Advances in Agriculture and Biology (2022) 5(1): 8-15

REVIEW PAPER

Growth of maize is improved by the combined use of natural and synthetic nutritional sources of potassium: A review

Khalid Mehmood[1*], Saima Nasreem[1], Abdul Latif[2] and Adnan Noor Shah[3]

[1]Department of Biology, Pir Mehr Ali Shah Arid Agriculture University Rawalpindi, Pakistan
[2]Barani Agricultural Research Institute, Chakwal, Pakistan
[3]Khwaja Fareed University of Engineering and Information Technology, Rahim Yar Khan, Pakistan

*****Corresponding author's email: khalidmehmood@uaar.edu.pk

Received: 4 May 2022
Accepted: 12 August 2022

Abstract

Maize, being the third most important cereal crop, is used as a source of nutrition, poultry feeds and for other industrial purposes. In industries, it is used in making flakes, custard, varnishes, paints and many more. It is an important source of human diet containing vitamins (vitamin C, vitamin E, vitamin K, vitamin B_1, vitamin B_2, vitamin B_3, vitamin B_5vitamin and B_6 (pyridoxine)), nutrients (phosphorus, magnesium, manganese, zinc, copper, iron and selenium, potassium and calcium) and other phytochemicals important for human well-being. Potassium (K) has an important role in regulating many plants' functions like photosynthetic rate, chlorophyll content, antioxidant enzyme activity, cellular homeostasis and growth. By keeping in view all these regulating functions, K can be an important source in increasing crop yield of maize while making it more nutritious. Soil is an important source of K as it contains a more exchangeable form of K but in some conditions like calcareous soil, salinity stress, drought and biotic or abiotic stress cause severe deficiency of K in plants. In such situations, exogenous K can play a helpful role in high maize production. This present review deals with natural and synthetic sources of K that are being used for increasing maize production. Synthetic sources of K include inorganic fertilizers like NPK, muriate of potash, sulphate of potash and potassium thiosulphate, while natural sources include organic manure, cattle dung, compost of different crop residues, wood ash, rocky minerals and biofertilizers. In some cases, both the natural and synthetic sources of K are used in combined form to get significant results.

Keywords: Maize, Natural, NPK, Nutritional source of K, Potassium, Synthetic

Citation: Mehmood, K., Nasreen, S., Latif, A., & Shah, A. N. (2022). Growth of maize is improved by the combined use of natural and synthetic nutritional sources of potassium: A review. *Advances in Agriculture and Biology, 5*(1), 8-15.

Introduction

Maize (*Zea mays* L) is a cross pollinated, monoecious crop and now a days is considered as the backbone of poultry feed industry (Saif-ul-Malook et al., 2014). It is also important for many industries like manufacturing jelly glucose, flakes, energile and custard etc. (Khan et al., 1999). It is being utilized to produce shortening compounds, ammunition, varnishes, paints and soaps (Ali, 1995). Maize oil and starch both are being used in many industries and for domestic purposes (Batool et al., 2019; Noor et al., 2021; Aslam et al., 2021). For instance, oil of maize is mostly used in bakery products, cooking, oleomargarine and salad dressing while starch after its fermentation is used to produce biofuel or as ethanol, cloth dying, paper industrial, and hides tanning (Khuspe et al., 2016). Maize fodder contains 51.69%, 22.98% and 40.18% neutral detergent fiber, acidic detergent fiber and crude fiber respectively. Fodder also contains 28.8% cellulose, 10.35% crude protein and 9.09% moisture. Its grain contains 71.97% starch, 4.85% oil, 9.74% protein and 9.44% crude fiber (Ali et al., 2014).

Potassium is the third most important plant nutrient after nitrogen and phosphorous that is involved in photosynthesis, quality crop production, resisting disease and starch-sugar interconversion (Basak & Sarkar, 2017). Potassium has vital role in many crops for keeping up their osmotic capability, turgidity and closing, and opening of stomata (Hue, 1995). K also has role to uptake of water from soil to plant, maintenance of water in xylem tissues (Marschner, 1995). K affects cell growth, for instance sufficient K cell dividers are thicker, in this way enhancing plant protection from lodging, diseases and pests (Bergmann, 1992). K-inadequate plants demonstrate low protection from disease. Seeds and natural products are withered, shivered and small. Symptom of deficiency of K in severe cases are leaf tips and margin burning (Singh & Trehan, 1998). Potassium is the most basic macronutrient required by plants in development, improvement, growth and yield. It is a vital component for increasing the grains yield of maize (Bukhsh et al., 2012; Iqbal et al., 2022). It has been viewed that K is the most fundamental macronutrient of plants due to its primary importance in biochemistry and physiology of the plants (Nawaz et al., 2006). After sowing amid 38 to 52 days, the maize plants require the aggregate potassium up to 38% for the entire developing season (Rehman et al., 2008). It has been thought that K has the most critical role in quality and yield improving component in maize hybrid production (Bukhsh et al., 2012).

