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Efficiency of K-sulphate and K-feldspar Combined with Silicate Dissolving Bacteria on Yield and Nutrient Uptake by Maize Plants

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A FIELD experiment was carried out in 2014 growing season in Hehia, El-Sharkia Governorate, Egypt to asses application of 95 kg K ha^{-1} applied to maize (*Zea mays*) as potassium sulphate (KS) or potassium feldspar (KS) combined with potassium dissolving bacteria (*i.e.,* silicate dissolving bacteria "SDB", *Bacillus circullans*) individually or in different combination ratios. 50% KS + 50% KF gave the highest values of height of maize plants, leaf area, ear length, ear diameter, ears yield, stover and grains dry weight, NPK-uptake, protein content and biological yield. The treatments of 25% KS + 75% KF and control gave the lowest among the treatments receiving K. The application of 50% KS + 50% KF gave increases in stover and grains dry weight which ranged from 40 – 51 % and 87 – 118 %, respectively. The treatment of (K3) at 45, 90 and 180 days gave the highest value of soil available potassium (295, 375 and 247 mg kg^{-1}, respectively), while the lowest ones (63, 58 and 51 mg kg^{-1} , respectively) were found with untreated soil.

Keywords: Potassium sulphate, Potassium feldspar, Nutrient uptake, Maize, *Bacillus circullans.*

Maize (*Zea mays* L.) is a cereal of high economic relevance and a variety use (Fancelli and Dourado, 2003) ranging from food and feed to the high-technology industries (Paes, 2008). Potassium (K) is one of the macronutrient essential for maize growth and plays an important role in plant growth, metabolism and development. Without adequate potassium, the plants will have poorly developed roots, grow slowly, produce small seeds and have lower yields. Soluble potassium in soils is frequently not sufficient for high production of maize , although most soils have high contents of insoluble forms of potassium (Sheng and Huang, 2002). In Egypt, farmers apply high rates of chemical potassium fertilizers (such as potassium sulphate) to maize. The high price of chemical fertilizers contributes to increasing production cost of crops, which may be one of the reasons for us aiming at providing plants with K released from mineral non- soluble sources (Manning, 2010 and Labib *et al*., 2012). The use of rhizobacteria including potassium solubilizing bacteria as biofertilizers was suggested as a sustainable solution for crop fertilization (Vessey, 2003, Sheng, 2005, Setiawati & Handayanto, 2010 and Ekin, 2010). Potassium solubilizing bacteria is a heterotrophic aerobic bacteria which obtain their energy and cellular carbon from organic material sources in soil (Zakaria, 2009) and play an important role in maintaining soil structure by their contribution in forming water-stable soil aggregates. These bacteria are able to solubilize rock K, such as micas, illite and orthoclases (feldspar), also through production and excretion of organic acids (Ullman *et al.*, 1996) by chelating silicon ions releasing K into solution (Bennett *et al.*, 1998). Potassium solubilizing bacteria *Bacillus mucilaginosus* were reported to have increased K availability in soils and increased mineral content in plant (Sheng *et al*., 2002 and Zakaria, 2009). Bakken *et al.* (2005) reported that fertilizers containing biotite as its main K-bearing mineral and between 5 and 20% carbonate, released K at a slower rate than soluble K fertilizer. Girgis *et al.* (2008) showed that inoculation with potassium solubilizing bacteria caused partial degradation of minerals resulting in the release of soluble K and P. Badr (2006) used potassium solubilizing bacteria to enhance available K in the matured compost. Response of potato plants to K-biofertilizer was enhanced in sandy soil of low K content (Sugiyama and Ae, 2006). Priyono and Gilkes (2008) evaluated the effectiveness of intensively milled gneiss and potassium feldspars as K-fertilizers with ryegrass and concluded that such materials are most advantageous for amending K-deficient soils. Abd El-Hakeem and Fekry (2014) reported that addition of 50% potassium sulphate plus 50% K- feldspar + silicate dissolving bacteria (SDB) increased yield and NPK-uptake. Abdel-Salam & Shams (2012) and Labib *et al.* (2012) applied 50% potassium sulphate +50% K- feldspar combined with SDB gave the highest quality parameters of potato tubers, total yield and NPK uptake. The objective of the current study is to asses K fertilization (K- sulphate and K-feldspar) of maize through the use silicate dissolving bacteria.

