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Effect of potassium application on maize to sandy soil under deficit irrigation conditions

Munir J. Rusan [a,*], Ayat Al-Masri [a], Rashid Lubani [b]

[a] Department of Natural Resources and Environment, Jordan University of Science and Technology, Irbid, Jordan
[b] Arab Potash Company. Amman, Jordan

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Author(s)

M.J.Rusan *
A. Al-Masri
R.Lubani

* Corresponding author

Abstract

Maize is widely growth in arid and semi-arid region where, drought is common and a limiting factor for crop production. Potassium plays a key role in enhancing plant growth under drought condition. The objective of this study is to determine the effect of K fertilization with and without NP on maize growth grown in sandy loam soil under adequate and deficit irrigation conditions. The following treatments were investigated in pot experiment: (1) control with no fertilizer application (C); (2) 128 kg N + 328 kg P_2O_5 ha^{-1} (NPK0); (3) 128 kg N + 328 kg P_2O_5 ha^{-1} + 152.5 kg K_2O ha^{1} (NPK1); (4) 128 kg N + 328 kg P_2O_5 ha^{-1} + 305 kg K_2O ha^{-1} (NPK2); and 128 kg N + 328 kg P_2O_5 ha^{-1} + 457.5 kg K_2O ha^{-1} (NPK3). Treatments were investigated under adequate and deficit soil moisture content. Each pot filled with 3.5 kg air-dry soil and seeded with maize and pots were watered according to the treatments. The results indicated that plant growth and nutrient uptake were significantly reduced under water stress condition. The application of NP increased plant growth and nutrient uptake and further were increased with K application. K application also enhanced plant tolerance to deficit soil moisture condition. In addition, K enhanced nutrient uptake and leaf chlorophyll content. Based on the results, it can be concluded that application of NP for maize was not adequate to achieve the highest plant growth, unless it is combined with K application. In addition, K application enhances plant tolerance to water stress.

Keywords: Maize, K fertilization, water stress, sandy soil.

Introduction

Maize (*Zea mays* L.), a crop of worldwide distribution, is an important cereal crop for human food and livestock feed consumption as well as for food industry owing to its high nutritional value (Ali et al., 2016). Maize is grown considerably in arid and semi-arid regions where drought is common and one of the most limiting factors for maize production in this region (FAO, 1999; Hammad and Ali, 2014). The impact of drought became even more sever due to prevailing climate change (Song et al., 2010) and several researchers predicted the climate change enhanced drought will be more severe in term of intensity and duration in several parts of the world (Liu et al., 2020; Qing et al., 2022; Kang et al., 2022).

Although maize as a C4 crop is relatively an efficient water user but is negatively affected by soil moisture deficit during vegetative and reproductive growth stages (Aslam et al., 2015; Vennam et al., 2023). Among cereal crops, Gopalakrishna et al. (2023) considered maize as the most susceptible to drought. Researchers reported a significant reduction in photosynthetic rate and maize grain quality (Yousaf et al., 2023). Moreover, maize has a relatively high nutrients requirement and besides water soil fertility level is considered another limiting factor for maize production. Therefore, growers should grow maize in a soil with high soil fertility level with balanced supply of all essential plant nutrients (Khalid and Shedeed, 2015).

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Potassium is an essential plant nutrient for plant growth and development (Caliskan and Caliskan, 2018). K is of particular importance when maize is growing in arid and semi-arid region because K play a key role in increasing water use efficiency and enhancing crops tolerance to drought stress (Rengel and Damon, 2008; Khalid and Shedeed, 2015). Adequate supply of K to crops, not only increases the quantity and quality of yields of cereal crops but also enhances their tolerance to biotic and abiotic stresses (Pettigrew, 2008; Zorb et. al., 2014). K enhances tolerance to water stress through enhancing root growth during early growth stages which lead to enhancing water and nutrient uptake and consequently support plant survival during stress condition (Hammer et al., 2009; Vennam et al., 2023). K plays a key role in enhancing water use efficiency and crop tolerance to drought stress through its role in stomatal regulation (Studer et al., 2017). Under soil moisture stress conditions, adequate supply of K enhances root growth, which consequently enhances plants water uptake and improved crop yield (Römheld and Kirkby, 2010; Hassan et al., 2017).

