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Maize (*Zea mays* L.) Response to Potassium Application and K^+ Uptake in the Soil: A Review

Bismark Asante-Badu[1], Michael Osei Appiah[2],
Lehlogonolo Evans Kgorutla[1], Zhou Xue[1], Gao Qiang[1]

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ABSTRACT

Potassium (K) is among the essential macronutrients needed for plant growth and it's also an extremely dynamic ion in both soil and plant systems. K^+ moves intensely in a plant system but moderately in a soil system. The average soil deposits of K generally are plentiful, but their mainstreams are not readily available for crop uptake. Many researches have dealt with the response of crops to potassium application, but few literatures have tackled that of maize to available K and its uptake. This review seeks to discuss current progress concerning the relevance of K in maize crop production and its uptake; how this physiological action transforms into growth and yield. We have reviewed available studies on the content, roles of K in the soil-plant system and factors contributing to K uptake and transportation in plant. Also, the benefits of Potassium Solubilizing Microorganisms (KSMs) as an alternative or in combination with exchangeable K+ are reviewed. Furthermore, K deficiencies in maize causing constraint in physiological activities and rendering weak resistance to pests are also discussed. The current study indicates that intensive agricultural production has led to K nutrient limitation in organic or coarse-textured soil resulting in the reduction of available K reserves. However, an optimal application of K can prevent these fertilization imbalances, which will eventually increase soil fertility.

Key words: Growth, K fertilization, KSMs, Maize Grain/Yield content, Maize.

Maize (*Zea mays* L.) is part of the important cereal crops cultivated globally. It's the main dietary component of millions of people in several parts of the world, specifically in Asia, Africa and the United States of America (USA) (Dowswell 2019). As of the year 2019 (FAOSTATS 2019), the USA was the leading global producer of maize with 370 million tons accounting for 32.69% of the overall world production. China, Brazil, Argentina and India also add up to the top 5 maize producing countries (accounting for 71.03%). Other countries like Mexico, Indonesia, Ukraine, South Africa, France and Canada are next in line to compete within production. In the year 2017, the total world maize production was projected to be around 1.134 million tons (Fig 1).

In a recent study (Khatibzadeh, Kashaf *et al*. 2016, Dowswell 2019), it was revealed that in Latin America and Africa, maize is used primarily for food consumption whereas in Asia, it is used both as food and animal feed (Khatibzadeh, Kashaf *et al*. 2016, Xu, He *et al*. 2017, Jiang, Liu *et al*. 2018, Dowswell 2019). Maize is not only an indispensable source of human and animal nutrient but also a primary constituent of materials for manufacturing many industrial products (Henchion, Hayes *et al*. 2017, Loy and Lundy 2019). These products include corn starch, maltodextrins, corn oil, corn syrup and products of fermentation used in the distillation industries (Durani, Tripathi *et al*. 2019). Besides this, maize is also recently used as biofuel (Serna-Saldivar 2016). Currently, about 1 billion tons of maize is being cultivated on approximately 180 million hectares of in land in different soil types, climate and management practices with broader plant biodiversity. The global food grain production extends to over 170 countries (Mohd Zakir Hussain 2019).

[1]College of Resources and Environmental Science, Jilin Agricultural University, Changchun, 130118, China.
[2]College of Animal Science and Technology, Jilin Agricultural University, Changchun, 130118, China.

Corresponding Author: Zhou Xue and Gao Qiang, College of Resources and Environmental Science, Jilin Agricultural University, 2888 Xincheng Street, Changchun, 130118, Jilin Provinc, P.R. China. Email: zhouxue_jlau@163.com; gyt199962@163.com

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Maize is a multipurpose crop grown in several agro-ecological zones. Maize and other cereal crops account for the vast majority of the overall consumption of fertilizer because it requires an appropriate quantity of plant nutrients, especially nitrogen (N), phosphorus (P) and K for good growth and yield. This makes K critical as macro nutrient needed to support maize production and its quality. K also has a noteworthy role in the process of photosynthesis and food production (Hussain 2018). It acts primarily as a charge transporter within plant cells by acting as a catalyst for many enzymatic developments required for plant processing (Sardans and Peñuelas 2015). In Africa, a report (FAO 2019) indicates that Sub-Saharan Africa (SSA) ecological zones had the lowest of cereal yield estimates, especially maize production a few decades ago. Notwithstanding, it has been stated to have tripled currently vis-a-vis increment in

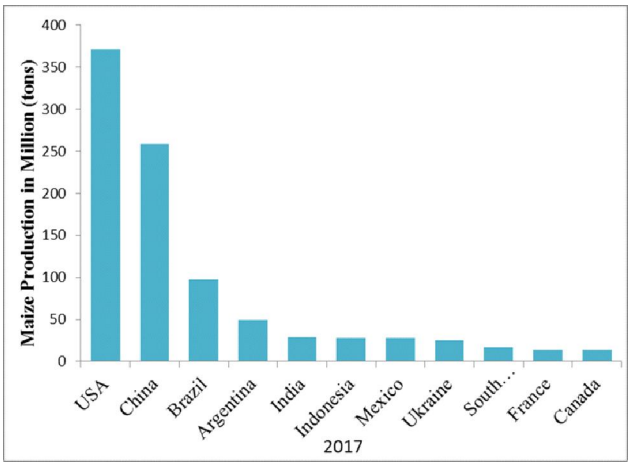

Fig 1: Global maize production for Top Ten countries as in 2017. (Source: Author's calculation using data from FAOSTAT, 2019).

production and yield with the application and combination of plant nutrients such as NPK and other micro nutrients (Kihara, Sileshi *et al*. 2017, FAO 2019). Examining this massive profitability of K, necessary attention should be given to its optimum application to curb limitation resulting from low nutrient use efficiency and fertilization imbalances. Maize uptake of plant nutrients usually leads to continuous dwindling of soil nutrients resulting in low fertility (Baghdadi, Halim *et al*. 2018). This reduction in soil fertility generally constrains maize production in regions with tropically low input systems. Insufficient K levels in soil (Bahadur, Maurya *et al*. 2016) lead to poorly developed roots, slowed plant growth, reduced size of maize grains and decrease of yield. Research indicates that photosynthesis, homologous transport, water relations and enzyme activation is affected by K (Bennett, Rogers *et al*. 2001, Deshwal and Kumar 2013, Meena, Maurya *et al*. 2014).

