinwari, and A.J. Zamany wrote the manuscript with input from all authors.
- All authors reviewed and approved the final version.

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Declaration of Interests

The authors confirm that there are no conflicts of interest in any aspect of this paper.

DATA AVAILABILITY STATEMENT

Data are available upon request from the corresponding author, subject to approval of the relevant ethics committee.

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