RESPONSE OF MAIZE TO ORGANIC AND INORGANIC POTASSIUM FERTILIZATION

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ABSTRACT

Fertilizer is the basic input for sustainable crop production for the growing World under the current cropland. Among macronutrients, potassium contributes greatly to plant growth, development and yield. Evaluating the effect of potassium (K) on hybrid maize (CS-200), a field trial was therefore designed and conducted at agronomy research farm during *kharif* 2017 and 2018 at The University of Agriculture Peshawar. Different K sources i.e. potassium chloride, potassium sulfate, poultry manure, farm yard manure and potassium doses i.e. 30, 60, 90 and 120 kg K ha^{-1} were investigated by using RCB design with four replicates. One control replication^{-1} was kept for its comparison with rest treatments. Seeds sowing was done in rows 70 cm apart with 25 cm inter plant spacing with in the row. Potassium chloride significantly improved grains cob^{-1} (394.35), heavier grains (298.37 g), more grain yield (4949 kg ha^{-1}), while both organic sources exhibit statistically similar grains cob^{-1} (383.60), grain weight (282.82 g) and grain yield (4356 kg ha^{-1}). Potassium chloride exhibits more protein content of the grain (9.21 %), more grain K (0.54 %), higher soil available K (158.91 mg kg^{-1}), higher leaf water content (91.53 %) and reduction in water lost after 90 minutes (61.93 %) interval. Potassium supplied at 120 kg K ha^{-1} produce heavier grains (297.18 g), more grain nitrogen (1.63 %), grain protein (9.29 %), soil available K (162.39 mg kg^{-1}) and more leaf relative water status (90.34 %). Statistically similar results for 90 and 120 kg K ha^{-1} was noted for grain yield (4859 kg ha^{-1}), grains K content (0.59 %) and reduction in water lost from cut leaf surfaces after 90 minutes (60 %). Potassium chloride enhanced yield, yield components, physiology and grain quality significantly along with maximum net returns (PKR 197718/- ha^{-1}) with maximum VCR value (4.53). Potassium applied at 90 and 120 kg K ha^{-1} enhanced yield, growth, yield components, physiology and grain quality. Application of potassium at 90 kg ha^{-1} from potassium chloride was economical for enhancing growth, phenology, yield, yield attributes, physiology, grain quality and is thus recommended for cultivation of maize under the climatic conditions of Peshawar valley.

Keywords: Relative water content, excised leaf water loss, yield, grain quality.

INTRODUCTION

Corn (*Zea mays* L.) is a high potential cereal of Pakistan and throughout the world (NARC, 2015) and is now gaining an important position in Pakistan's economy due to its higher yield capacity and short growing period (PARC, 2016). During 2018, area occupied by maize in Pakistan was 1.229 million ha approximately with 5.702 million tones production with 4640 kg ha^{-1} as an average yield (Pakistan Bureau of Statistics, 2017-18). Area occupied by maize in KP (Khyber

Pakhtunkhwa) during 2018 was 0.4734 million ha with 0.8901 million tones production giving an average yield of 1900 kg ha^{-1} (Crop Statistics, KP 2016-17). Maize grain is composed of starch 72%, vitamin A and B 3-5%, 10% proteins content, 4.8% oil content, 5.8 % fiber content, 3.0% sugar and 1.7% ash content (Arain, 2013) and tanning materials for lather industry (Jack, 2010). Maize is great source of roughages for livestock because of the largest concentration of energy, component for concentrate foods. It has also been used for bio-fuel production (Jaliya et al., 2008). Potassium, being a primary macronutrient has a significant role in agriculture (Bukhsh et al., 2012) by enhancing crop growth, development and yield (Bukhsh et al., 2008). Potassium acts as a cofactor for enzymes in various metabolic pathways, stomatal conductance and regulation of cell osmotic pressure. Potassium is a macronutrient but badly ignored in the Pakistan as farmers generally believes that K application do not increase yield significantly. However K content of Pakistani soil is decreasing at an alarming rate of 0.3 kg ha^{-1} $annum^{-1}$ because of continuous cropping and its lower application to the soil (Ahmad et al., 2012). Potassium application to the soil in Pakistan is quite low (0.8 kg ha^{-1} $annum^{-1}$) as compared to the world's average (15.1 kg ha^{-1} $annum^{-1}$) (Ahmad & Rashid, 2003 ; Bukhsh et al., 2010). There is a general opinion that Pakistani soil type are illite clay minerals and a misconception to have enough ability to make K accessible to the crop (Bukhsh et al., 2008). However most of the soil in Pakistan contains large quantity of total potassium and merely a minute quantity exists in available form for the crops (Tariq et al., 2011; Shah et al., 2018). Potassium is depleted by continuous cropping (Mengel et al., 2001; White, 2003), while release of potassium from soil is not enough to fulfill crop demands (Tariq & Shah, 2002) and thus additional K must be applied from fertilizers to boots up crop yield. Hence the current research was designed to explore the significant effect of K sources and K levels on the productivity of hybrid corn along with their interactive effects under the climatic conditions of Peshawar.

III. MATERIALS AND METHODS

Details of the experimental location

A two-year research was conducted at The University of Agriculture, Peshawar in Agronomy Research Farm, during *kharif* 2017 and *kharif* 2018. The site is situated at 34 °N, 71 °E, at an elevation of 350 m. The research site was irrigated from river *Kabul* through Warsak canal. Peshawar has semiarid climate where annual average rainfall is quite lower (300 to 450 mm), most of the rainfall occurs during summer (60–70%), while 30–40% occurs during winter (Amanullah et al., 2010). Soil texture of the research site is clay loam, alkaline with a pH value of 8.2, and high in calcium with lower organic matter (8.7 g kg^{-1}).

Treatment plans

Potassium sources (potassium chloride, potassium sulphate, farm yard manure and poultry manure) and their different levels (30, 60, 90 and 120 kg K ha^{-1}) were investigated for the productivity of maize at The University of Agriculture Peshawar in agronomy research farm in *kharif* 2017 and *kharif* 2018. One control was kept $replication^{-1}$ for comparison with the treated plots. The design, RCB having four replications were used for conducting the research. Each replication was consisted of 17 treatments containing one control for K. Maize local hybrid (CS-200) as test crop was sown in plots having size of 21 m^2 occupying 6 rows, each 70 cm apart. Nitrogen was applied from urea (46%) and P from SSP (18 % P) at 180 kg N and 90 kg P ha^{-1} respectively. The two organic sources of K i.e. poultry manure (PM) and farm yard manure (FYM) along with potassium sulfate contains additional macronutrients which were compensated as it influences the yield. The amount of N and P supplied through organic sources PM and FYM were compensated from urea and SSP, while sulfur in sulphate of potash, was compensated from *Kumulus* a rich pure source of sulphur (80 % elemental S). All potassium levels were applied during sowing, phosphorus at preparation of seed bed, while N in splits i.e. half during crop sowing and half at vegetative (V8) stage. A composite soil sample was used for analyzing K status before sowing at a soil depth of 30 cm. The available potassium was 112 mg/kg. Due to problems in decomposition, during both the years the organic sources of K i.e. FYM and PM was applied to the field four weeks before sowing. Thinning was done during vegetative phase (V4 stage) of the crop. To avoid disease and pest attack regular protection measures were carried out, consisting of Furadon (@ 20 kg ha^{-1}) to manage corn borer (*Chilo partellus*) and *chloropyrifos* at the rate of 2 kg ha^{-1} (20 % EC) to control white fly (*Bemisia tabaci*). After third irrigation earthing up was done to minimized crop lodging.