Potassium supplementation enhances the overall yield of maize because of increment in the kernel weight (Sharma et al., 2005). All the growth attributes of maize flourished by the use of K. Use of K fertilizer likewise enhanced the adequacy of the photosynthetic apparatus of the plants (leaf zone and no. of leaves) (Kubar et al., 2013).

Soil contains 2.1 to 2.3% reservoirs of K that are high enough for plants and can be easily absorbed (Schroeder, 1978). But K availability to plants depends on some of soil properties like its pH, texture, and moisture content. Some soil also contains potassium silicates minerals that can be used by plants as K source. But for K uptake require assistance of some microbes for conversion of these compounds in soluble form (Masood & Bano, 2016). Potassium uptake into the plants cell is facilitated by specific type of channels and transporters that have affinity for K^+ ions and work through exchange system (Wang & Wu, 2013). Root epidermal and cortical cells are involved in K uptake from soil. After K uptake into roots it is stored in vacuoles, used for maintaining cellular functions as well as transported to upper portion of plants via xylem (Ragel et al., 2019). Formation of proteins, transfer of water, nutrients, carbohydrates, photosynthesis, stimulate early growth, insect and disease resistance K has an important role (Abegaze, 2008).

Weed pervasion, imbalanced or sometimes no use of fertilizers and some other factors such as calcareous nature of soil, the availability of K to crop is limited due to which yield and growth of crops such as maize will be affected (Bukhsh et al., 2008; Khan et al., 2013). Potassium deficiency in plants results in demolition of chlorophylls, photosystem II reaction center and increased production of reactive oxygen species (ROS) such as superoxides and peroxides (Qi et al., 2019). In case of K deficiency in soil, plants roots tend to absorb more amount of Na^+ ions from soil that causes greater accumulation of Na ions in cell as well Na/K ratio is increased. A higher Na/K ratio is harmful for many cellular functions like it causes ionic toxicity, and photosynthetic activity of plant is reduced to a greater extent (Du et al., 2017). A variety of techniques are being used to manage nutrient supply of K especially in soil where sources of K are low or in less soluble form. These management techniques help the plants to maintain a higher amount of K in cells and ultimately results in higher growth of plants. Potassium is the seventh most abundant element in earth's crust in form of minerals like feldspar, nepheline and leucite. Out of these, nepheline is a more soluble form of potassium, so it is used as natural source of K (Manning, 2010). In dried sea areas, K deposition through crystallization process and salt deposition results in formation of clay minerals. Salts of K like KCl, K_2SO_4 and KNO_3 are readily soluble in water so these salts can be directly used for agricultural purposes (Stewart, 1985). Green sand is olive-green colored sand with large pores and contains readily soluble form of potassium with other ions like calcium, magnesium and other micronutrients. So, use of this sand as K source provides a source of natural fertilizer of potassium (Hue & Silva, 2000). Potassium thiosulphate (KTS) is a synthetic source of potassium that is used in form of inorganic fertilizer. It is either directly applied to soil or solubilized in water used in irrigation. Liquid product of KTS contains 25% K_2O and 17% S which can be applied alone, or it can be combined with other fertilizers like ammonium polyphosphate or urea-ammonium nitrate to get better results (Cai et al., 2018).

Increased demand of maize as cereal crop as well as for other commercial purposes requires that its quality and production level must be increased. Potassium as being third most important macronutrient of plants and its regulatory role in physiological functions, management strategies are implied by farmers and agriculturists. This review article summarizes natural and synthetic sources of potassium solely and in combined form, their impact on growth and yield of maize and somewhat comparison of different forms of potassium in term of better maize production. This study will shed light on the most suitable source of potassium for K deficiency management in maize, and hence will be of great interest for the readers.

Effects of synthetic fertilizer application on maize crop

The impact of potassium on sandy clay loam soil and corn as a test crop was investigated by Bukhsh et al. (2011). They applied different levels of potassium (0, 100, 150, 200, 250 Kg/ha). The results showed that increased plant density led to higher plant bareness, resulting in fewer grains and lighter cobs. The application of potassium reduced plant nudity in all three hybrids, improving grain count and weight when applied at 100-200 kg/ha. Another experiment conducted by Ali et al. (2004) to check the response of corn to various levels of potassium and irrigation frequencies. It was found that potassium applied at 150 kg/acre increased tasseling days, 100-grain weight, and yield. Weekly irrigation led to better cob weight, 1000-grain weight, and days to tasseling. Germination percentage and emergence were not significantly affected by irrigation. Potassium applied at 90 kg/ha and 100 percent at sowing time improved flag leaf values and area, while grain yield showed a positive association with increased potassium doses. The recommendation was to apply potassium @ 90 kg/ha at sowing time to boost corn efficiency. Asif et al. (2007) conducted a study to assess the effect of timing and doses of potassium on corn's phenology, leaf area, and grain yield. It was observed that potassium timing and doses significantly influenced yield, phenology, and flag leaf area. Reproductive stages like tasseling, silking, and physiological maturity were delayed at 60 kg/ha potassium application, while increasing K to 90 kg improved them. Sowing potassium @ 100 percent did not delay silking and tasseling. A 90 kg/ha K application with 100 percent at sowing time resulted in improved flag leaf values and area. Corn grain yield positively correlated with potassium doses, suggesting that 90 kg/ha at sowing time is ideal. Çelik et al. (2010) subjected sorghum and corn hybrids to potassium at different levels (0, 60, 120 kg/ha) and splits (1 month and 2 months). Potassium had a significant effect on various parameters in both sorghum and corn except plant height.