Most crops, including maize, require as high amount of K as N and excluding K from long term fertilization, especially under intensive cultivation, will lead to soil K depletion (Majumdar et al., 2021; Das et al., 2019, 2020, 2022). Neglecting, K fertilization will eventually threaten crop production, soil health, agricultural sustainability and global food security (Regmi et al., 2002; Cakmak, 2010; Lu et al., 2017; Brownlie et al., 2024).

The impact of both deficit irrigation and low soil fertility levels is worsened and exacerbated by fertilizer mismanagement practices. Adopting fertilizer best management practices is vital for improving growth and production of crops under various farming system (Hasanuzzaman et al., 2018). On the other hand, farmers are traditionally and commonly have been applying only N and P for a long period of time, which led to soil K depletion and soil nutrient imbalance with respect to K (Brownlie et al., 2024). Therefore, the hypothesis of this study is that the application of potassium to potassium-depleted sandy soil will improve plant growth deficit irrigation. The main objective of this study was to determine the effect of application of different K rates on growth and nutrient uptake of maize grown in sandy soil under adequate and deficit irrigation conditions.

Material and Methods

A greenhouse pot experiment was conducted to determine the effect of potassium rate on the nutrient uptake and growth of maize grown in sandy loam soil under adequate and deficit soil moisture conditions. The soil used in the experiment was collected from agriculture fields from the top 30 cm from eastern part of Jordan (Mafraq Governorate), where coarse textured soils are common. The soil was air-dried and sieved through a 5 mm sieve. The soil was analyzed for texture by hydrometer method (Gee and Bauder, 1986); soil pH and soil EC were measured on 1:1 soil : water suspension (McLean, 1982 and Rhoades, 1982, respectively); total N by Kjeldahl (Nelson and Sommers, 1980); available P by extraction with sodium bicarbonate (Olsen et al., 1954); exchangeable K, Ca and Mg by extraction with 1 M NH_4OAc (Thomas, 1982); cation exchange capacity (CEC) by the method of Palemio and Rhoades (1977). The major soil characteristics are presented in Table 1.

Table 1. Soil characteristics before conducting the experiment.

Soil pH	8.10
Soil EC, dS m^{-1}	0.75
CEC, Cmolc kg^{-1} soil	7,21
Soil N, %	0.04
Soil P, mg kg^{-1}	10.34
Soil K, mg kg^{-1}	208
Ca, %	13.11
Na, %	3.22
Soil Texture	Sandy loam

The following treatments (Table 2) were investigated in a randomized Complete Block Design (RCBD) with four replication and a total of 40 experimental units.

Each pot was filled with 3.5 kg air-dried soil. According to the treatment, N and P were added to each pot as di-ammonium phosphate while potassium as potassium sulfate. Four maize seeds per pot were seeded. After germination three homogeneous plants were kept per pot. Pots were watered periodically according to the treatments and the soil moisture was kept at 100% and to 50% of the field capacity during the period of the experiment. Time of irrigating plants was determined by weighing each pot every two days and adding water to achieve the initial wet weight of the 100% and 50% of field capacity.

Table 2. Treatments' structure

Two Soil moisture levels (Main plot):	-
100% Field Capacity water content (Adequate)	100%-FC
50% Field Capacity water content (Deficit)	50%-FC
Five Fertilizer application treatments (Sub plot)*:	-
No fertilizer application	C
128 kg N + 328 kg P_2O_5 + 000 kg K_2O ha^{-1}	NPK0
128 kg N + 328 kg P_2O_5 + 152.5 kg K_2O ha^{-1}	NPK1
128 kg N + 328 kg P_2O_5 + 305 kg K_2O ha^{-1}	NPK2
128 kg N + 328 kg P_2O_5 + 457.5 kg K_2O ha^{-1}	NPK3