Weather data

The cardinal temperature (Maximum and minimum temperatures in ^{0}C) and rainfall (cm) for the growing period of maize is presented in figure 1.

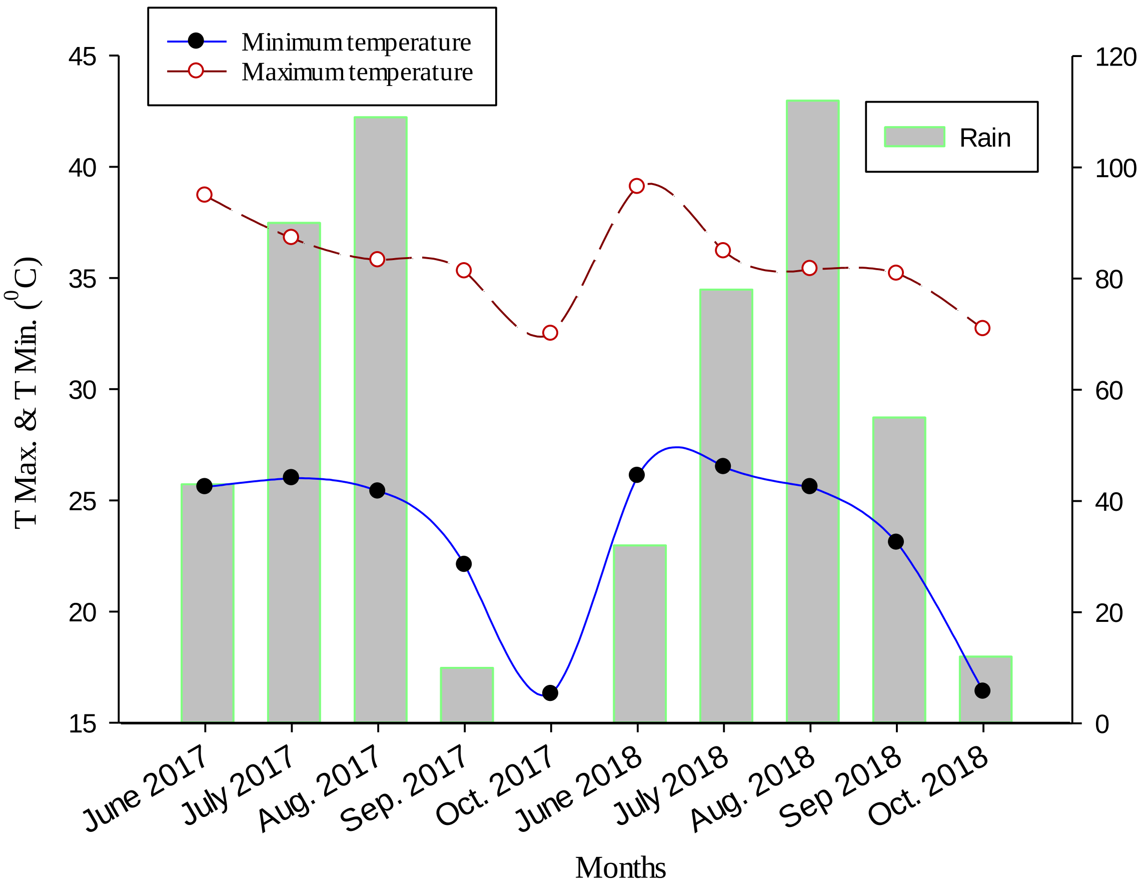

Figure 1. Weather data of the research site during the growing sesaon (2017-2018).

Grains ear^{-1} was recorded by picking ten ears at random from each plot in four harvested middle rows and their grains were counted. For grains weight, seeds from seed-lot of each plot were taken, 1000 seed were separated with the help of seed counter and were weighed through sensible electronic scale. Threshed seeds of the four middle rows were used for grain yield. Seed lot of the middle four rows were weighed through sensitive balance and was transformed to kg ha^{-1} through the equation given below:

$$\text{Grain yield (kg ha}^{-1}\text{)} = \frac{\text{Grain yield in four middle rows}}{\text{R - R distance} \times \text{Row length} \times \text{No of rows}} \text{ x } 10000$$

For determination of grain protein (%) following equation was used:

Grian protein (%) = N% in grain × 5.7 (Mariotti et al., 2008).

For analysis of K in both seed and plant tissues same procedure were used. The plant samples used for K analysis were washed through distilled water, rinsed with tissue paper and were kept in an oven at 60 C^0 for 24 hours. These samples were then grounded to fine powder after 24 hours and 0.5 g samples was taken in a flask. Further 10 ml HNO_3 (concentrated) was added to these samples, mixed it and left overnight in shade. After 24 hours 4 ml perchloric acid was taken with the help of burette and poured to this sample solution and transferred it to the hot plate (digestion assembly). End color was white fumes and the samples were get ready to be analyzed by flame photometer. Potassium in plant samples were analyzed through formula:

$$\text{K (\%)} = \frac{\text{Instrument reading} \times \text{volume made}}{\text{weight of soil} \times \textit{volume taken} \times 10{,}000}$$

AB-DTPA extractable soil K was analyzed by using the procedure of Soltanpour & Schawab, 1977. Solution of AB-DTPA was made by mixing 2g of DTPA (0.005 M) in 0.5 L of water containing 4 ml of ammonia solution (1:1) to assist dissolution and to avoid bubbles. Sodium bicarbonate (134 g) was taken and dissolved 1.2 L of water. These two solutions were added and mixed by maintaining pH at 7.6 through ammonia and HCl and the finally 2L volume was made. A soil sample of 0.5 g was placed in a flask, 1 ml of AB-DTPA was poured and stirred gently on a shaker for 15 minutes, while flask was left uncovered. This solution was then filtered through whatmaan 42 and stored for analysis. The soil available K content was determined by flame photometry where, it was first calibrated against the standards i.e. 0, 20, 40, 60, 80 and 100 mg K/L. The absorbance was then converted to concentrations.

$$\text{K (mg/kg)} = \frac{\text{Reading}}{\text{Dilution Factor}} \times \frac{\text{volume of AB} - \text{DTPA}}{\text{weight of soil}}$$