The effect of potassium sulfate (K_2SO_4) at different rates (50, 100, 150, 200 mm) was studied under 150 mM sodium chloride stress (Kausar & Munazza, 2014). They found that K_2SO_4 enhanced biomass production, increased vital nutrient absorption, and improved soil quality in salt-affected soils. Aslam et al. (2014) studied the role of potassium in corn crops under drought conditions. Drought-tolerant and sensitive hybrids were tested, and K was applied at two different levels. Phosphorus had a more pronounced effect when combined with specific corn varieties and rates. Hamayun et al. (2011) studied the effects of different levels of K and iron on corn's growth and nutrient absorption. Increasing potassium and iron levels improved dry weight, but high potassium levels reduced concentrations of P, Mg, and Ca in leaves and roots. Total concentrations of Fe increased with higher K and Fe levels, although they decreased with high K levels.

Amanullah et al. (2016) investigated the impact of basal and foliar supplementation of zinc and potassium on corn under moisture stress conditions. They found that potassium (1 - 3%) and zinc (0.1 - 0.2%) were effective in enhancing growth and yield-related components under water stress. Application in the vegetative stage was more effective than in the reproductive stage. Tariq et al. (2011) compared muriate of potash and sulfate of potash for their effects on maize crop growth and yield. Both sources of potassium resulted in increased growth and yield, with muriate and sulfate of potash outperforming NPK fertilizer. Sadiq et al. (2017) conducted a study on corn using phosphorus and potassium treatments. Potassium @ 90 kg/ha increased various yield components, while phosphorus @ 120 kg/ha improved yield components associated with the development of yield. The recommended combination was 120 kg/ha of phosphorus and 90 kg/ha of potassium. Salami and Saadat (2013) explored the impact of potassium and nitrogen levels on sugar beet in calcareous soil. They found that increased potassium and nitrogen levels significantly improved sugar beet root and leaf growth, fresh and dry weight, and sugar beet yield. The combination of potassium @ 114 kg/ha and nitrogen @ 285 kg/ha was recommended for enhanced yield, nutritional status, and quality. Kakar et al. (2014) investigated the application of NPK under moisture stress conditions on corn. Foliar treatments significantly increased physiological maturity, yield, and harvest index. It was concluded that foliar application of NPK at a rate of 1% could enhance corn productivity.

Natural nutritional sources of potassium

Potassium deficiency has some major effects on growth, physiology and yield of maize crop. But there are some natural sources of potassium that can be implied to overcome potassium deficiency. These natural sources include wood ash, mined rock powder, manure, compost and other organic material. Some of the previous work on natural supply of potassium has been discussed briefly in the section below. To study the effect of soil applied potassium and its timing of application, 5 t/ha cattle dung was applied to soil and other plot was without cattle dung. The NPK content of cattle dung was 1.13% N, 0.11 P_2O_5 and 0.07% K_2O. Results have shown that phenological development (days to tasseling, silking and physiological maturity) were delayed with lower rate of potassium application. But phenological development was accelerated in treatments with higher application of potassium in form of cattle dung. Growth parameters, yield components, grain yield and shelling percentage of maize crop are also improved in case of cattle dung application in soil (Iqbal & Hidayat, 2016). Potassium deficiency can also be treated by increasing K uptake from soil. Root exudates from microbes and living plants help in increased mobility and uptake of K from soil. Plants roots are inoculated with *Bacillus spp.* Bacteria that increase root exudates helping the maize plants to uptake the K in high concentration (Shin, 2014).

Organic manure is a worthy type of fertilizer because it can supply fundamental and essential nutrients to soils. Nowadays the main reasons for decreased yield of crops are inadequate supply of fertilizer and poor fertility levels of soils and management as well. So, application of fertilizer in organic and inorganic form was carried out by Bilal et al. (2017). Maize crop was used, and impact of fertilizer was evaluated on corn crop. The data was recorded on seven quantitative characteristics such as height of corn plant, area of leaf, days to tasseling, number of grains, biological yield (kg/ha), 1000 of weight grain (g) and yield of grain (kg/ha). Except for days to tasseling, it was observed that all traits significantly differ from each other when treatment was applied. The greatest area of leaf was obtained through the application of poultry manure while least was recorded in control where no treatment was applied. Most extreme plant tallness (cm), grains count/cob, 1000 weight of grain (g) and yield of grain were observed in treatment where compost was applied. While the least results were observed in plots where no treatment was applied (control). The outcomes pointed out that natural compost gave great reaction for yield and its related attributes of corn in comparison to inorganic manure.