*N and P were applied as Diammonium phosphate (DAP) and the recommended rate of 70-80 kg DAP ha^{-1} (Athamenh et al., 2015) K as potassium sulfate

At the end of the growing period and immediately before harvest leaf Chlorophyll content was measured using Chlorophyll Content Meter (CCM-300) device (Gitelson et al., 1999). The whole plants were harvested, and the fresh weight was recorded, then oven-dried at 70°C and oven dry weight was recorded. Oven dried plants were ground to a fine powder using a laboratory mill with 0.5 mm sieve. The milled plant samples were analyzed for total N using a modified micro-Kjeldahl digestion procedure (Bremner and Mulvaney, 1982). Total P and K were determined in the dry ash digestion. P was determined using Vanadate–Molybdate–Yellow method, K by flame photometry (Chapman and Pratt, 1961). Representative soil sample was also taken from each pot after thoroughly mixing the soil. Soil samples were sieved through 2 mm sieve and analyzed for pH, EC, N, P, K as mentioned above.

General linear model (GLM) analysis was used to statistically analyzed all data collected from this search with SAS version 9.0 (2002) software. Means were subjected to analysis of variance (ANOVA) at five percent level of significance (P≤0.05). Means separation was performed according to Least Significant Difference LSD method at P≥0.05.

Results and Discussion

Treatments effect on shoot dry weight of maize is shown in Figure 1. Shoot dry weight was the lowest for the control treatment, where fertilizers were not added, under both adequate (100%-FC) and deficit (50%-FC) soil moisture contents. For all treatments, the shoot dry weight was significantly lower under 50%-FC moisture content. Application of NP fertilizers significantly increased dry weigh compared to the control. However combined application of K with NP resulted in further increase in dry weight, and the highest shoot dry weight was obtained with the highest K rates (NPK2 and NPK3) under adequate soil moisture content. Under water deficit condition however, the shoot dry weight increased similarly by all rates of K application. The application of NP was not adequate to get the highest plant growth, unless K is applied with NP, suggesting that both water deficit and poor soil fertility levels are the two limiting factors of maize growth under the conditions of this study. This result agrees with the findings of other researchers who reported reduction in maize growth under water deficit condition and poor soil fertility (Wang et al., 2013; Hammad and Ali, 2014; Amanullah et al., 2016; Vennam et al., 2023; Yousaf et al., 2023).

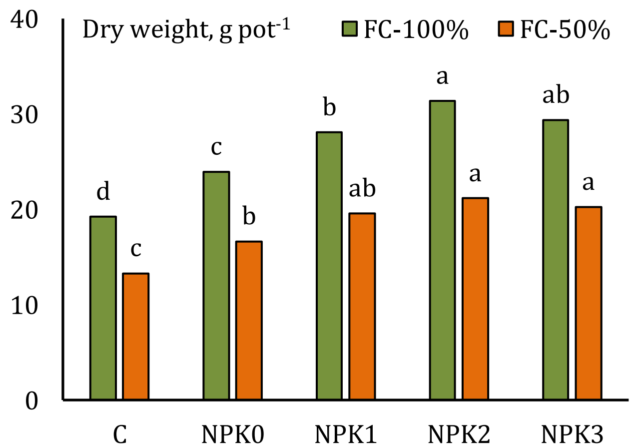

Figure 1. Shoot Dry weight of maize as affected by K application rate under two field capacity (FC) water contents. Columns with similar letters are not significantly different at P≤0.05.

Treatments effect on N uptake and chlorophyll content are shown in Figure 2 and Figure 3, receptively. Under both adequate and deficit irrigation contents, N uptake was the lowest for the control treatment and increased significantly by NP application. Combining the highest two rates of K (NPK2 and NPK3) with NP application resulted in further increase in N uptake.