For finding the relative water content (RWC) leaves were collected from each plot and were directly placed in air tight bags and then weighed with sensitive balance to record their initial fresh weight (FW). The leaf discs samples were then submerged completely in distilled water and stored in dark for 24 hours at 4 C^0. Then the leaf disc samples were rinsed with tissue paper to eliminate additional water on the surface and thereafter leaf turgid weight was determined. These samples were then placed in oven for 48 hours at 70 C^0 for 48 hours for calculating the dry weight. RWC was determined as follows:

$$\text{RWC(\%)} = \frac{\text{Fresh } leaf \text{ weight (FW)} - \text{leaf oven dry Weight}}{\text{leaf turgid weight} - leaf \text{ oven dry weight (DW)}} \times 100$$

The amount of water loss from the excised leaf surface at different rates in various time intervals was determined by cutting leaf discs (10 cm^2) taken from the plants at three places selected randomly in each plot and th4en averaged. The excised leaf discs were transferred directly to air tight plastic bags to avoid water loss and their weight were recorded instantly along with the plastic bag. Later on the weight of the plastic bags was subtracted and just discs weight were noted. After recording of fresh weight, the leaf discs were kept in sunlight at various intervals staring from 0 (Fresh weight) and 90 minutes to record the water loss as reduction in weight of the leaf discs. The amount of water loss was recorded as the differences between the initial (fresh weight) and final leaf discs weight (Ali et al., 2011) using the following equation:

$$\text{ELWL (\%)} = \frac{\text{Fresh weight (FW)} - \text{Weight after 90 minutes}}{\text{Oven dry weight (DW)}} \times 100$$

Statistical analysis

Finally data after collection were analyzed according to the design (RCBD) and comparison of means were done through LSD test (at 5 % significance), when the f-value were significant (Jan et al., 2009).

RESULTS

Grains cob^{-1}

The response of grains cob^{-1} (Table 1) of maize were statistically significant to different potassium sources, K levels, control vs. rest and interaction (KS x KL), while the effect of years and rest of the interactions were found insignificant. More grains cob^{-1} (394.35) was obtained when potassium was applied from potassium +chloride (KCl) followed by potassium sulfate (390.69) and the minimum grains cob^{-1} (383.60) was recorded by application of K from farm yard manure, while poultry manure application statistically produced more grains per row (387.56) as compared to farm yard manure. More grains cob^{-1} were recorded by application of 120 kg K ha^{-1} (400.55) which was statistically same with 90 kg K applied ha^{-1} (400.35), while minimum grains cob^{-1} (366.19) were noted from application of 30 kg K ha^{-1}. Potassium application recorded more grains cob^{-1} (389.05) as compared to K control (318.98). A linear increase (Figure 2) was noted for grains cob^{-1} with simultaneous increase in K levels from 30 to 120 kg ha^{-1} applied from potassium chloride. Shifting from KCl to rest of the K sources significantly reduced grains cob^{-1} of maize with keeping level of K constant.

Thousand grain weight (g)

The influence of potassium sources, K levels, control vs. rest and interaction (KS x KL) were significant statistically for 1000 grain weight (Table 2), while year effect and rest of the possible interactions were not significant statistically. Heavier grains (298.37 g) were obtained by application of potassium chloride followed by potassium sulfate (287.23 g) and lighter grains (282.82 g) were observed by application of K from farm yard manure. Between organic sources poultry manure surpassed farm yard manure by producing heavier grains (285.19 g). More 1000 grain weight (297.18 g) were recorded by application of 120 kg K ha^{-1} and the less 1000-grain weight (275.52 g) were obtained by 30 kg K applied ha^{-1}, while application of 60 kg K produced heavier grains (285.26 g) as compared to 30 kg K ha^{-1} application. Comparison of control and fertilized plots was highly significant statistically as control produce less 1000 grain weight (272.02 g) and the treated produce more 1000-grain weight (288.40 g). There was a linear trend (Figure 3) for 1000-grain weight between potassium sources and potassium levels. Application of K from 30 to 90 kg ha^{-1} from KCl linearly improved grains weight and further increase in K levels decrease grains weight, while no decline was noted after 90 kg K ha^{-1}.

Grain yield (kg ha^{-1})

Grain yield of maize (Table 3) was affected by K sources, K levels, year and interaction between K sources and K levels (KS x KL) while other interactions were insignificant statistically. Among potassium sources higher grain yield (4949 kg ha^{-1}) was recorded by the application KCl and the lower grain yield was observed by farm yard manure (4356 kg ha^{-1}) application. Between K organic sources poultry manure exceeded (4405 kg ha^{-1}) farm yard manure. More grain yield (4849 kg ha^{-1}) was achieved from 120 kg K ha^{-1} application which was similar statistically to 90 kg K ha^{-1} (4834 kg ha^{-1}) and minimum grain yield (4238 kg ha^{-1}) was Obtained from 30 kg K ha^{-1} application. The comparison between control and rest treatments showed statistically a significant effect as control produced low grain yield (3925 kg ha^{-1}) and K treated plots showed higher grain yield (4604 kg ha^{-1}). Grain yield recorded was different during both the years and grain yield was recorded during 2017 (4276 kg ha^{-1}) was higher as compared to 2018 (4250 kg ha^{-1}). Grain yield increased linearly (Figure 4) by increasing K levels from 30 to 90 kg K ha^{-1} and similar response was observed as we move from organic K to inorganic sources of K.

Grain crude protein content (%)

Grain crude protein (Table 4) was affected by various sources of potassium, K levels and interaction between potassium sources and its levels, while the effect of year and other possible interactions were found insignificant. More crude protein content (9.21 %) was obtained by application of potassium chloride followed by potassium sulfate (8.69 %) and minimum grain crude protein (8.42 %) was recorded for farm yard manure which was at par with poultry manure (8.48 %). Higher grain protein content (9.29 %) was observed by applying 120 kg K ha^{-1} and lower protein content (7.79 %) was observed from application of 30 kg K ha^{-1}. Potassium application at 60 kg K ha^{-1} produced more crude protein (8.52 %) in grain as compared to 30 kg K ha^{-1}. Potassium treated plots produce more crude protein in grains (8.70 %) as compared to control which yield statistically low grain crude protein (7.74 %). Increasing potassium levels (Figure 5) from 30 to 120 kg ha^{-1} increased grain protein content for all the sources of potassium. Each unit increase in K levels and a shift from organic to inorganic sources showed a significant increase in grain protein content of maize.

Grain K content (%)

Potassium content in the grain (Table 5) was affected significantly by K sources, their respective levels, while the effect of years and other interactions were non-significant statistically for grain K content. Potassium chloride application significantly enhanced grain K content (0.540 %)

followed by potassium sulfate application (0.519 %) which was similar statistically to poultry manure application (0.510 %) and lower grain K content (0.496 %) were obtained from farm yard manure applied plots. The effect of both organic K sources was similar for grain K content. Potassium applied at 120 kg K ha^{-1} significantly enhanced grains K content (0.593 %) followed by 90 kg K (0.587 %) and the minimum grain K content (0.415%) were obtained by application of 30 kg K ha^{-1}, however the effect of 60 kg K was superior and produce more grain K content (0.470 %) as compared to 30 kg K applied ha^{-1}. Comparison of control and rest plots showed a significant difference as potassium untreated plots produce lower grain K content (0.343 %) and potassium applied plots produced more grain K content (0.516 %).