Although K is not part of plant organelles or structural components, it is considered the most plentiful cation within the soil regarding its cation exchange capacity (CEC). Hence soil K is categorized into three forms: soil mineral, soil solution and exchangeable. Just as several nutrients, K uptake by roots of the plant occurs within the soil pool, but the level of K in this pool is deficient (Bruns and Ebelhar 2006, Breker, DeSutter *et al*. 2019). K impact on osmoregulation, photosynthesis, assimilation transport and enzyme activation is known to have direct repercussions on the response of maize regarding its productivity.

Our next sections will discuss the relevance of K in crop production and their uptakes, how these physiological actions transforms into plant development and yield and also suggest an alternate source for K uptake system to improve maize production. The role of K regarding maize growth, development, plus yield performance will also be studied.

The relevance of K in crop production

Globally, the significant challenges facing agricultural productions are the concern of enhancing crop yields in a more resource-efficient method. Fertilizers play a crucial role in realizing the potential of different crops and high-yielding crops, especially maize, which have high nutrient requirements. NPK fertilizers can be classified as the major nutrient elements for crops. Since their usage is more prevalent and in more significant amounts than other elements, K can be considered as an essential element for plant life (Fageria 2016). As a major crop nutrient, K is responsible for several plant physiological processes (Pettigrew 2008). This indicates that K functions in the activation of more than 60 enzymes that catalyze the uptake and transport of various metabolic products (Prajapati and Modi 2012, Wang, Zheng *et al*. 2013) and nitrate from plant roots to above-ground parts (Das and Pradhan 2016). Most of the experiments (Wang, Zheng *et al*. 2013) undertaken suggest that K aids in improving crop quality, growth and development. Potash fertilizer (K_2O) importance lies in its availability to plants rather than just its accessibility in the soil (Rehm and Schmitt 2002). K regulates the opening of plant leaf tissue, thereby reducing water loss via leaves, activates the enzymes required for growth, which helps prevent disease and control insects while maintaining stem strength and standing ability (Ahanger, Tomar *et al*. 2017). For persistent crops like alfalfa, K assists in stand persistence through winter and K essential roles in the basic tasks of plant development and growth are known (Oosterhuis 2014).

Most importantly, Roy and coworkers (Roy, Basu *et al*. 2019) observed that when using the highest dose of potassium fertilizer (at 100 kg per hectare), it served as the main support for sorghum plants under favorable conditions for a period.

Additionally, K enhanced photosynthesis and phloem transport of carbohydrates to roots from the leaves, which intern helped crop growth in drought conditions (Martineau, Domec *et al*. 2017). Notably, K fertilizer application intensified the drive of K from soil to root-surface thereby improving K availability in roots of wheat (Hussain, Khattak *et al*. 2015). In a recent study (Ortas 2018), it was observed that as K requirement tends to be high, it influenced the plant which resulted in the enhancement of the yield and growth of a crop.

Importance of K to maize

In maize development, the most significant function of K is to support water absorption which is essential in a period when water is not readily accessible (Anonymous 2015). K improves the growth of maize roots, thereby increasing its ability to absorb much water in the soil (Cox 2001). An analysis from Fertibase data in Africa (FAO 2019) disclosed that, fertilizers and other soil-rich inputs (such as NPK) were used to help improve maize production in some regions of that continent.

K application not only proliferates the grain yield of maize but also advances its various quality parameters (Hussain, Khattak *et al*. 2015). These improvements can also be observed in the proliferation of grain weight. For instance, in a study, maize and soybean plants were reported

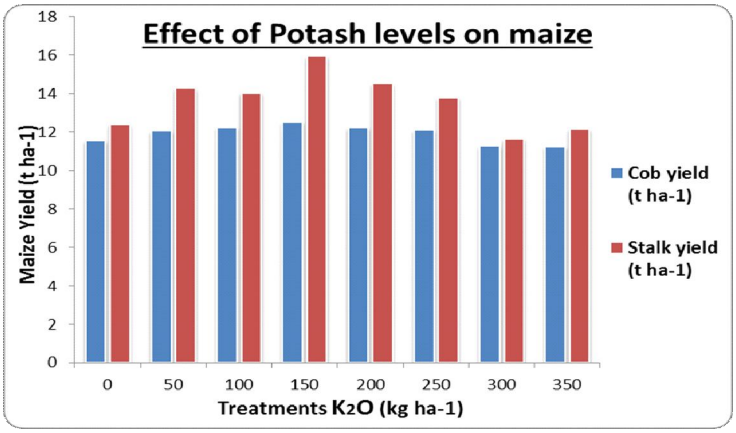

Fig 2: The effect of levels of Potash on maize cob, stalk yield (Sources: Extracted from Aman Amanullah and Irfanullah 2016).

to conserve water and reduce moisture stress by the closure of leaf stomata (opening in the leaves) mechanism, which is regulated by K (Miura and Tada 2014, Shabala and Pottosin 2014). Most importantly, K strengthens the stalks in maize and sorghum crops against invading organisms that causes stalk rot disease (Samal, Tanwar *et al*. 2019). Research has also proven that K application significantly enhances the bending resistant strength of maize stalk and above-ground K uptake of maize (Xu, Lai *et al*. 2018).