Enhancing N use efficacy by K application was also found by other researchers (Rutkowska et al., 2014). Leaf chlorophyll content was the lowest for the control treatment and under deficit irrigation contents for all treatments. Compared to the control, addition of NPK0 increased the leaf chlorophyll content. The highest two rates of K (NPK2 and NPK3) increased the leaf chlorophyll content further under both soil moisture contents. It has been documented that plants grown under water stress condition had lower chlorophyll content (Efeoğlu et al., 2009; Asgharipour and Heidari, 2011; Xiang et al., 2013; Karimpour, 2019; Wach and Skowron, 2022), but upon application of K to these plants enhanced their tolerance to water stress and their chlorophyl content significantly increased (Siddiqui et al., 2012; Talal et al., 2015).

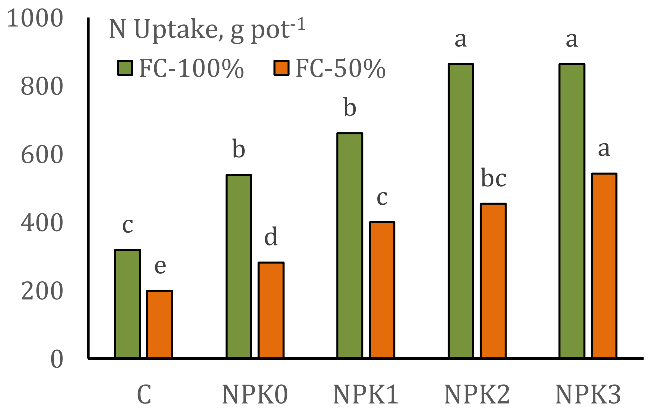

Figure 2. N uptake by maize as affected by K application rate under two field capacity (FC) water contents. Columns with similar letters are not significantly different at P≤0.05.

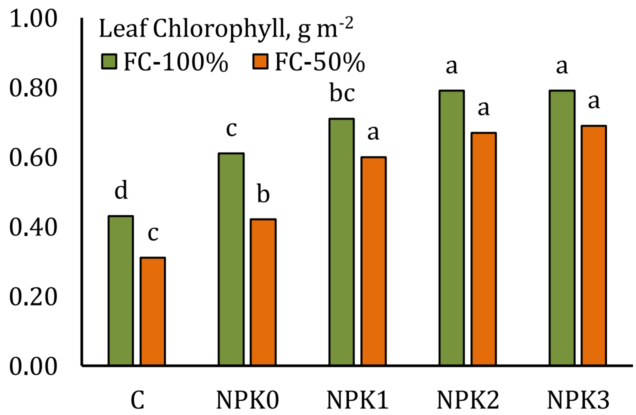

Figure 3. Leaf chlorophyll % of maize as affected by K application rate under two field capacity (FC) water contents. Columns with similar letters are not significantly different at P≤0.05.

Treatment effect on P and K uptake is shown in Figure 4 and Figure 5, respectively. Uptake of P and K was the lowest for the control treatments under both soil moisture contents. In addition, P and K uptake was lower for all treatment under deficit moisture content. Compared to the control treatment, the addition of NPK0 increased P and K uptake, then increased further with the highest two K rates. The increase in P uptake with K application was unpredictable but might be attributed to the indirect effect on shoot dry weight. As for K uptake, the increase was directly due to increasing the rate of K application up to the NPK2. This coincides with the finding of other researchers (Oltmans and Mallarino, 2015; Firmano et al., 2020; Volf et al., 2022) and they attributed such increase to the plant luxury consumption of K. On the other hand, the highest K rate (NPK3) reduced K uptake compared to NPK1 and NPK2, which can be attributed to the possible K leaching associated with high K rates under coarse textured soil as the case in our study (Rosolem and Stainer, 2017).