Soil potash content (mg kg^{-1})

Soil available K (Table 6) was affected statistically by various K sources, K levels, interaction (KS x KL) and control vs. rest, while the effect of years and rest of the possible interactions were found insignificant statistically. Soil available K content was higher (158.91 mg kg^{-1}) with application of potassium chloride followed by potassium sulfate (157.12 mg kg^{-1}) and minimum available K content (155.11 mg kg^{-1}) was recorded by farm yard manure applied plots which was alike to poultry manure (155.57 mg kg^{-1}). Soil available K was highly significant for potassium supplied at 120 kg ha^{-1} and significantly increase soil potash content (162.39 mg kg^{-1}) followed by potassium sulfate (158.72 mg kg^{-1}) and low soil potassium content (151.68 mg kg^{-1}) was recorded for 30 kg K applied ha^{-1}. Application of 60 kg K ha^{-1} recorded more soil K content (154.25 mg kg^{-1}) than 30 kg K. The control vs. treated plots showed a highly significant effect as K applied plots recorded high K available content (156.68 mg kg^{-1}) in the soil and unfertilized plots produce lower soil available K content (109.07 mg kg^{-1}). A linear trend (Figure 6) between potassium sources and potassium levels was observed as increasing K levels from 30 to 120 kg ha^{-1} linearly increased soil K content for all sources of potassium except for poultry manure, where decline in soil K content was observed beyond 90 kg K ha^{-1}.

Relative water content (%)

Relative water content (Table 7) is the water content present in the fresh leaf to the maximum amount of water the leaf can hold at a given temperature and pressure. Leaf water content was affected significantly by different potassium sources, potassium levels and interaction between KS x KL, while rest of the interactions and the effect of years was insignificant for leaf relative water content. Higher relative water content (91.53 %) were obtained by potassium chloride application followed by poultry manure (87.11 %) which was similar statistically to potassium sulfate (87.05 %), while lower relative water content (82.99 %) were obtained by application of farm yard manure. Higher levels of potassium i.e. 120 kg K ha^{-1} application significantly produce more relative water content (90.34 %) followed by 90 kg K ha^{-1} (89.34 %) and the lower water content (83.74) were obtained by application of 30 kg K ha^{-1}. Application of 60 kg K ha^{-1} produce more relative water content (85.26 %) than 30 kg K ha^{-1} application. Comparison of control and rest showed a significant difference as control produce low water content (81.88 %) and potassium treated plots produce more leaf water content (87.17 %). Increasing potassium levels (Figure 7) from lower (30 kg K ha^{-1}) to higher level (120 kg K ha^{-1}) and shifting from organic to inorganic sources significantly increase relative water content.

Excised leaf water loss (%) after 90 minutes

Water lost from the excised leaves (%) after an interval of 90 minutes (Table 8) was significantly affected by sources of potassium, their levels, interaction (KS x KL) and control vs. rest, while the effect of years and other interactions were found non-significant statistically. Water lost was lower (61.93 %) from the excised leaf surfaces by the application of potassium chloride followed by potassium sulfate (65.85 %) and more water loss was observed from the excised leaves by farm yard manure (67.34 %) application and poultry manure (67.59 %) which was statistically similar. Among potassium levels application of 120 (60.96 %) and 90 kg K ha^{-1} (60.74 %) reduced the amount of water lost from the excised surfaces and gave similar results statistically, while more water was lost (71.89 %) from the excised surfaces by application of K at 30 kg ha^{-1}. Water lost from the excised leaf surfaces was more in control plots (76.73 %), while treated plots reduced water lost (65.68 %) significantly. Water lost from the excised surface of the leaf was reduced significantly by increasing K levels (Figure 8) from 30 to 90 kg ha^{-1}. Potassium application from inorganic sources drastically reduced the amount of water lost from the excised leaf as compared to organic sources irrespective of the level applied.

Discussion

Potassium application to corn has positive effect on crop yield and growth (Kubar et al., 2013) because of enhancing grains per cob (Ahmad & Akram, 2017) and cob length (Bukhsh et al., 2012). Application of K improve grains per cob's row and grains per ear (Amanullah et al., 2007) due to more K uptake which in turns contributed to photosynthetic activities, translocation and improved enzymatic activities (Akhtar et al., 2003). Application of potassium to maize in comparison to control significantly increase grains weight by 9% and grains number per cob by 5% (Zare et al., 2014) due to ionic balance which in turns trigger assimilates. Other possible reason could be the higher pollen viability under applied K (Monjardino et al., 2006) and better seed set.

Hormones like *Zeatin*, Z *ribiside* and abscisic acid contents were improved with K application which strengthen the sink its filling and grain development (Lv et al., 2017a ; Lv et al., 2017b) and thus increase grains weight. Potassium applied to maize produces heavier grains (Aslam et al., 2014) due to more translocation to the cob, efficient uptake of nitrogen and role of K in enzyme activation during photosynthesis which tends to transport more assimilates to the sinks (Abasiyeh *et al*., 2013). Improved grains weight were observed by application of K (Ali et al., 2015) due to assimilation and utilization of nitrogen (ondieki et al., 2011) in plant biomass as K enhanced N uptake. Inadequate potassium in the plants reduce the photo-assimilate pool formed in the leaves (Ahamd et al., 2012) and as a results lower photo-assimilates for the sink is available (Bukhsh et al., 2011a) which results in lighter grains.

Yield of maize was enhanced by the K application (Ahamd & Akram, 2017) as compared to control plot, probably is a clear indication of available K deficiency (Tariq et al., 2011) and contribution of potassium in photosynthesis, uptake of nutrients and activation of enzymes for synthesis of protein (Meille and Pellerin, 2008). More grains per cob and heavier grains (Pettigrew, 2008) were obtained by the application of potassium which finally contributed to the grain yield. Application of potassium to maize in comparison to control significantly increase grains weight by 9%, grains number per cob by 5% and eventually grain yield by 16.5% (Zare et al., 2014) due to ionic balance and proper isohydric behavior (Reddya *et al.*, 2004). Maize grain yield was increased (32.1%) by application of potassium as compared to control (Jiang et al., 2018) due to adequate N uptake, protein formation and translocation of sugars to the sinks (Amanullah et al., 2016). Ear length, diameter, height (Ertiftik & Zengin, 2016), grains weight, row number per cob and grain yield (Ali et al., 2016) were enhanced by the application of potassium. This may be the result of more nutrients, majorly nitrogen in plant tissues and its translocation to the cob (Farooqi et al., 2012).