The role of K uptake on maize growth, grain and yield component

K importance to the growth of maize

Plant growth, nutrient uptake response and grain yield response are affected by placement effect. Regardless of the yield response, K application increases the accumulation of K in the vegetative tissue of maize crop, instead of the grain which increases the extent of K cycle that is recovered in the soil when only the grain harvest occurs. Various researches and information on K in plants have been discussed regarding maize response (Römheld and Kirkby 2010, Zörb, Senbayram *et al*. 2014). For example, a study by (Amanullah and Irfanullah 2016) indicated that the heading date of maize in non-treated control plots was unaffected comparing to plots treated with cow dung when different rate of K levels was applied at different times. In addition, the number of days to tasseling (56 days) was delayed before 100% of K was used when the plant was at the knee height level. Conversely, early tasseling (55 days) was noticed once 100% of K was used at the time of sowing. Also, in another research (Jiang, Liu *et al*. 2018) conducted on maize K uptake, it was revealed that K_{150} treatment was considerably improved by 55.9% compared to the K_0 treatment (no K fertilization) and the average K uptake by K_{50} and Krec treatments were 158.5 and 187.9 kg/ha respectively leading to 21.7% and 7.16% lesser than the K_{150} treatment. Consequently, K application resulted in a significant upsurge in K absorption in corn, as follows: K_{150} > Krec > K_{50} > K_0 as reported by (Jiang, Liu *et al*. 2018). In another observation (Amanullah and Irfanullah 2016), the yield components such as cob length, 1000-grain weight and the number of grains per cob, were unaffected but total cob growth recorded a substantial increase during potash application (Fig 2). However, this increase in cob yield did not reflect considerably in the final yield. Cob yield was increased in terms of added potash level of 150 kg ha^{-1} and it was perceived at par with up to 250 Kg K_2O ha^{-1}, but substantially different from the control and the highest treatment at 350 Kg K_2O ha^{-1}. However, K fertilization at the late stage of the growth phase is necessary to increase crop height and ear height (Saleem, Javed *et al*. 2011). Nonetheless, there is an unclear application time (be it early stage or later stages) for maize growth. Therefore there is the prerequisite for further analysis to find the stage of growth for K application.

K importance in grain and yield components of maize

In a study by (Pettigrew 2008), it was revealed that maize yield varies by species, variety and location of crop. It was also determined by the availability of primary factors such as soil status of nutrient and fertilizer application. Grain production is one of the most significant determinants of crop yield. In maize for example, yield depends on the number of plants per unit area, the number of cobs per plant, the number of grains per panicle and the grain weight (Ahmad and Akram 2017). Furthermore, grain yield, grain number per row, 1000 gain weight, biological yield, grain weight per ear of maize in various K treatments showed significant variations (Ali, Hussain *et al*. 2016). To achieve or maintain maximum maize yield, it is often necessary to supplement K fertilization, especially in soils with low soil K testing. In a study (Bukhsh 2011) conducted, it was observed that, when K is used in research treatments, it significantly improved the yield of the grain and decreased maize plant exposure to adverse conditions like stress in maize hybrids (Basak and Biswas 2010, Bukhsh 2011, Basak and Biswas 2012).

The evaluation of the yield component of maize (Quansah 2010) is widely affected by organic and inorganic fertilizers (such as K, N and P) and their combination. Also, research (Quansah 2010) demonstrated that the maximum

grain yield of 1829 kg ha^{-1} was attained when there was a blend of P and K in a ratio of 90 × 60 kg ha^{-1}. Furthermore, some research also showed that K fertilizer alone will do better, but when in combinations with other nutrient during interactions, it results in increase in the effectiveness of maize grain yield (Hussain, Khan *et al*. 2007).

Interestingly, K is well-known for its interaction with virtually all the essential macro nutrients, secondary nutrients and micro nutrients and has the future yield and quality improvements that require a better consideration and management of these interactions (Anonymous 1998). In agreement with (Haile, Markos *et al*. 2015) on findings in Africa, it was observed that the highest PLHT, EL, NSPE and TSW was recorded with the use of NP + K and the yield component of potash produced in maize was significantly greater than those provided by topical control. Their experiment revealed in Table 1 that yield increase for PLHT, EL, NSPE and TSW treatments were 18, 14, 20.5 and 25.6%, respectively, in comparison to the control treatment.

In a recent study by Hirniak *et al*. (Hirniak 2018), it was evident that N and K fertilization affected the leaf K concentration and the N x K interaction was significant ($P \leq 0.05$) at both sites. To exert these multiple diverse roles, K is absorbed and utilized with other nutrients availability and absorption, such as plant residues, animal sources, biosolids and significant minerals. The authors report also indicated that organic fertilizer can be used, especially cattle manure, which can provide a significant proportion of K for crop productivity (Plunkett 2016). It should be noted that the absorption of K by maize is also high. The diagram (Fig 3) shows the stages in the cycle of another component of K, their addition in the soil and how losses occur through leaching as this stage gives a better introspection of research on the K cycle.

Table 1: The effect of potassium applied alone and in combination with NP on the yield components of maize at Hadero (in Africa).

Treatments	PLHT(cm)	EL (cm)	NSPE	TSW (g)
C	226.6	23.6	353.3	295.8
K	267.5	27.0	425.6	371.5
NP	274.8	28.7	493.8	387.8
NPK	297.5	30.5	576.0	432.5
LSD (0.05)	9.6	1.1	34.6	22.9
CV (%)	7.5	5.0	8.7	5.0

Source: Extracted from Markos (Haile, Markos *et al*. 2015).

Earlier research studies have also proven that N and K stimulated crop growth and yield in a synergistic approach (Rietra, Heinen *et al*. 2017) (Fridgen and Varco 2004). In addition, other studies have depicted that the yield response of maize to K is dependent on N and P nutrition as their interaction is positive in general (Bruns and Ebelhar 2006) (Wang, Cai *et al*. 2007) (Duncan, O'Sullivan *et al*. 2018). Hence, a critical look at K concentrations in grain during plant K uptake and evaluating the optimum economic rate under different indigenous soil for K supply levels will be a useful research area for future investigation. Most particularly, improving K-use efficiency with other macro or micro nutrients will become crucial for a global nutrient interactive balance.

K nutritional role in disease, drought and stress resistance

Researchers have reported the mechanical effects of K on plant disease resistance in various scientific articles. Many of these field studies have specifically observed a correlation between potassium concentration in plants and soils and drought avoidance mechanisms (Arquero, Barranco *et al*. 2006, Fayyaz, Etemadi *et al*. 2013, Tomlinson, Poorter *et al*. 2013). Drought effects are generally asymmetric for various crop organs; because crop disseminates and reserves more K in the stem and part of K is transported into the leaves in the driest period (Sardans and Peñuelas 2015).