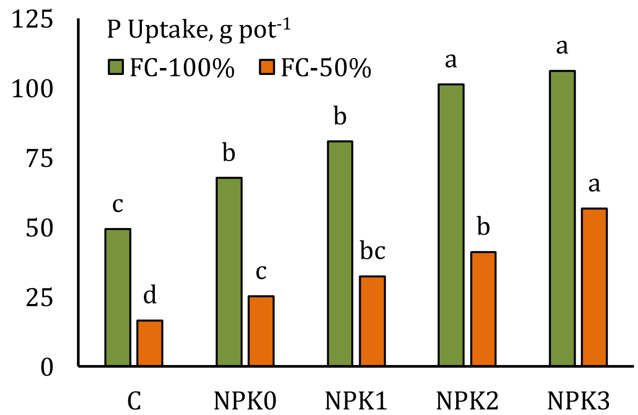

Figure 4. P uptake by maize as affected by K application rate under two field capacity (FC) water contents. Columns with similar letters are not significantly different at P≤0.05.

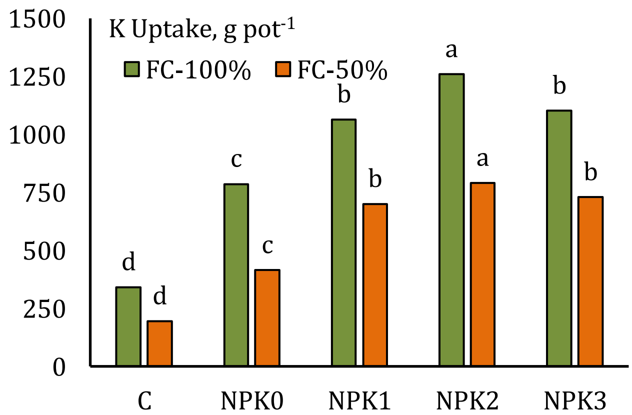

Figure 5. K uptake by maize affected by K application rate under two field capacity (FC) water contents. Columns with similar letters are not significantly different at P≤0.05.

Treatments effect on soil pH and soil EC are shown in Figure 6 and Figure 7, respectively. Soil pH was not affected by any of the treatments. Soil EC was the lowest for the control and then for the NPK0 treatment. Increasing K application rates significantly increased soil EC, due to the relatively high salt index of the applied potassium sulfate (Rusan, 2023).

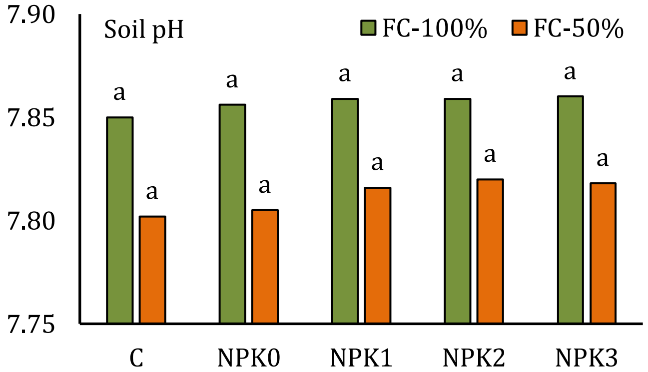

Figure 6. Soil pH as affected by K application rate under two field capacity (FC) water contents. Columns with similar letters are not significantly different at P≤0.05.

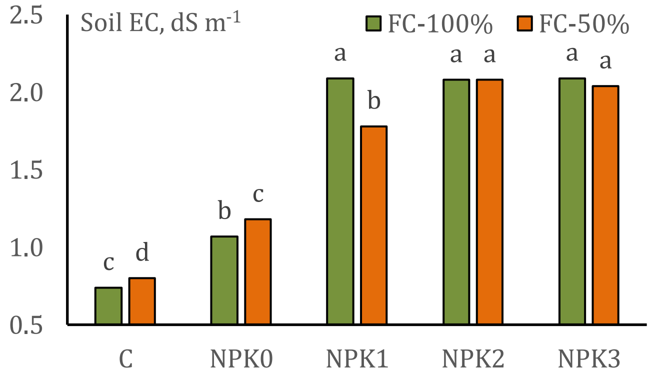

Figure 7. Soil EC as affected by K application rate under two field capacity (FC) water contents. Columns with similar letters are not significantly different at P≤0.05.