Different crop residues are rich source of inorganic ions like carbon, potassium and nutrition. These ions are readily available to crops, while the decomposition of crop residues so, these can be used as soil amendment for availability of K and other inorganic ions. In addition to ions availability, it also helps in nutrient retention, water availability, soil health and increased crop performance. Potassium ions are highly mobile from crop residues to soil and then to crop growing in that soil as potassium is unbounded monoatomic cation (Thiyageshwari et al., 2018). An experiment was conducted to study the effect of crop residues and K management on maize productivity, K mobility, and K assimilation of crop. Four crop residues level

(0, 2, 4 and 6 mg/ha), five potassium levels (0, 50%, 100% and 150%) and 50% recommended dose of potassium + potassium solubilizing bacteria were used. According to results, increased grain yield (10.17%), dry mass production, K availability and uptake in maize was observed @ 6 mg/ha dose of crop residues. Same results were observed for 50% recommended potassium dose + potassium solubilizing bacteria as compared to no K (Madar et al., 2020).

Mined rock powder is another natural source of K for plants but there is an issue in solubility of this powder in soil so that potassium can be available to plants. For this purpose, an experiment was conducted in a soil which was fertilized with rocky K and P material along with K and P dissolving bacteria [PDB (*Bacillus megaterium* var. *phosphaticum*) and KDB (*Bacillus mucilaginosus* and *B. subtilis*)] for finding the availability and uptake of K and P in calcareous soil (limited availability of K and P). According to results, co-inoculation of PDB and KDB with rocky K and P material increased K and P availability and uptake, root and shoot growth in maize grown on calcareous soil (Abou-el-Seoud & Abdel-Megeed, 2012). Seaweed has ability to accumulate K as plenty amount of K is present in seawater. So, seaweeds biomass can be directly used as a potassium source for plants because it contains almost 2% of K that is readily available to plants. But there is some problem in transfer of seaweeds from oceanic area to farms so K can be extracted from seaweeds biomass in liquid form and can be directly applied to plants (Mikkelsen, 2007). Another important source of naturally occurring potassium is wood ash. It contains a high reservoir of K and in addition to it wood ash and can also be used as soil amendment because it contains carbonates and oxides. The potassium content of wood ash is related to age of wood and older woods have high amount of potassium (Gorecka et al., 2006).

Combined use of natural and synthetic potassium sources

Several studies have showed that combine use of natural and synthetic source of K provide more desirable results in crop production, biomass and yield as compared to using them solely. A 15-year study was carried out on maize and wheat. Initially only nitrogen as nutritional source was tested which resulted in no significant change in yield. Afterward, nitrogen was combined with phosphorous and potassium as plant nutritional source. This treatment showed improved results in crops yield but remarkable results were obtained when NPK along with organic manure was applied to soil (Zhang et al., 2009). A field experiment was carried out to study the combined effect of organic and inorganic K sources on maize in form of compost of wheat and rice straws as organic source while sulphate of potash as inorganic source. Results have shown that treatment containing 25% compost and 75% sulphate of potash caused highest leaf area index, leaf area duration, crop growth rate, dry mass production, 1000-grain weight, seed yield, biological yield and harvest index (Ali, 2016). Potassium is an essential nutrient for plant production and yield, so another experiment was conducted in which K-enriched compost from city market waste along with potassium fertilizer was used to study its effect on maize hybrid (Hycorn-11-plus). Results of this experiment revealed that application of K-enriched compost with 75% K fertilizer help to improve growth, yield and potassium content of maize hybrid (Shah et al., 2019).

A field experiment was conducted to study the effect of three levels of compost application along with four levels of potassium fertilization on yellow maize hybrid 'Poineer SC 30N11'. Compost was applied in three levels that were as 0, 5 and 10 ton/ha in main plots while potassium fertilization was applied in four forms as untreated, nano-potassium fertilization, humic acid and potassium sulphate. As a result of this experiment, it was found that application of compost as organic manure along with potassium forms significantly improved plant height, ear length, grain numbers per row, grains number per ear, 100-grain weight, biological yield, K content and grain protein contents. Increased level of compost to 5 and 10 ton/ha enhanced biological yield, K content and grain protein. There was significant interaction between 10 ton/ha compost manure and 500 cm^3/ha nano-potassium, or 10 ton/ha humic acid as highest mean was obtained for all the parameters with this combination (Kandil et al., 2020).