There is proof showing that biotic stresses significantly constrain maize crop production (Meena, Bahadur *et al*. 2016). Stress brought about by both insect damage and diseases are mostly decreased when K is sufficiently supplied (Meena, Maurya *et al*. 2016, Rawat, Sanwal *et al*. 2016). Interestingly, the US Department of Agriculture found that one of K prominent role is the defense of plants (Berens,

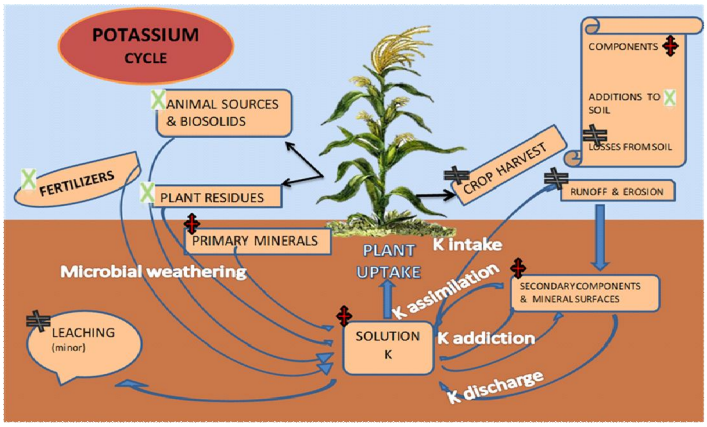

Fig 3: Potassium cycle depicting K uptake in maize growing season.

Berry *et al*. 2017). In maize production, it was revealed that K increased drought resistance and ultimately improved the growth of maize plants under drought situations (Cox 2001). This resistance to stress, temperature and disease depends on the capability of soil K uptake by crop (Mikkelsen 2007). In Africa, 25% of maize crop yield was lost due to diseases alone in 2013 (E Isabirye and Rwomushana 2016). When the balance of K application is not corrected, drought situations and high rainfall or large quantities of irrigation will also cause a problem. Hence, the application of potash in soils should be optimized to increase resistance mechanisms, especially in the developing regions of the world, to improve maize crop response to drought stress.

Similarly, K application improved maize crop resistance to drought tension and also increased crop growth, dry matter segregation and maximized yields (Amanullah and Irfanullah 2016). K is also noted to play a vital role in plants as its presence results in enhanced resistance of maize plants to *Fusarium* spp (plant pathogen). For instance, the "stay-green" variety in a study was proven to be more immune to *Fusarium* spp. compared to the "classic" variety (Bocianowski, Szulc *et al*. 2016). Because of its fundamental role in plants, K nutrition affects maize crop resistance to almost all abiotic and biotic stresses directly and indirectly (Zörb, Senbayram *et al*. 2014). K helps the maize plant to resist disease and pest attacks, builds strong and healthy stems and also provide support for drought survival (Mohd Zakir Hussain 2019). Lopez and Vlek, 2006 revealed in their study that grain production in fields with high infestation was found to due to K-limitation. Notably, low K absorption will lead to a reduced water circulation in maize plants and will render plants extra susceptibility to drought and temperature variations.

Increased electrolyte leakage and decreased proline as well as sugar levels is an indication of water stress or plant oxidation, but the use of KCl and KNO_3 can improve all of these properties (Kumar, Shahi *et al*. 2019). Drought stress may be increased in crops with insufficient K content and thereby N uptake may be difficult. Inadequate K will slow down stomata closure and this will also lessen protection from drought stress (Rawat, Sanwal *et al*. 2016, Tighe-Neira, Alberdi *et al*. 2018). Normally it is believed that high K status in crops reduces the incidence of diseases and pests. Therefore following the above instances, vigorous experiment aimed at optimizing maize plant K nutritional status will be imperative to improve the stress tolerance of crop plants.

Time and methods of K application in maize

Many studies have depicted that maize typically absorbs most of their K during the early growth phase, unlike that of N and P (Mallarino, Bordoli *et al*. 1999, Saleem, Javed *et al*. 2011) whereas in other studies, K nutrient accumulation is mostly in vegetative tissue (Oltmans and Mallarino 2015) but decelerate during the reproductive stages (Elmore, Sawyer *et al*. 2019). In a study (Saleem, Javed *et al*. 2011) conducted, it was observed that split application methods of K significantly affected maize crop production likened to a single application of K. Notably, recent research have also proven that single application of K before planting is sufficient for maize grown on sandy soils in contrast to a split application at 12 inches tall (Raza, Bin Khalid *et al*. 2019).

In addition, compared with 100% NPK results from studies (Shanmugasundaram, Malarkodi *et al*. 2019), it has been showed that long-term multi-level fertilization of K can improve the availability of K in the soil (for instance, for 14.41% for corn and 18.32% finger millet). The best time to fertilize according to some authors depends on the nutrient absorption pattern of the crop and many previous research articles have addressed this (Szczerba, Britto *et al*. 2009) (Britto and Kronzucker 2008) (Kronzucker and Britto 2011). Physiological maturity and tallness of maize crops are considerably affected by K quantity and application time. Research on maize grains demonstrates that the application of K at different levels significantly affects the crude starch content of the grains as well as their performance (Hussain 2018). In a current study (Jiang, Liu *et al*. 2018), the authors reported that although K uptake by maize in K_{150} treatment (with 150% of recommended K rate) was greater than Krec treatment (the recommended K rate), grain yield was lesser than Krec treatment. The authors attributed it probably to K surplus consumption in K_{150} treatment. In the same way, N, P and K can cause environmental problems if not applied properly as excessive K fertilization can lead to the reckless use of resources and unnecessary financial costs to farmers (Johnston 2003). K deficiency response below 30 kg Kha^{-1} may be due to sufficient levels in the soil pool used for the experiment and the additional use of potash on such soils can be a waste. This may increase the concentration of K in the soil to unacceptable levels and therefore lead to frugal economic returns (Kogbe and Adediran 2003). When K is not applied to such soil, it will save farmers more money and will reduce environmental pollution. This means that inappropriate use or excess K in the soil may also lead to environmental problems (Kogbe and Adediran 2003). However, in another study, higher stalk yields were observed when K fertilizer was added at a higher rate (120 kg ha^{-1}) either at the sowing time or full dose when administered separately. Interestingly, it was observed from these results that K content was higher, that is 120 kg ha^{-1}, which resulted in an upsurge in both the stem and grain yields, especially during the split application period (Saleem, Javed *et al*. 2011). In Table 2, K produced the highest grain yield (8014 kg ha^{-1}) in three splits of 120 kg ha^{-1}, followed by two split (6661 kg ha^{-1}) and the lowest grain yield of 2923 kg ha^{-1} was observed in the control treatment. In maize, K uptake increases rapidly after the vegetative growth stage, approximately 4 to 6 weeks after planting. Uptake of K is completed soon after silking, which is the reproductive stage (Iqbal and Hidayat 2016). Taken together, there is therefore the requisite to determine which stage of maize development that K affects growth and yield and further link this information to current fertility management practices.