Treatments effect on soil N, P and K contents at the end of the experiment are presented in Figure 8, Figure 9 and Figure 10, respectively. Soil N was not significantly affected by the treatments under both soil moisture contents. On the other hand, and compared to the control treatment, soil P increased similarly by all other treatments under adequate soil moisture contents. However, under deficit moisture, the highest rate of K reduced P uptake, which can be due to competition between high rate of K and P (Studer et al., 2017) or might be due the indirect effect of K on P uptake through increasing dry weight. On the other hand, soil K was the lowest for the control and the NPK0 treatments. Increasing the rates of applied K, resulted in higher soil K under both adequate and deficit irrigation conditions.

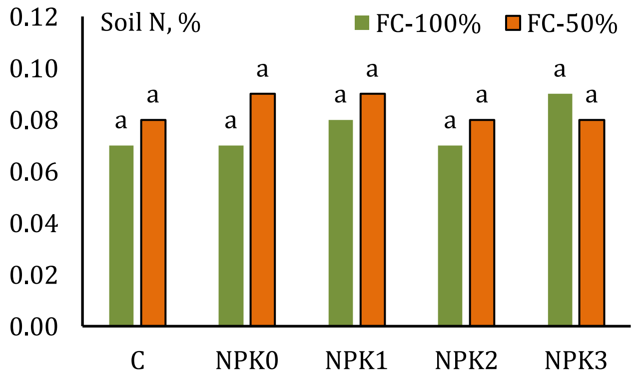

Figure 8. Soil N content as affected by K application rate under two field capacity (FC) water contents. Columns with similar letters are not significantly different at P≤0.05.

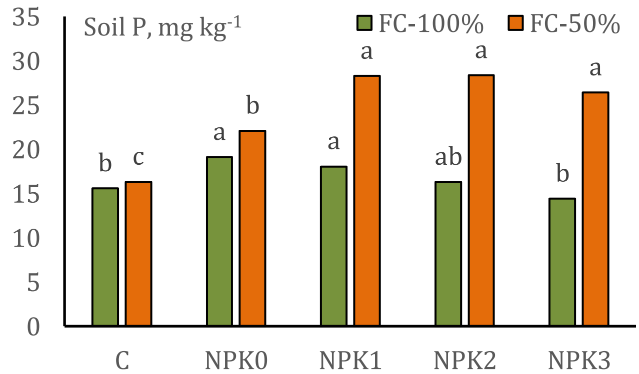

Figure 9. Soil P content as affected by K application rate under two field capacity (FC) water contents. Columns with similar letters are not significantly different at P≤0.05.

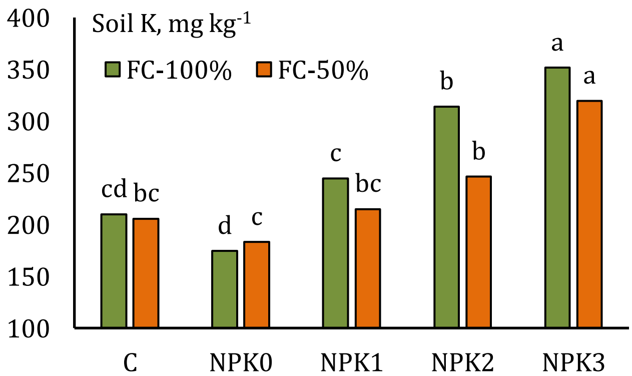

Figure 10. Soil K content as affected by K application rate under two field capacity (FC) water contents. Columns with similar letters are not significantly different at P≤0.05.

Conclusion

Based on the obtained results, it can be concluded that maize growth in sandy loam soil is severely reduced under deficit irrigation level, especially when grown under poor level of soil nutrients. Potassium was necessary to be applied in combination with NP to achieve the possible highest plant growth. The NPK2 dose application (305 kg K_2O/ha) not only gave the highest plant growth and nutrient uptake but also enhanced plant tolerance to water stress conditions. This also suggests including K fertilization as one of the strategies to combat drought stress in arid and semi-arid environment.

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