Biofertilizers in the form of microbes are important for increasing maize production as the potassium solubilizing bacteria help in increased uptake of potassium along with other nutrients. A field experiment was carried out in which NPK fertilizer along some microbes (*Azospirillum brasilense* and *Rhodotorula glutinis*) were applied on maize crop. According to results, plant height, grain index, grain yield, straw yield and ear height were increased significantly in treated maize as compared to control (El-Kholy et al., 2005). Another experiment was carried out to check the combined effect of NPK fertilizer with A*zotobacter chroococcum*, *Bacillus megaterium*, *Pseudomonas fluorescence* and enriched compost was tested for its performance on maize hybrid. Highest dry mass production, grain yield and cob mass were observed as a result of these inoculations (Umesha et al., 2014).

Table 1 Results of different form of potassium sources on maize crop production

Source of potassium	Form of potassium used	Results obtained	References
Synthetic	Inorganic K	Increase in seed weight and number of cobs	(Bukhsh et al., 2011)
Synthetic	Inorganic K	Enhanced tasseling days, 1000-gram weight and yield	(Ali et al., 2004)
Synthetic	Inorganic K	High leaf area, no of flag leaves and grain weight	(Asif et al., 2007)
Synthetic	Inorganic K	improvement in rate of growth, yield of corn grains, amount of NPK, oil protein and starch quality	(Bukhsh et al., 2009)
Synthetic	Inorganic K	High growth except plant height, high grain yield and grain weight	(Çelik et al., 2010)
Synthetic	Inorganic K	Improved photosynthetic rate, relative water content, plant potential, transpiration rate, biological yield, weight of grain and yield	(Aslam et al., 2014)
Synthetic	Murate of potassium	Increase in plant height, 1000 grains weight, days to maturity, tasseling, silking, leaf area index and grain yield	(Liaqat et al., 2018)
Synthetic	Combined potassium and phosphorous	Enhanced grain weight, number of grains per cob, leaf area and length of cob	(Akther et al., 1999)
Synthetic	Potassium and iron	Increased dry mass production	(Hamayun et al., 2011)
Synthetic	NPK fertilizer	Highest increase in growth rates	(Saleem et al., 2011)
Synthetic	Potassium and nitrogen	Enhanced yield, nutritional status and quality	(Salami & Saadat, 2013)
Synthetic	Potassium and zinc	Increase in cumulative average yield, corn productivity and growth	(Amanullah et al., 2016)
Natural	Cattle dung	Accelerated phenological development	(Iqbal & Hidayat, 2016).
Synthetic	muriate of potash and sulphate of potash	Significantly higher Grain yield	(Tariq et al., 2011)
Natural	Crop residues	Increased grain yield, dry mass production, K availability and uptake	(Madar et al., 2020)
Natural	PDB and KDB with rocky K and P material	Increased K and P availability, uptake, root and shoot growth	(Abou-el-Seoud & Abdel-Megeed, 2012)
Natural	Seaweeds	Improved crop production	(Mikkelsen, 2007)
Natural	Wood ash	Increased availability and uptake of potassium	(Gorecka et al., 2006)
Natural and synthetic combined	NPK and organic manure	Improvement in crop yield	(Zhang et al., 2009)
Natural and synthetic combined	Sulphate of potash and compost of wheat & rice	Highest leaf area index, leaf area duration, crop growth rate, dry mass production, 1000-grain weight, seed yield, biological yield and harvest index	(Ali, 2016)
Natural and synthetic combined	NPK fertilizer and biofertilizers	Significant increase in plant height, grain index, grain yield, straw yield and ear height	(Umesha et al., 2014)

PDB = Phosphorus dissolving bacteria; KDB = Potassium dissolving bacteria

Conclusion

This article highlights the critical role of potassium as a vital macronutrient in maize, contributing significantly to both physiological and morphological functions. The presence of abiotic and biotic stress factors can lead to potassium deficiency in plants, disrupting their functionality and resulting in ionic toxicity due to the increased uptake of sodium and other ions. An elevated Na/K ratio in maize plants induces water stress, which hampers normal maize growth and ultimately leads to reduced crop yields. Various potassium management strategies are currently in practice, including soil reclamation through the application of potassium-based fertilizers such as NPK, muriate, and sulfate of potash, as well as synthetic inorganic potassium sources. However, there is a growing shift towards exploring organic sources of potassium due to their cost-effectiveness and eco-friendliness. Natural sources of potassium such as organic manure, crop residues, wood ashes, mineral rocks, seaweeds, and greensands are being widely used either independently or in combination with synthetic sources. Further research is essential to develop more economically viable potassium sources derived from natural materials, particularly in underdeveloped and developing countries where this nutrient is in high demand.

References

Abegaze, A. (2008). Indigenous soil nutrient supply and effects of fertilizer application on yield, N, P and K uptake, recovery and use efficiency of barley in three soils of teghane, the northern highlands of Ethiopia. *African Journal of Agricultural Research, 3*, 688-699.

Abou-el-Seoud, I. I., & Abdel-Megeed, A. (2012). Impact of rock materials and biofertilizations on P and K availability for maize (*Zea mays*) under calcareous soil conditions. *Saudi Journal of Biological Sciences*, *19*(1), 55-63.