Table 2: Effect of split application of potash fertilizer on yield and yield component of maize. (Source: extracted from Saleem (Saleem, Javed *et al.* 2011).

Treatment	Days to 50% silking	Plant height (cm)	Ear height (cm)	Stalk yields (kg ha^{-1})	Grain yield (kg ha^{-1})
T1 (Control)	55	210	103	7333	2923
T2 (60 kg at planting time)	57	210	101	7600	4073
T3 (120 kg at planting time)	55	223	108	12667	6073
T4 (30 kg at planting and 30 kg after one month)	56	226	110	11822	4786
T5 (20 kg at planting, 20 kg after one month and 20 kg after two months)	56	222	108	11556	5761
T6 (60 kg at planting and 60 kg after one month)	56	228	116	12222	6661
T7 (40 kg at planting, 40 kg after one month, 40 kg after two months)	57	233	121	14356	8014
LSD	1.74	14.94	11.81	1795	724.9
CV %	1.75	3.97	6.06	9.11	7.45

Importance of KSM to crops growth

The soil is the warehouse of the nutrients and energy for the organism under the microbial-soil-plant system. As earlier stated, N and P are components of organic material, whereas K is not. In a research conducted (Qi, Duan *et al*. 2012), high-yield cultivars were reported to have been introduced and that intensive planting consumes K fertilizer of more than ten metric tons per annum in global farmland. Since the expenses of K-fertilizer (the cost of potash $470 per ton since 2011) are escalating each year (Meena, Maurya *et al*. 2014) and utilization of this fertilizer affects nature, it is therefore important to have an alternative source of K to keep up K level in soils for economical and sustainable crop production. Remarkably, research have also suggested that, the most usually discovered soil segments of K are about 90-98% which are feldspar and mica (McAfee 2008).

Microorganisms also assume a vital part in a natural P and K cycles as P-or K-solubilizing organisms in the crop rhizosphere (Diep and Hieu 2013). The exploitation of K-solubilizing microorganisms (KSMs) results in the increment of K amount in the soil arrangement which eventually lead to improvement in crop growth during its development. In addition, the use of KSMs as biofertilizers can build the convergence of available K^+ in the soil pool, which will relieve K inadequacy or mitigate K problems in a more eco-friendly way (Saha, Maurya *et al*. 2016). The overall out pool of soil K is very unpredictable and the KSMs can solubilize this through the generation of acids, which can be accessible for the plant (Singh, Biswas *et al*. 2010, Basak and Biswas 2012). The most significant portion of the whole soil K accessible to plants is generally situated in the topsoil. This is in line with the study by Prajapati *et al*. (Rajawat, Singh *et al*. 2012), which showed that mineral K-solubilization is the main machinery for the generation of organic acids which assume the critical job in the mineralization of natural K within the soil.

Parmar and Sindhu (Parmar and Sindhu 2013) in their studies discovered that the microorganisms in the soil or rhizosphere solubilize mineral K through the synthesization of organic acids. Furthermore, studies on a wide scope of KSMs particularly; *Bacillus mucilaginous*, *Paenibacillus* spp., *Bacillus edaphicus*, Burkholderia, *Acidothiobacillus ferrooxidans*, *Bacillus circulans*, *Pseudomonas spp* (Sheng, Zhao *et al*. 2008) (Singh, Biswas *et al*. 2010) (Lian, Fu *et al*. 2002) (Liu, Lian *et al*. 2012) (Rajawat, Singh *et al*. 2012) (Basak and Biswas 2012) are known to discharge K in available structure from K-bearing organisms. These living organisms (Alori, Dare *et al*. 2017) as elucidated have a role to play in conversion of insoluble or mineral basic K compounds into a dissolvable structure and thus make them available for crop uptake. Additionally, available reports demonstrate that these microorganisms implemented a particular mechanism for K rock mineralization that may incorporate redox responses by creating chelating molecules and organic acids for K dissolution to enhance bio-accessibility as elaborated in (Fig 4) (Lian, Wang *et al*. 2008, Uroz, Calvaruso *et al*. 2009).

A substantial collection of proofs also recommends that improvement of the K status of plants can incredibly upgrade plants' opposition against stress and infections (Rehm and Schmitt 2002).

An examination of maize and wheat was conducted by assessing the solubilizing capacity of *B. mucilaginosus*, *Rhizobium* spp. and *A. chroococcum*, in a phytotron development chamber showing the impact of KSMs in hydroponics (Meena, Bahadur *et al*. 2016, Meena, Maurya *et al*. 2016). As indicated by these studies, KSMs substantially improved the K content, plant biomass, rough protein and chlorophyll content in the harvests of maize and wheat (Meena, Maurya *et al*. 2016). It was likewise revealed that *B. mucilaginous* demonstrated fundamentally higher solubilization and uptake of K than *A. chroococcum* and *Rhizobium* spp. (Singh, Biswas *et al*. 2010). Table 3 gives a summary of the influence of KSMs on the nutrient uptake and growth of some crops according to various researches conducted. These KSMs (Meena, Maurya *et al*. 2014) have the immense potential for utilizing fixed K and all-around gradual discharge of K under soil frameworks with low K availability in tropical and subtropical developing nations.

In many cases, soil extraction strategies are dependent on interchangeable K that is rich in soil without 2:1 layer silicates (Mengel 2001). Bio-altering of K mineral (mica waste) with KSMs can substitute an attainable innovation to solubilize mineral K that is existing in mica into plant functional supplement effectively utilized as a basis of K nourishment for continued yield creation and keeping up soil K (Basak and Biswas 2009) (Singh *et al*. 2015a, Meena *et al*. 2015b) (Maurya *et al*. 2014).