Material and Methods

A field experiment was carried out during 2014 growing season in Hehia , Egypt to study the asses of the efficiency of K fertilization (K- sulphate and K-feldspar combined with silicate dissolving bacteria "SDB" of *Bacillus circullans*) to maize (*Zea mays* L.,cv. 2031 hybrid). The physical and chemical properties of the soil (Table 1) were determined according to Piper (1950); Black (1968) and Jackson (1958).

The experiment was done using the randomized complete block design in three replicates. It involved application of K at 95 kg ha^{-1} to maize as K-sulphate (KS) or K-feldspar (KF) or combination of both. Treatments were as follows:

- Non –fertilized (K0)
- 100% KS (K1)
- 75% KS + 25% KF (K2)
- 50% KS+ 50% KF (K3)
- 25% KS + 75 % KF (K4)
- 100% KF (K5)

TABLE 1. Some physical and chemical properties of the investigated soil.

Soil characteristics	Values
Soil particles distribution	
Sand ,%	47.92
Silt,%	18.25
Clay,%	33.83
Textural class	Sandy Clay Loam
Field capacity (FC),%	27.95
$CaCO_3$, (g kg^{-1})	18.5
Organic matter,(g kg^{-1})	4.4
pH*	7.95
EC,(dSm^{-1}) **	1.12
Soluble cations and anions, (mmolc L^{-1}) **	
Ca^{++}	4.54
Mg^{++}	2.32
Na^{+}	2.91
K^{+}	1.24
$CO_3^{=}$	-
HCO_3^{-}	1.56
Cl^{-}	3.44
$SO_4^{=}$	6.01
Available nutrient , (mg kg^{-1}soil)	
N	109
P	11.23
K	182

* in soil paste   ** in soil paste extract.

The KS contained 410 g K kg^{-1} whereas KF contained 95 g K kg^{-1} .The plot area was 21 m^2 (3 × 7m), each plot had five rows 60 cm apart and 7 m long. All treatments received 240 kg N (as ammonium sulphate, 200 g N kg^{-1}) + 30 kg P (as ordinary super phosphate, 68 g P kg^{-1}). N- fertilizer was applied in 3 equal splits 15, 40 and 60 days after seeding P and K fertilizers were applied during land preparation. The K- feldspar inoculated with silicate dissolving bacteria, "SDB", (*Bacillus circullans*) in a concentration of (10^{10} cells ml^{-1}) at rate of 20 ml kg^{-1} K- feldspar; and is produced commercially by Soil Microbiology Unit of National Research Centre, Cairo, Egypt.

At harvest, plant samples were separated into stover and grains, dried at 70°C, ground and digested with concentrated mixture of $H_2SO_4/HCLO_4$ for chemical analysis (Chapman and Pratt, 1961). Total N was determined using the microKjeldahl method according to Chapman and Pratt (1961). P was determined colourmetrically using ascorbic acid (Watanabe and Olsen, 1965), while K was measured by flame photometer. Soil samples were taken after tittering, booting and harvest stages (45, 90 and 180 days after seeding) and available potassium was determined according to Chapman and Pratt (1961).

Results and Discussion

Plant growth parameters, stover and grain yields

Data presented in Table 2 show that all treatments significantly increased the height of plants, leaf area, ear length, ear diameter, ear yield, stover and grain dry yield and biological yield.

TABLE 2. Effect of potassium sulphate (KS) and potassium feldspar (KF) treated with silicate dissolving bacteria on plant growth measurements, stover and grains dry weight of maize plants.