More crude protein were recorded by application of K at higher rates (Ahmad & Akram, 2017) due to K synergy with nitrogen (Mallarino et al., 2011). The major constituent of protein is nitrogen and K application (120 kg K ha^{-1}) increase nitrogen in grain due to synergistic interaction and transportation of other nutrients (Kumar et al., 2015) to the sinks and finally boost up the grain crude protein content (Gnanasundari et al., 2018). Same findings were revealed by Ortas, 2018, who reported that soil applied potassium enhanced N and K uptake by plants. Potassium application increase grain crude protein (Rehman *et al*., 2008) as K stimulates nitrate ion and promote its uptake and translocation to the grain. More nitrogen was obtained by application of K (Martineau et al., 2017) as K is responsible for the acropetal transport of nitrate.

High K content of the grain with higher levels of potassium application was mainly due to the reason that K availability was higher and consequently its uptake by the plant (Wakeel et al., 2005). Potassium concentration and its uptake by roots was higher in all the levels of applied K as compared to untreated K plots which tends to increase plant K content (Srinivasa, 2013). Higher application of K tends to enhance mobile ions to the plant roots and make nutrients available for uptake (Hussaini et al., 2008) and hence more K uptake was observed (Ortas, 2018). Application of K increase tissue K content (Jiang et al., 2018) as compared to K unfertilized plots.

Application of potassium increased the soil K status (Tariq et al., 2011) significantly over control and possible reason could be the conversion of non-exchangeable K to exchangeable-K. Potassium chloride provide more K to the soil as compared to sulfate of potash (Tariq & shah, 2002) due to conversion of K to exchangeable K and limited leaching. Water relations in plant is improved by addition of K and helps to maintain turgidity (Aslam et al., 2013) due to higher osmotic potential and relative water content. Higher K application to maize results in higher leaf K content and thus retain more water content and leaf turgor (Negina & Moshelion, 2016). Different antioxidant enzymatic activities i.e. peroxidase, superoxide dismutase and catalase enhance tolerance to osmotic stress (Zare et al., 2014) thereby reducing water loss. Leaf osmotic potential and its water content were decreased at lower K input while external K supply enhanced K leaf content (Sami et al., 2020) and leaf turgor of maize. Another reason of lower water content is the reduced activities of antioxidant enzymes under deficient K (Jan et al., 2017).

It is an established fact that K fertilization utilized the available moisture effectively (Mahmood et al., 1999) and their by reducing water loss due to involvement of K in osmo-regulation (Mahmood *et al*., 2000). In fact potassium is the key component of plant to mitigate water loss (Bakhsh et al., 2012) by adjustment of the biophysical role. Water retention in plant tissues was improved by addition of K, thereby reducing water escape from tissues (Bukhsh et al., 2011b). Regulation of stomatal conductance under K application is another reason of reduced water loss (Majore et al., 2002) due to maintenance of proper water balance. Potassium nutrition decrease water loss by reducing evapotranspiration (Martineau et al., 2017) and keep water potential of the leaf at an optimum level (Martínez-Vilalta et al., 2014). Water loss was more in K unfertilized tretaments as both stoma opening and closing is defective under limited K supply (Blatt et al., 2014).

CONCLUSIONS

Between inorganic potassium sources, potassium chloride significantly enhanced growth, phenology, yield, yield components, physiological attributes and qualitative traits of maize. Poultry manure performs better than farm yard manure by increasing grains cob^{-1}, heavier grains, more grain yield, more relative content and lower water lost from the excised leaf surfaces. More net return was obtained by application of potassium chloride with a higher value cost ratio (4.53) as compared to the rest potassium sources. Application of K at 120 kg ha^{-1}, produce heavier grains, grain protein, soil available K content and relative water content. Regarding potassium levels, response of maize was same statistically to application of 120 and 90 kg K ha^{-1} for grain yield, grains K content and reduction in excised leaf water loss. Application of potassium at the rate of 90 kg ha^{-1} from potassium chloride was more economical for enhancing growth, phenology, yield, yielding attributes, physiology and grain quality and is thus recommended for maize production.

Table 1. Grains cob^{-1} of maize as affected by potassium sources and their levels.

Treatments	Year		
	2017	2018	
Potassium Sources (S)			Means
Potassium Chloride (KCl)	396.16	392.54	394.35 a
Potassium Sulfate (K_2SO_4)	395.90	385.47	390.69 b
Farmyard manure	384.93	382.27	383.60 d
Poultry manure	392.58	382.53	387.56 c
LSD (P=0.05)			2.83
Potassium levels (kg ha^{-1})			
30	376.58	355.80	366.19
60	392.72	385.48	389.10
90	399.83	400.87	400.35
120	400.43	400.66	400.55
LSD (P=0.05)			2.83
Control vs rest			
Control (CR)	319.00	318.97	318.98
Rest	392.39	385.70	389.05

Significance			*
Year (Y) means	355.70	352.33	NS
Interactions	Significance	Interactions	Significance
S x L	*	Y x CR	NS
Y x S	NS	Y x S x L	NS
Y x L	NS		

Mean values in each row and column followed by similar letter (s) are not significantly different from one another at 0.05 level of significance.

Table 2. Thousand grain weight (g) of maize as affected by potassium sources and their levels.

Treatments	Year		
	2017	2018	
Potassium Sources (S)			Means
Potassium Chloride (KCl)	298.41	298.33	298.37 a
Potassium Sulfate (K_2SO_4)	287.28	287.19	287.23 b
Farmyard manure	283.61	282.03	282.82 d
Poultry manure	285.65	284.72	285.19 c
LSD (P=0.05)			1.02
Potassium levels (kg ha^{-1})			
30	276.12	274.92	275.52 d
60	285.07	285.45	285.26 c
90	295.57	295.74	295.66 b
120	298.20	296.16	297.18 a
LSD (P=0.05)			1.02
Control vs rest			
Control (CR)	273.39	270.65	272.02
Rest	288.74	288.07	288.40

Significance			*
Year (Y) means	281.06	279.36	NS
Interactions	Significance	Interactions	Significance
S x L	*	Y x CR	NS
Y x S	NS	Y x S x L	NS
Y x L	NS		

. Mean values in each row and column followed by similar letter (s) are not significantly different from one another at 0.05 level of significance.

Table 3. Grain yield (kg ha^{-1}) of maize as affected by potassium sources and their levels.

Treatments	Year		
	2017	2018	
Potassium Sources (S)			Means
Potassium Chloride (KCl)	4960	4938	4949 a
Potassium Sulfate (K_2SO_4)	4691	4698	4695 b
Farmyard manure	4382	4329	4356 d
Poultry manure	4445	4365	4405 c
LSD (P=0.05)			49
Potassium levels (kg ha^{-1})			
30	4268	4208	4238 c
60	4489	4456	4473 b
90	4843	4825	4834 a
120	4878	4840	4859 a
LSD (P=0.05)			49
Control vs rest			
Control (CR)	3932	3918	3925

Rest	4620	4582	4601
Significance			*
Year (Y) means	4276	4250	*
Interactions	Significance	Interactions	Significance
S x L	*	Y x CR	NS
Y x S	NS	Y x S x L	NS
Y x L	NS		

Mean values in each row and column followed by similar letter (s) are not significantly different from one another at 0.05 level of significance.