Furthermore, the K solubilization from K mineral, as discussed by Rajawat and co-workers (Rajawat *et al*. 2012) is a core distinctive for KSMs, which fundamentally upgrade the fertility status of soil and inevitably advance plant development. Several types of research (Shin 2014, Ahmad, Nadeem *et al*. 2016, Yadav and Sidhu 2016) have revealed that, if there is an increase in K mobility in the soil, its availability would be enriched as well as some useful microorganisms and these positive effect can subsequently support amending K accessibility for crop uptake. Importantly, most microorganisms are possible agents to discharge K from potassic minerals and thus bring K solution for plant utilization. In addition, microbial inoculants' response to crops enhances soil fertility to increase maize yield (Bahadur *et al*. 2016). Therefore taken together, future studies are however recommended to focus on issues of KSMs striving in different soil types with mineral resources and its uptake by maize in Africa, Asia, USA and Europe, where maize production is massive for crop development and yield.

Factors affecting K uptake by maize

Reduction in soil temperature decreases K utilization and absorption rates by crops. For that reason, the most severe factors affecting maize response to fertilization are the

Table 3: Effect of potassium solubilizing microbes on crop growth and nutrient uptake.

Crops	Microbes	Effects on crops	References
Maize	*A. chroococcum, B. megaterium*, *B. mucilaginosus*.	Increased growth and uptake of N, P and K.	(Wu, Cao *et al*. 2005)
Wheat	*Bacillus* sp.	Increased grain yield and disease resistance.	(Zablotowicz, Tipping *et al*. 1991)
Black pepper	*Paenibacillus glucanolyticus*	Enhanced K-uptake and dry weight in inoculated plants.	(Sangeeth, Bhai *et al*. 2012)
Maize/wheat	*B. mucilaginosus*, Azotobacter chroococcum.	Higher K-mobilization, root shoot growth and yield.	(Singh, Biswas *et al*. 2010)
Sudangrass	*Bacillus mucilaginosus*	Higher biomass yield, uptake and % K-recovery increased root shoot growth	(Basak and Biswas 2009)
	Bacillus mucilaginosus	Higher biomass accumulation and nutrient acquisition	(Basak and Biswas 2010)
Eucalyptus	Ectomycorrhizal fungi (UFSC-Pt22 and UFSC-Pt186)	Enhanced N, P, K content and plant growth	(Alves, Oliveira *et al*. 2010)
Eggplant	*B. mucilaginosus* KCTC 3870	Increased P and K uptake	(Han and Lee 2005)

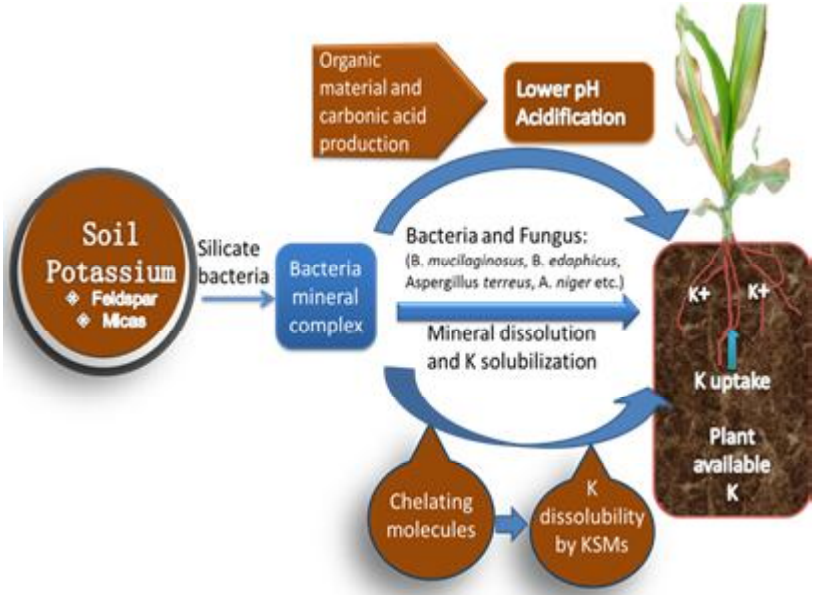

Fig 4: K-solubilizing mechanisms illustrating potassium solubilizing microbes' activities.

quantity of soil K supplied and removed during harvest (Hirniak 2018). Despite the topsoil texture and the mineralogy, K application methods are essential for different soils across regional agro-ecological distribution.

Research have also indicated that the overall amount of K that crop absorbs during its growing period is reliant on the crop type, the availability of K in the soil and the amount of K applied (Greenwood and Karpinets 2007, Parmar and Sindhu 2013, Yadav and Sidhu 2016, Dwivedi *et al*. 2017). Maize response to K is relative with yield response indicating a productive cycle of K within the maize crop system. The level and amount of K absorbed and their discharge in large amounts during the decomposition of the straw near the planting time affect maize growing cycle (Jan *et al*. 2018).

K uptake is again affected by the environmental condition (Rao and Srinivas 2017) (Li *et al*. 2016) (Oltmans and Mallarino 2015) (Bar-Yosef *et al*. 2015). Similarly, in a study conducted (Kihara *et al*. 2016), it was demonstrated that K limitation was particularly manifested in higher yield levels being reduced and relatively fertile soil being affected. Interestingly, Chen and Gabelman (Chen and Gabelman 2000) found in tomato that K+ absorption efficiency is related to high K+ influx around the root surface and low pH. Electrochemical proton gradients can help stimulate K+ absorption. Hence, some CT / KUP / HAK transporter use this co-transport to transport K+ and H+ together (Rodríguez-Navarro 2000).

Furthermore, drought stress or excessive water can also reduce K utilization and absorption in maize crops, but increasing soil K content can aid in overcoming these adverse effects (Kihara *et al*. 2016). In the same way, compacted soils tend to have poor K absorption regardless of the K amount in the soil pool. In such situations, the availability of K must be kept to exchange within the soil solution, as these nutrients do not just move into plants, but it will depend on some energy to get them inside. Therefore plants must have a living, breathing, healthy root system to absorb these nutrients (Smith 2010).