Treatment	Plant height (m)	Leaf area (cm^2)	Ear length (cm)	Ear diameter (cm)	Ear yield (Mg ha^{-1})	Grain yield (Mg ha^{-1})	stover yield (Mg ha^{-1})	Biological yield (Mg ha^{-1})
K0	2.68	453	14.33	4.43	5.46	3.44	9.79	15.44
K1	3.41	661	21.33	5.70	8.21	6.43	14.00	22.21
K2	3.15	559	17.67	5.03	7.01	4.97	12.28	19.33
K3	3.52	726	20.67	6.17	9.19	7.52	15.03	24.22
K4	3.0	491	16.00	4.73	6.15	4.29	11.33	17.48
K5	3.22	596	19.33	5.40	7.06	5.25	13.17	20.17
Means	3.16	581	18.22	5.24	7.18	5.32	12.60	19.81
LSD 0.05%	0.03	28.14	4.69	0.22	0.45	0.324	0.33	0.63

Treatments are K0: no –K; K1, K2, K3, K4 and K5 of KS 100%, 75% KS+25% KF, 50% KS + 50% KF, 25% KS + 75% KF and KF 100% (100% is 95 kg K ha^{-1}).

Application of K3 gave the highest positive response which followed the pattern K3 > K1> K5> K2 > K4 > K0. The increases regarding grain yield were 119, 87, 53, 44 and 24% due K3, K1, K5, K2 and K4, respectively; comparable increases regarding ear yield were 68, 50, 29, 28 and 13, respectively. These results are in agreement with those obtained by Abdel-Salam & Shams (2012) and Abd El-Hakeem & Fekry (2014).

The highest values of ears and stover yields given by fertilized treatments were obtained by the 50% K-sulphate + 50% K-feldspar (K3), while the lowest was obtained by the 25% K-sulphate + 50 % K-feldspar (K4). Therefore with half of the K rate given as feldspar, the silicate dissolving bacteria (SDB) seemed of high activity. The use of SDB and the positive response obtained by such bacteria with feldspars was reported by Vessey (2003); Sheng (2005); Dawwam *et al.*, (2013) and Priyanka & Sindhu (2013). Potassium dissolving bacteria play an important role in formation of humus in soil and cycling of minerals tied up in organic matter (Zakaria, 2009). Solubilization of rock- K, through production and excretion of organic acids or through chelating silicate ions to bring K into solution (Ullman *et al.,* 1996). Inoculation with potassium solbilizing bacteria either potassium or feldspar was applied slowly or integrated might provide faster and continuous supply of K for improving plant growth, yield and its quality (Badr *et al.,* 2006; Eweda *et al.,* 2007; Abdel-Salam & Shams, 2012 and Abou-El-Seousd & Abdel-Megeed , 2012).

Nutrient uptake

Data in Table 3 indicate that all treatments increased stover and grains N, P and K-uptake by maize plants as compared to control (untreated). The K3 gave the highest N, P and K-uptake in stover and grains. The treatment of K4 showed the lowest one of the fertilized treatments. The pattern was K3 > K1> K5> K2 > K4 > K0. The increases regarding N, P and K uptake in grain were 230,165,107, 78 and 39% for N-uptake due K3, K1, K5, K2 and K4, respectively; 487, 328 , 205, 149 and 59% for P-uptake; comparable increases regarding K-uptake were 215, 146, 89,68 and 35, respectively. These results are in agreement with those obtained by Foth (1990) and Abd El-Hakeem & Fekry (2014) who used applied K as 50% potassium sulphate plus 50% K- feldspar combined with SDB and increased yield of sweet potato as well as increased uptake of N and K. The current results are similar to those reported by Abdel-Salam & Shams (2012) and Labib *et al.* (2012) who applied 50% potassium sulphate +50% K- feldspar + SDB) and obtained high yield as well as N, P and K uptake in tubers and shoots of potato plants.

TABLE 3. Effect of potassium sulphate (KS) and potassium feldspar(KF) treated with silicate dissolving bacteria on stover and grains N,P and K uptake (kg ha^{-1}) by maize plants.

Treatment	Stover			Grains		
	N – uptake	P- uptake	K- uptake	N – uptake	P- uptake	K- uptake
K0	101	11.98	18.46	46.96	5.85	76.06
K1	226	13.88	39.91	124.9	25.08	187.00
K2	170	28.64	30.62	83.86	14.59	128.00
K3	254	55.6	45.53	155.4	34.34	240.00
K4	136	21.55	26.46	65.30	9.31	103.00
K5	201	36.88	34.63	97.74	17.87	144.00
Means	181.3	28.09	32.60	95.69	17.84	146.00
LSD 0.05%	11.82	3.44	1.85	8.93	2.26	10.55

Treatments are K0: no –K; K1, K2, K3, K4 and K5 of KS 100%, 75% KS+25% KF, 50% KS + 50% KF, 25% KS + 75% KF and KF 100% (100% is 95 kg K ha^{-1}).