Table 4. Grain protein content (%) of maize as affected by potassium sources and their levels.

Treatments	Year		
	2017	2018	
Potassium Sources (S)			Means
Potassium Chloride (KCl)	9.22	9.20	9.21 a
Potassium Sulfate (K_2SO_4)	8.69	8.68	8.69 b
Farm yard manure	8.42	8.41	8.42 c
Poultry manure	8.49	8.47	8.48 c
LSD (P=0.05)			0.08
Potassium levels (kg ha^{-1})			
30	7.97	7.98	7.97 d
60	8.52	8.52	8.52 c
90	9.03	8.99	9.01 b
120	9.30	9.28	9.29 a
LSD (P=0.05)			0.08
Control vs rest			

Control (CR)	7.72	7.76	7.74
Rest	8.71	8.69	8.70
Significance			*
Year (Y) means	8.22	8.22	NS
Interactions	Significance	Interactions	Significance
S x L	*	Y x CR	NS
Y x S	NS	Y x S x L	NS
Y x L	NS		

Mean values in each row and column followed by similar letter (s) are not significantly different from one another at 0.05 level of significance.

Table 5. Grain K content (%) of maize as affected by potassium sources and potassium levels

Treatments	Year		
	2017	2018	
Potassium Sources (S)			Means
Potassium Chloride (KCl)	0.541	0.539	0.540 a
Potassium Sulfate (K_2SO_4)	0.527	0.512	0.519 b
Farm yard manure	0.499	0.493	0.496 c
Poultry manure	0.504	0.516	0.510 bc
LSD (P=0.05)			0.02
Potassium levels (kg ha^{-1})			
30	0.403	0.427	0.415 c
60	0.478	0.461	0.470 b
90	0.590	0.584	0.587 a
120	0.600	0.587	0.593 a
LSD (P=0.05)			0.02

Control vs rest			
Control	0.337	0.348	0.343
Rest	0.518	0.515	0.516
Significance			*
Year means	0.427	0.431	NS
Interactions	Significance	Interactions	Significance
S x L	NS	Y x CR	NS
Y x S	NS	Y x S x L	NS
Y x L	NS		

Mean values in each row and column followed by similar letter (s) are not significantly different from one another at 0.05 level of significance.

Table 6. Soil available K content (mg kg^{-1}) as affected by potassium sources and potassium levels.

Treatments	Year		
	2017	2018	
Potassium sources (S)			Means
Potassium Chloride (KCl)	158.79	159.04	158.91 a
Potassium Sulfate (K_2SO_4)	157.60	156.64	157.12 b
Farm yard manure	155.49	155.65	155.57 c
Poultry manure	154.19	156.03	155.11 c
LSD (P=0.05)			1.26
Potassium levels (kg ha^{-1})			
30	151.78	151.59	151.68 d
60	153.46	155.04	154.25 c
90	158.40	158.36	158.38 b

120	162.43	162.36	162.39 a
LSD (P=0.05)			1.26
Control vs rest			
Control	110.15	108.00	109.07
Rest	156.52	156.84	156.68
Significance			*
Year means	133.33	132.42	NS
Interactions	Significance	Interactions	Significance
S x L	*	Y x CR	NS
Y x S	NS	Y x S x L	NS
Y x L	NS		

Mean values in each row and column followed by similar letter (s) are not significantly different from one another at 0.05 level of significance.

Table 7. Leaf relative water content (%) of maize as affected by potassium sources and their levels.

Treatments	Year		
	2017	2018	
Potassium Sources (S)			Means
Potassium Chloride (KCl)	91.44	91.62	91.53 a
Potassium Sulfate (K_2SO_4)	88.02	86.08	87.05 b
Farmyard manure	83.56	82.41	82.99 c
Poultry manure	87.00	87.22	87.11 b
LSD (P=0.05)			0.67
Potassium levels (kg ha^{-1})			
30	84.10	83.38	83.74 d
60	85.72	84.81	85.26 c

90	89.61	89.06	89.34 b
120	90.61	90.08	90.34 a
LSD (P=0.05)			0.67
Control vs rest			
Control (CR)	82.58	81.17	81.88
Rest	87.51	86.83	87.17
Significance			*
Year (Y) means	85.05	84.00	NS
Interactions	Significance	Interactions	Significance
S x L	*	Y x CR	NS
Y x S	NS	Y x S x L	NS
Y x L	NS		

Mean values in each row and column followed by similar letter (s) are not significantly different from one another at 0.05 level of significance.

Table 8. Excised leaf water loss (%) of maize after 90 minutes interval as affected by potassium sources and their levels.

Treatments	Year		Means
	2017	2018	
Potassium Sources (S)			
Potassium Chloride (KCl)	62.11	61.76	61.93 c
Potassium Sulfate (K_2SO_4)	65.69	66.01	65.85 b
Farmyard manure	67.30	67.39	67.34 a
Poultry manure	67.47	67.70	67.59 a
LSD (P=0.05)			0.63
Potassium levels (kg ha^{-1})			
30	71.81	71.96	71.89 a

60	69.14	69.11	69.12 b
90	60.75	60.73	60.74 c
120	60.87	61.06	60.96 c
LSD (P=0.05)			0.63
Control vs rest			
Control	77.03	76.44	76.73
Rest	65.64	65.71	65.68
Significance			*
Year means	71.34	71.07	NS
Interactions	Significance	Interactions	Significance
S x L	NS	Y x CR	NS
Y x S	NS	Y x S x L	NS
Y x L	NS		

Mean values in each row and column followed by similar letter (s) are not significantly different from one another at 0.05 level of significance.

FIGURES

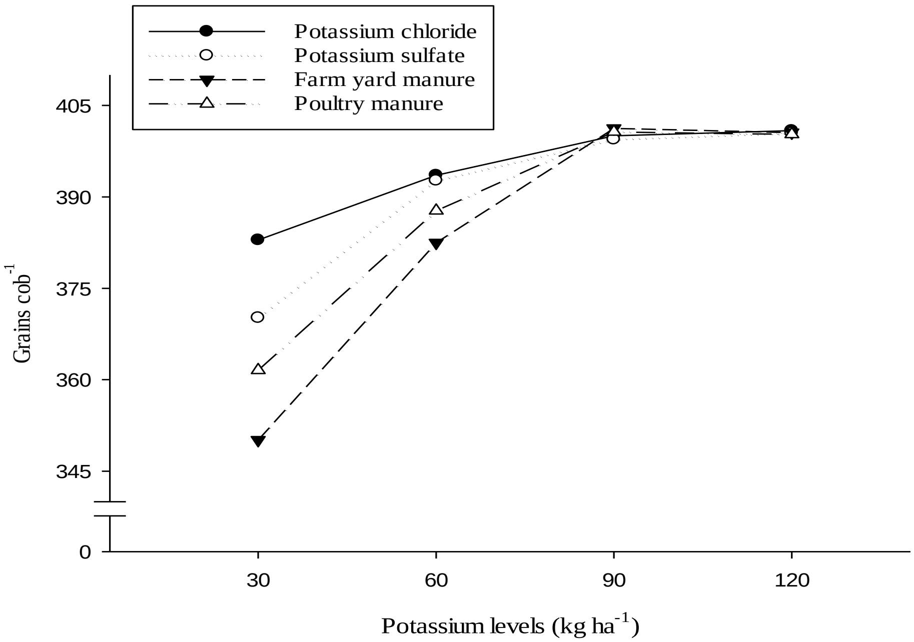

Figure 2. Interaction between potassium sources and potassium levels for grains cob^{-1} of maize.