Ali, M. (2016). Integrated potassium management through composted straws and inorganic fertilizer in maize. *Maydica*, *60*(4), 1-7.

Ali, Q., Ali, A., Ahsan, M., Ali, S., Khan, N. H., Muhammad, S., Abbas, H. G., Nasir, I. A. & Husnain, T. (2014a). Line × tester analysis for morpho-physiological traits of *Zea mays* L. seedlings. *Advancements in Life Sciences 1*(4), 242 −253.

Ali, S. (1995). Effect of source and rate of potash on yield and quality of spring maize. *Pakistan Journal of Biological Sciences*, *1,* 1982-1984.

Ali, T., Anwar, S. Shah W. A. & Ahmad, B. (2004). Response of maize hybrids/cultivars to various levels of potassium and irrigation frequencies. *Journal of Agronomy, 3,* 201-207.

Amanullah, Iqbal, A., Irfanullah & Hidayat, Z. (2016). Potassium management for improving growth and grain yield of maize (*Zea mays* L.) under moisture stress condition. *Nature Scientific Reports 6,* 34627.

Asif, M., Amanullah, & Anwar, M. (2007). Phenology, leaf area and yield of spring maize (Cv. Azam) as affected by levels and timings of potassium application. *World Applied Sciences Journal, 2*(4), 299-303.

Aslam, M. A., Aziz, I., Shah, S. H., Muhammad, S., Latif, M., & Khalid, A. (2021). Effects of biochar and zeolite integrated with nitrogen on soil characteristics, yield and quality of maize (*Zea mays* L.). *Pakistan Journal of Botany*, *53*(6), 2047-2057.

Aslam, M., Zamir, M. S. I., Afzal, I., &Amin, M. (2014). Role of potassium in physiological functions of spring maize (*Zea mays* L.) grown under drought stress. *Journal of Animal & Plant Sciences*, *24*(5), 1452-1465.

Basak, B. B., & Sarkar, B. (2017). Scope of natural sources of potassium in sustainable agriculture. In *Adaptive soil management: From theory to practices* (pp. 247-259). Springer, Singapore.

Batool, A., Wahid, A., Abbas, G., Shah, S. H., Akhtar, M. N., Perveen, N., & Hassnain, Z. (2019). Application of *Moringa oleifera* plant extracts for enhancing the concentration of photosynthetic pigments leading to stable photosynthesis under heat stress in maize (*Zea mays* L.). *Pakistan Journal of Botany, 51*(6), 2031-2036.

Bergmann, W. (1992). Nutritional disorders of plants. 2nd ed. Gustav Fischer Verlag, Jena, Germany.

Bilal, M., Tayyab, M., Aziz, I., Basir, A., Ahmad, B., Khan, U., Zahid, M. & Ali, N. (2017) Impact of integrated fertilization (organic and in-organic) on grain yield of maize crop. *Agriculture, Forestry and Fisheries, 6*(5), 178-183.

Bukhsh, M., Ahmad, R. Ishaque, M. & Malik A. (2009). Response of maize hybrids to varying potassium application in Pakistan. *Pakistan Journal of Agricultural Sciences. 46*(3), 179-184.

Bukhsh, M., Ahmad, R., Ali, A., Ishaque, M., & Rehman, A. (2012). Potassium use efficiency of maize hybrids. *Journal of Animal & Plant Sciences. 22*(3), 728-732.

Bukhsh, M., Ahmad, R., Cheema, Z. A., & Ghafoor, A. (2008). Production potential of three maize hybrids as influenced by varying plant density. *Pakistan Journal of Agriculture Sciences. 45,* 413-417.

Bukhsh, M., Ahmad, R., Iqbal, J., Rehman, A. Hussain, S., & Ishaque, M. (2011). Potassium application reduces bareness in different maize hybrids under crowding stress conditions. *Pakistan Journal of Agricultural Sciences, 48,* 31-37.

Cai, Z., Gao, S., Xu, M., & Hanson, B. D. (2018). Evaluation of potassium thiosulfate as a nitrification inhibitor to reduce nitrous oxide emissions. *Science of the Total Environment*, *618*, 243-249.

Çelik, H., Aşik, B. B., Gürel, S., & Katkat, A. V. (2010). Effects of potassium and iron on macro element uptake of maize. *Zemdirbyste-Agriculture, 97*(1), 11–22, Du, Q., Zhao, X., Jiang, C., Wang, X., Han, Y., Wang, J., & Yu, H. (2017). Effect of potassium deficiency on root growth and nutrient uptake in maize (*Zea mays* L.). *Agricultural Sciences*, *8*(11), 1263.

El-Kholy, M. A., El-Ashry, S., & Gomaa, A. M. (2005). Biofertilization of maize crop and its impact on yield and grains nutrient content under low rates of mineral fertilizers. *Journal of Applied Sciences Research*, *1*(2), 117-121.