Additionally, K needs moisture for mobility to the roots of the crops for uptake and this moisture needs to flow through the roots to the “new” supply of K. But, very wet soil can also diminish root growth, aeration and K uptake by maize plants (Kihara *et al*. 2016). Cold soil temperatures can decline the metabolic processes of the crop, which affects the uptake of K and also slow down the discharge of K^+ within the soil solution. K use efficiency is sometimes as a result of lower fertilizer consumption in Africa, consuming only about 1.5% of global potash fertilizer production (Manning 2015).

Transportation of K^+ in root system

In agricultural production, the supply of K+ in the soil may be a limiting factor. The transport of dissolved phloem substances and their maintenance require K+ cations: anions balance in the cell fluid and vacuole. In corn (Zea mays) and other crops, the lateral roots head and the outer portion of new lateral roots originate from the endoderm (Orman-Ligeza *et al*. 2013). Hence, the development of the maize lateral root primordia also indicates that lignin is degraded in the cell wall of the endoderm mucosa.

The accumulation of K^+ in the roots of symbiotic plants will result in high energy consumption and require a special transportation system (Tardieu *et al*. 2017). The transmembrane movement of K+ is catalyzed by channel proteins and transport proteins and these channels are excited by the negative potential of the plant cell membrane. (Wang and Wu 2013).

In addition, the carrier may use H^+ and in some cases, Na^+ gradient or ATP hydrolysis may be used to stimulate K^+ transport. After preliminary identification of plant cDNA channels and cDNA transporter molecules (Pottosin *et al*. 2014), many plant genes encoding K^+ vectors were cloned using *S. cerevisiae* and *E. coli*. In addition, xenopus oocytes expressions have been described to function in this manner. (Ragel *et al*. 2015, Ketehouli *et al*. 2019).

A complete genomic study showed that the six main families of cationic carriers in Arabidopsis have different selectivities and are K+ permeable: K+ shaker channels (9 genes), Double pores K channels (Six genes), cyclicnucleotide -gated channels (20 genes), putative anti-K+ IH+ (six genes), KUP/HAK/KT transporter (13 genes) and HKT transporter (one gene). In addition, another K+ -permeable carrier LCT has been found in other crops (Almeida *et al*. 2017, Feng *et al*. 2020). These molecular transfers of K+ by plant in the soil is briefly described in Fig 5.

Effect of K deficiency in maize plant

Owing to the lack of attention to potash, the world’s agricultural land suffers from severe K fertilizer deficiencies, especially in Africa, Asia and Europe (Bengtsson, Öborn *et al*. 2003, Hedlund, Witter *et al*. 2003, Kaizzi, Byalebeka *et al*. 2012, He, Yang *et al*. 2015). Some previous studies outlined that K deficiency has been amongst the main constraints to crop production (Singh *et al*. 2015, Meena *et al*. 2015a, Meena *et al*. 2015b). Notably, in phytonutrients, the dearth of K limits the growth of crops and reduce yield. Furthermore, when K is limited, the plant will be constricted on the quantity of N it can absorb from the soil, thus impacting stalk strength, disease tolerance and grain quality.

K deficiencies in maize crops can also hamper their capability of utilizing N and this may result in an amplified possibility for nitrate leaching. Likewise, the absence of K might raise crop’s vulnerability to diseases and later the necessity for pesticide applications (Zörb, Senbayram *et al*. 2014, Wakeel, Gul *et al*. 2016). In a study conducted by McKenzie *et al*. (McKenzie and Pauly 2013), the authors reported that soil K deficiency (potential test for potassium below 150 lb / ac) usually required high K application rates for maximum productivity to be achieved. Similarly, in high K -deficient soils, some researchers (Zörb *et al*. 2014) suggest that soil K can be established initially by applying 200 to 300 lbs/ft of K_2O (broadcast and incorporation) followed by 30 lbs/acre per year in the subsequent years. In addition,

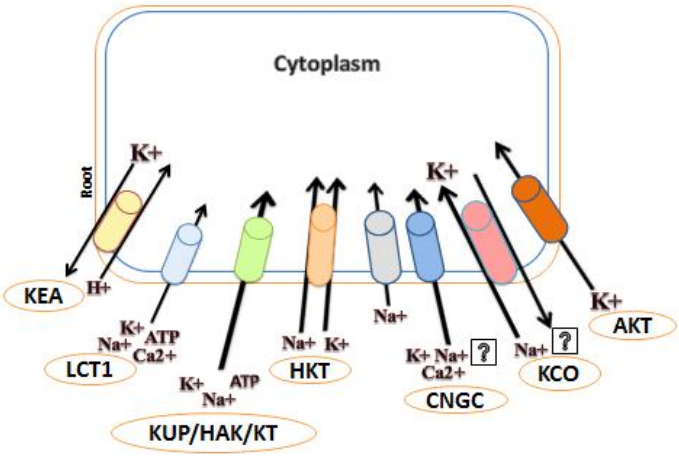

Fig 5: Plant K+-permeable cation transporters. The K+ osmotic transporter family of at least seven families in plants has been characterized in several studies (Okada, Yamane *et al*. 2018, Feng *et al*. 2020). These have involved the implementation of KUP/HAK/KTs (K+ absorption/high affinity K+.), LCT (low affinity cation transport Protein) and KEAs structure (K+ exchange exchange antiporter) (Feng *et al*. 2020) (Okada *et al*. 2018). The proton concentration gradient allows the operation of Na+/H+ (K+, Na+/H+ antiporter) on the plasma membrane to excrete Na+ into the cytoplasm to the external environment or vacuole. At high external concentrations, Na+ can also enter cells by using KUP /HAK type K+ carriers. K+ from the plant is KCO (K+ channel outward rectifier) exhibiting K+ selective current when depolarized. Due to the external environment or the vacuoles formed by the CNGC (Cyclic Nucleotide Gated Channels), the potential gradient generated by the pump causes Na + to enter the cytoplasm of the cell which is a carrier of HKT (high affinity K + transporter type) on the plasma membrane in some species.