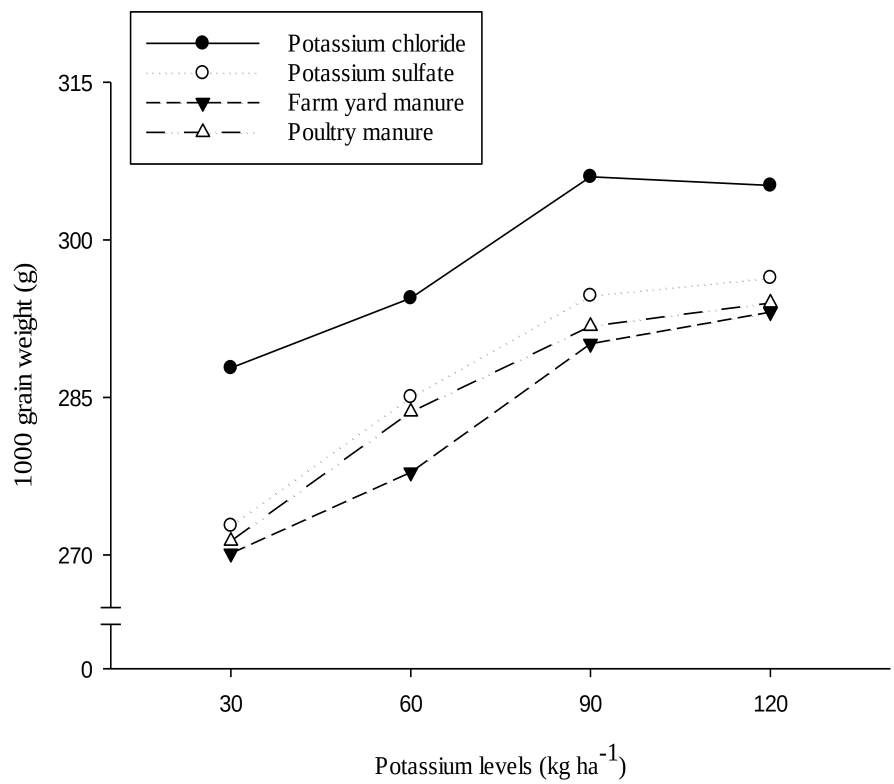

Figure 3. Interaction between potassium sources and potassium levels on 1000 grain weight (g) of maize.

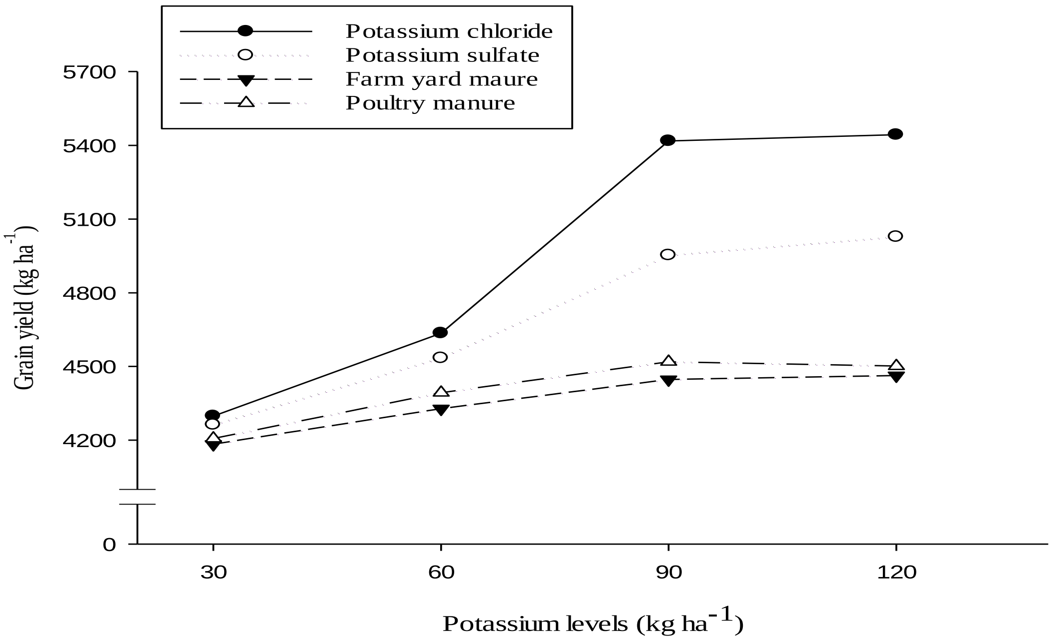

Figure 4. Interaction between potassium sources and their levels for grain yield of maize.