Górecka, H., Chojnacka, K., & Górecki, H. (2006). The application of ICP-MS and ICP-OES in determination of micronutrients in wood ashes used as soil conditioners. *Talanta*, *70*(5), 950-956.

Hamayun, M., Khan, S. A., Khan, A. L., Shinwari, Z. K., Ahmad, N., Kim, Y.-H. & Lee, I.-J. (2011). Effect of foliar and soil application of nitrogen, phosphorus and potassium on yield components of lentil. *Pakistan Journal of Botany*, *43*, 391-396.

Hue, N. V. (1995). Sewage Sludge. In: J. E. Rechcigl (ed) Soil amendment and environmental quality. Lewis Publ., Boca Raton. FL. 193 – 239.

Hue, N. V., & Silva, J. A. (2000). Organic soil amendments for sustainable agriculture: organic sources of nitrogen, phosphorus, and potassium. *Plant nutrient management in Hawaii's soils, approaches for tropical and subtropical agriculture. College of Tropical Agriculture and Human Resources, University of Hawaii, Manoa*, 133-144.

Iqbal, A., & Hidayat, Z. (2016). Potassium management for improving growth and grain yield of maize (*Zea mays* L.) under moisture stress condition. *Scientific Reports*, *6*(1), 1-12.

Iqbal, J., Sarwar, G., Shah, S. H., Sabah, N. U., Tahir, M. A., Muhammad, S., Manzoor, M. Z., Zafar, A., & Shehzad, I. (2022). Evaluating the combined effect of compost and mineral fertilizers on soil health, and growth and mineral acquisition in maize (*Zea mays* L.). *Pakistan Journal of Botany, 54*(5), 1793-1801.

Kakar, K. M., Khan, A., Khan, I., Shah, Z., & Hussain, Z. (2014). Growth and yield response of maize (*Zea mays* L.) to foliar NPK-fertilizers under moisture stress condition. *Soil and Environment*, *33,* 116-123.

Kandil, E. E., Abdelsalam, N. R., Mansour, M. A., Ali, H. M., & Siddiqui, M. H. (2020). Potentials of organic manure and potassium forms on maize (*Zea mays* L.) growth and production. *Scientific Reports*, *10*(1), 1-11.

Kausar, A., & Munazza Gull, M. (2014). Effect of potassium sulphate on the growth and uptake of nutrients in wheat (*Triticum aestivum* L.) under salt stressed conditions. *Journal of Agricultural Science*, *6*(8), 101-112.

Khan, M A., Akbar, S., Ahmad, K., & Baloch, M. S. (1999). Evaluation of corn hybrids for grain yield in D.I. Khan. *Pakistan Journal of Biological Sciences, 2*, 413-414.

Khan, M. A., Kakar, S., Marwat, K. B., & Khan, I. A. (2013). Differential response of (*Zea mays* L.) in relation to weed control and different macronutrient combinations. *Sains Malaysiana*, *42*(10), 1395-1401.

Khuspe, J. D., Meena, R., Sadashiv, G. N., Ram, B., Jat, L. K., & Parihar, M. (2016). Effect of potassium application, soil potassium status and their interactions on dry matter yield of maize (*Zea mays* L.). *Environment & Ecology*, *34*(2), 587-591.

Kubar, S., Zia-ul-hassan, A. N. Shah, I. Rajpar, & Qureshi, S. A. (2013). Response of maize to a novel organic potassium fertilizer developed from fruit and vegetable waste. *Pakistan Journal of Agriculture*, *29*(1), 1-12.

Liaqat, W., Jan, M. F., Ahmad, H., Rafiullah, Khan, E. H., Khan, N., & Rehan, W. (2018). Impact of mineral potassium on phenology, growth and yield of maize hybrid. *International Journal of Environmental Sciences and Natural Resources*, *8*(5), 168-171.

Madar, R., Singh, Y. V., Meena, M. C., Das, T. K., Paramesh, V., Al-Mana, F. A., ... & O Elansary, H. (2020). Residue and potassium management strategies to improve crop productivity, potassium mobilization, and assimilation under zero-till maize–wheat cropping system. *Agriculture*, *10*(9), 401.

Manning, D. A. (2010). Mineral sources of potassium for plant nutrition: A review. *Agronomy for Sustainable Development*, *30*(2), 281-294.

Marschner, H. (1995). Mineral Nutrition of Higher Plants (2nd ed.). Academic Press, San Diego, CA.

Masood, S., & Bano, A. (2016). Mechanism of potassium solubilization in agricultural soils by the help of soil microorganisms. In Potassium Solubilizing Microorganisms for Sustainable Agriculture (pp. 137-147). Springer, New Delhi.

Mikkelsen, R. L. (2007). Managing potassium for organic crop production. *HortTechnology*, *17*(4), 455-460.

Nawaz, I., Zia-ul-Hassan, Ranjha, A. M., & Arshad, M. (2006). Exploiting genotypic variation among fifteen maize genotypes of Pakistan for potassium uptake and use efficiency in solution culture. *Pakistan Journal of Botany*, *38*, 1689-1696.