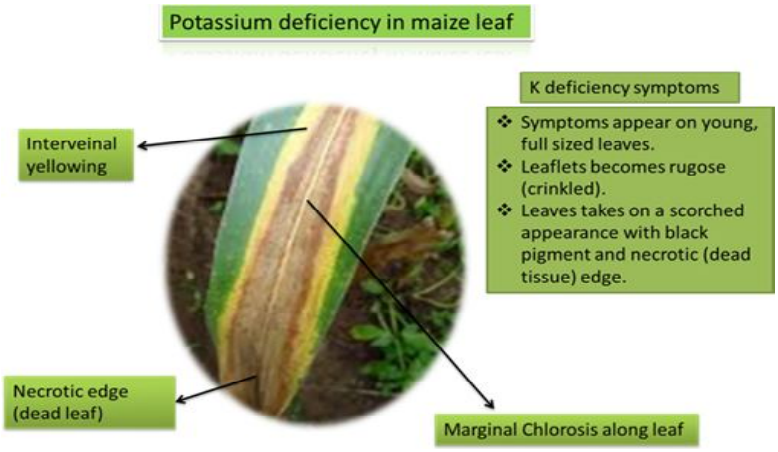

Fig 6: Potassium Deficiency symptoms in maize leaf.

similar results can be obtained by bundling a strip of 50 to 80 pounds per hour for several years to establish soil K levels. K deficits in cereal crops (Zörb, Senbayram *et al*. 2014), might constrain crop capacity to exploit N, causing an increased likelihood for nitrate leaching. Water is indispensable for the massive flow of nutrients which prevents soil depletion but on the other hand, a dry weather and soil compaction can lead to K deficiency (Rawat *et al*. 2016; Anser Ali and Hussain 2012).

Notably, K-deficient crop shows signs of wilting under dry conditions, which are associated with the grains forming depressions and the tip of the ear lacking grain. Correspondingly, insufficient K levels in crops also depict physical appearances of less leaf area, less solar radiation interception and reduced photosynthesis per unit leaf area. K deficiency in soil hinders plants from up taking an adequate amount of K which prompts K insufficiency disorder (Das and Pradhan 2016). Since K is a crucial growth facilitator in crops, its deficit in crops will induce stunted growth. Many researchers have also concluded that symptoms of K deficiency are similar to symptoms of nitrogen deficiency (Pan *et al*. 2017).

However, in contrast to this, Smith (Smith 2010) pointed out that K shortage in plant leaves depicts a yellowing color flow from the outside of the leaves whereas in N deficiency, the yellowing color initiates at the tip and flows down the midrib of the leaf. Interestingly, the dearth of K is highly phloem-moving, as described by (Grusak, Broadley *et al*. 2016) by initially appearing on older, more mature leaves of plants. The edges of the leaves in a more severe case appear dead (brown), whereas the new leaves remain green because K in the old tissue is reactivated to supply

K to the new tissues as shown in Fig 6. In many cases, deficiency of K will render the weak maize resistance to pest, the roots will be very ghoulish and above all, the grains will not ripen well.

On the basis of these above mentioned symptoms resulting from lack of K, farmers therefore must lookout on the dangers of these K deficiencies and application should be optimized to improve production. Most importantly, to ascertain a correct deficiency and the best potash fertilizer program usage in the global region, rigorous soil test in an agro-ecological zone is necessary.

PERSPECTIVE AND CONCLUSION

In brief, this article revealed that K played an active role in activating various enzymes that affected metabolism and the quantity of this drive is sometimes minimal. K availability varied with soil type and is affected by physicochemical properties of the soil. K application period in maize also varied by soil type, growth period and crop hybrids; therefore, further research is necessary to ascertain the correct timing and mode of K application taking into consideration other preferable nutrients that can combine with K effectively.

This study also depicted that the solution to augment maize production is the proper administration of K fertilizers with the right organic nutrients. In a global region (for example, savannah zones in Africa), where rainfall is scarce, soil organic matter content is low. Traditional agricultural systems also cause nutrient loss; continued decline in crop yields and incomes which eventually causes farmers to fall into a brutal circle of poverty. Therefore, the K content of the national fertilizer program must be considered with the aim of increasing crop yield and productivity in these regions.

In summary, a further look at KSMs use will serve as a suitable alternative to the traditional potash that comes with high expenses for most local farmers. This kind of microbial association is proven to be cost-effective and environmentally friendly and can be used to promote sustainable agriculture.

RECOMMENDATIONS

The ratio of K fertilizer application can be based on crop uptake and soil test done for inadequacy. Therefore future recommendations should be geared towards extensive research to estimate the application rate for each regional distribution (for Asia, Africa, USA, Europe, etc.). The exact period to apply K fertilizer should be when the need arises for additional compound fertilizer such as Cl and S, which must be readily available in the soil pool. The application ought to be done in the cropping season. For instance, in maize production, the band method of application is recommended when fertility is lower in the subsoil than the broadcast method. We also recommend an integral blend of both applications of organic and inorganic fertilizers for readily available K uptake by the plant.

There is a requisite to design further studies through research experimentation containing different soil types. By using microbes and synthetic fertilizers, researchers can find the best amalgamation of various fertilizers and microorganisms. The soil pool should be compensated with other sources of K so that the required amount needed for crop growth will be met. This can be replenished from an exchangeable K that is freely available for plant uptake (Fotyma 2007, Lalitha and Dhakshinamoorthy 2014). Hence this review suggests a maximum utilization of KSMs as an alternative method to increase the effectiveness of soil exchangeable K uptake by plants root (Basak 2009; Meena *et al*. 2014).

Future study

We recommend that soil scientist should consider the factors in K applications contributing to maximizing K uptake plus possible application methods. Future research of priority should include identifying ways to make K readily available for plant uptake. The findings from this review are critical; therefore, future research must be focused on using different K rates to comprehend the different crop growth stages and soil type, which helps to recognize the K-sensitive growth stage of the crop. Further studies on soil fertility investigations as an important tool for effective use of K and its uptake should be considered. This will curtail the excessive use of K to save farmers' economic resources and avoid global environmental problems. Careful research into organic minerals like KSMs as an alternative source in K uptake is also important.

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Author contributions

Zhou Xue conceived the study and supervised the manuscript. Michael Osei Appiah and Lehlogonolo Evans Kgorutla reviewed the paper. Bismark Asante-Badu wrote the original draft of the manuscript. All authors reviewed the manuscript and agreed with its contents.

Conflict of interest

The authors declare that they have no conflict of interest.

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