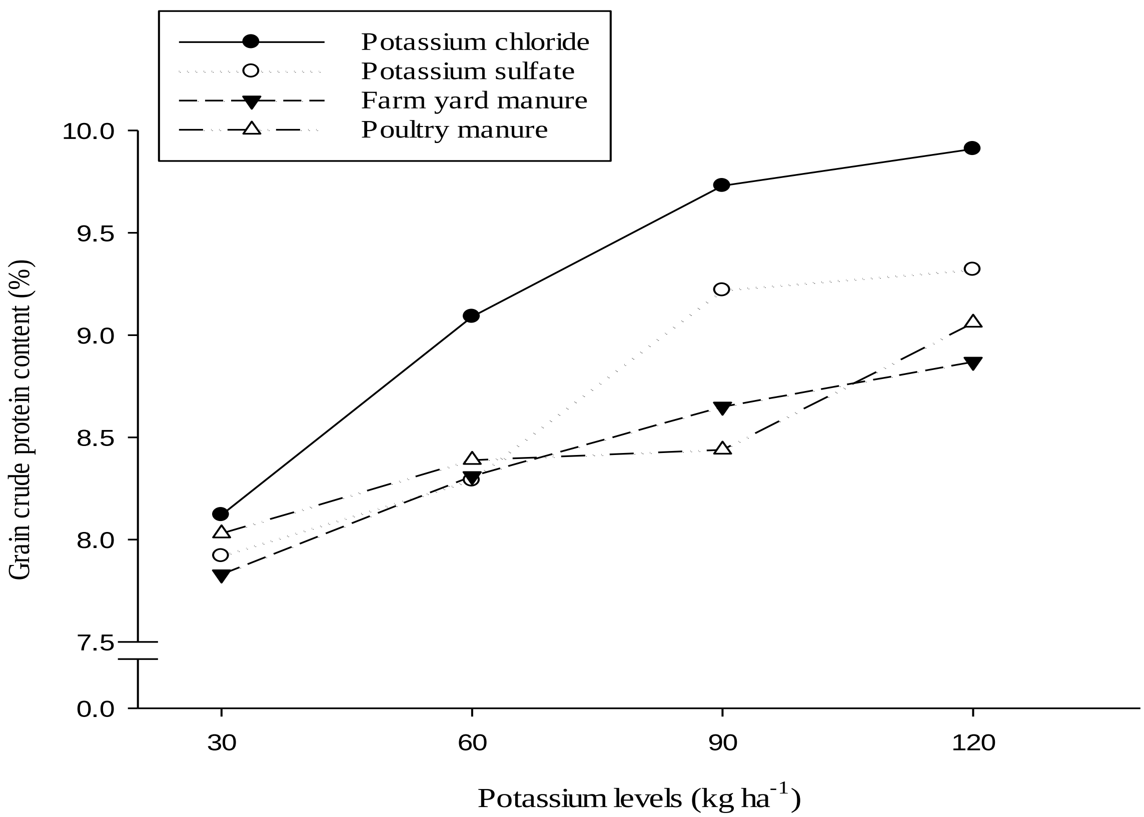

Figure 5. Interaction between potassium sources and potassium levels for grain crude protein content of maize.

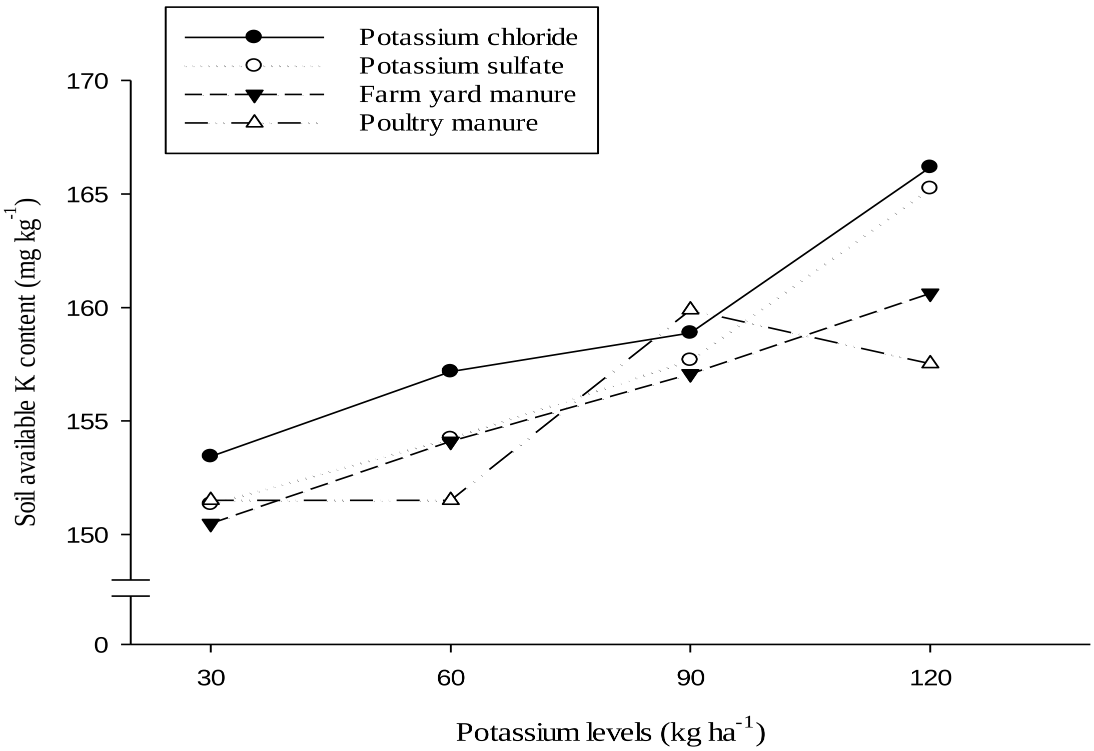

Figure 6. Interaction between potassium sources and their levels for soil available K after harvest of maize.

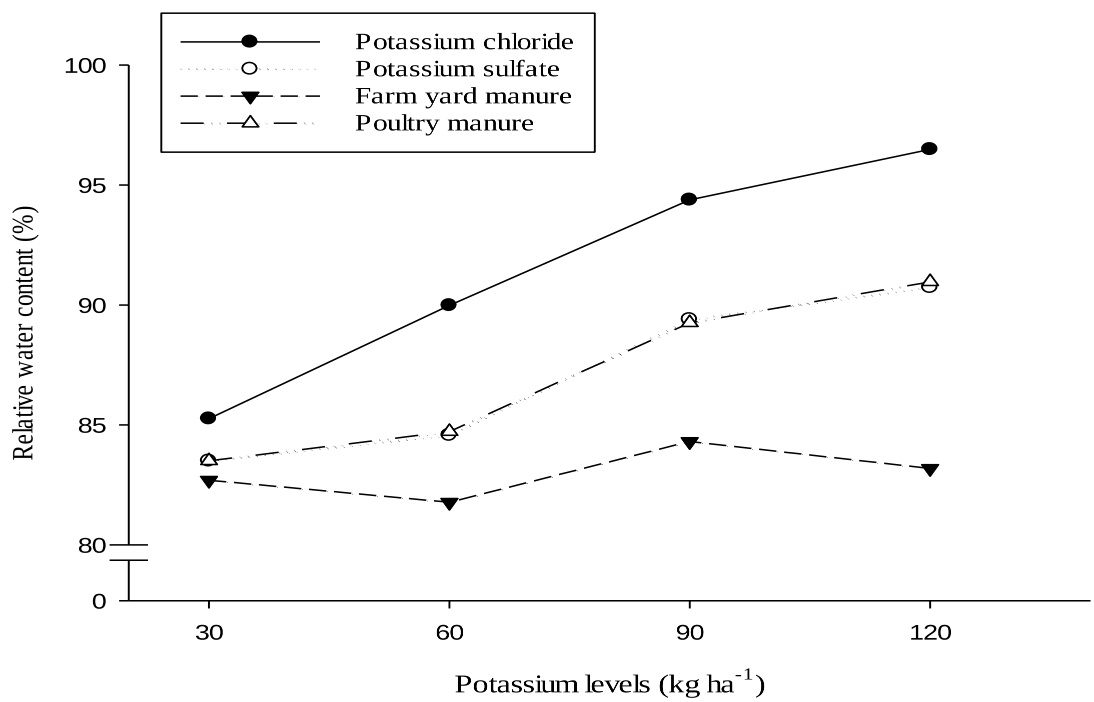

Figure 7. Interaction between potassium sources and their levels for relative water content of maize.

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