Noor, K., Sarwar, G., Shah, S. H., Muhammad, S., Zafar, A., Manzoor, M. Z., & Murtaza, G. (2021). Formulation of phosphorous rich organic manure from rock phosphate and its dose optimization for the improvement of maize (*Zea mays* L.). *Journal of Plant Nutrition, 44*(1), 96-119.

Qi, D. U., Zhao, X. H., Le, X. I. A., Jiang, C. J., Wang, X. G., Yi, H., Wang, J., & Yu, H. Q. (2019). Effects of potassium deficiency on photosynthesis, chloroplast ultrastructure, ROS, and antioxidant activities in maize (*Zea mays* L.). *Journal of Integrative Agriculture, 18*(2), 395-406.

Ragel, P., Raddatz, N., Leidi, E. O., Quintero, F. J., & Pardo, J. M. (2019). Regulation of K+ nutrition in plants. *Frontiers in Plant Science, 10*, 281. doi: 10.3389/fpls.2019.00281

Rehman, S. U., Ahmad, M., Bukhsh, H. M., & Ishaque, M. (2008). Comparative performance and profitability of two corn hybrids with organic and inorganic fertilizers. *Pakistan Journal of Agricultural Sciences, 45*, 8-12.

Sadiq, G., Khan, A. A., Ullah, I., Rab, A., Fayyaz, H., Naz, G., Nawaz, H., Ali, I., Raza, H., Amin, J., Ali, S., Khan, H. A. Khan, A. A., & Khattak, W. A. (2017). Impact of phosphorus and potassium levels on yield and yield components of maize. *Pure and Applied Biology, 6*(3), 1071-1078.

Saif-ul-malook, Ahsan, M., Ali, Q., & Mumtaz, A. (2014). Genetic variability of maize genotypes under water stress and normal conditions. *Researcher, 6*, 31–37.

Salami, M., & Saadat, S. (2013). Study of potassium and nitrogen fertilizer levels on the yield of sugar beet in jolge cultivar. *Journal of Novel Applied Sciences, 2*(4), 94-100.

Saleem, A., Javed, I., Saleem, R., Ansar, M., & Zia, M. A. (2011). Effect of split application of potash fertilizer on maize and sorghum in Pakistan. *Pakistan Journal of Agricultural Research, 24*, 1-4.

Schroeder, D. (1978). Structure and weathering of potassium-containing minerals. IPI Research Topics, 5-25.

Shah, A. N., Kandhro, M. N., Jogi, Q., Zia-UL-Hassan, S., Murtaza, G. (2019). Integration of potassium fertilizer with mechanically prepared potassium-enriched compost from city market waste for improvement in maize production. *Pure and Applied Biology, 8*(1), 847-855.

Sharma, S., Duveiller, E., Basnet, R., Karki, C. B., & Sharma, R. C. (2005). Effect of potash fertilization on helminthosporium leaf blight severity in wheat, and associated increases in grain yield and kernel weight. *Field Crops Research, 93*(1), 142–150.

Shin, R. (2014). Strategies for improving potassium use efficiency in plants. *Molecules and Cells, 37*(8), 575.

Singh, J. P., & Trehan, S. P. (1998). Balanced fertilization to increase the yield of potato. In: Proceedings of the IPI-PRII-PAU Workshop on: Balanced Fertilization in Punjab Agriculture, held at Punjab Agricultural University, Ludhiana, India, 15 – 16 December 1997, 129–139.

Stewart, J. A. (1985). Potassium sources, uses and potential. Potassium in Agriculture, American Society of Agronomy, Madison, WI, pp 83–98.

Tariq, M., Saeed, A., Nisar, M., Mian, I. A., & Afzal, M. (2011). Effect of potassium rates and sources on the growth performance and on chloride accumulation of maize in two different textured soils of Haripur, Hazara division. *Sarhad Journal of Agriculture, 27*(3), 415-422.

Thiyageshwari, S., Gayathri, P., Krishnamoorthy, R., Anandham, R., & Paul, D. (2018). Exploration of rice husk compost as an alternate organic manure to enhance the productivity of black gram in typic haplustalf and typic rhodustalf. *International Journal of Environmental Research and Public Health, 15*(2), 358.

Umesha, S., Srikantaiah, M., Prasanna, K. S., Sreeramulu, K. R., Divya, M., & Lakshmipathi, R. N. (2014). Comparative effect of organics and biofertilizers on growth and yield of maize (*Zea mays* L). *Current Agriculture Research Journal, 2*(1), 55-62.

Wang, Y., & Wu, W. H. (2013). Potassium transport and signaling in higher plants. *Annual Review of Plant Biology, 64*, 451-476.

Zhang, H. M., Bo-Ren, W. A. N. G., Ming-Gang, X. U., & Ting-Lu, F. A. N. (2009). Crop yield and soil responses to long-term fertilization on a red soil in southern China. *Pedosphere, 19*(2), 199-207.