Quality yield of maize

Data presented in Table 4 show that the application of treatment K3 gave the highest harvest index, shelling ratio, protein content and the 100 grain weight (31.06, 81.85, 11.78% and 38.71 g, respectively),while the lowest one was obtained with untreated soil (without application of K) , (22.28, 63, 7.97% and 26 g, respectively). Quality values followed the pattern of K3 > K1> K5> K2 >

K4 > K0. The increases regarding protein content were 47, 39, 33, 20 and 10% due K3, K1, K5, K2 and K4, respectively; comparable increases regarding the 100 grain weight were 48, 36, 29, 20 and 15, respectively. These results are agreement with those obtained by Xiong *et al.* (2007) who found that K increased forage maize yield and quality yield. Abd El-Hakeem and Fekry (2014) reported that 50% potassium sulphate + 50% K- feldspar+ SDB improved the quality of tuber roots and total sugar in sweet potato and Abd El-Baky *et al*. (2010) reported positive effect on sweet potato and Sugiyama & Ae (2006) and Labib *et al.* (2012) reported positive effect on potato.

TABLE 4. Effect of potassium sulphate(KS) and potassium feldspar (KF) treated with silicate dissolving bacteria on quality yield of maize plants.

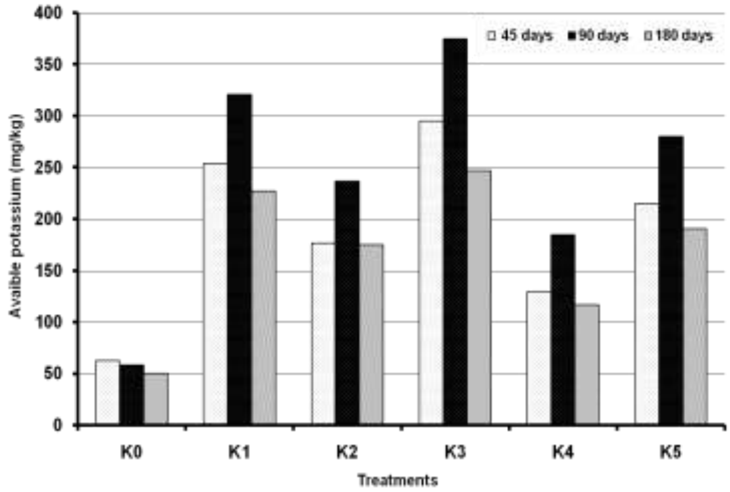
Treatment	Protein content (%)	Harvest index (%)	Shelling ratio (%)	100 Grain weight (g)
K0	7.97	22.28	63.00	26.06
K1	11.08	28.95	78.33	35.41
K2	9.61	25.72	70.47	31.33
K3	11.78	31.06	81.85	38.71
K4	8.78	24.57	69.88	29.93
K5	10.60	26.04	75.00	33.58
Means	9.97	26.44	73.09	32.50
LSD 0.05%	10.55	1.14	0.84	1.08

Treatments are K0: no –K; K1, K2, K3, K4 and K5 of KS 100%, 75% KS+25% KF, 50% KS + 50% KF, 25% KS + 75% KF and KF 100% (100% is 95 kg K ha^{-1}).

Available potassium in soil

Data illustrated in Fig. 1 represent the values of available potassium (mg kg^{-1}) in the treated soil with K-sulphate or K-feldspar inoculated with SDB during different periods after seeding (45, 90 and 180 days). The treatment of 50% KS + 50% KF gave the highest values of available potassium (295, 375 and 247 mg ka^{-1}, respectively), while the lowest ones (62.9, 58.4 and50.8 mg kg^{-1} respectively,) were obtained with untreated soil during the indicated periods. These results are in agreement with those obtained by Blum and Stillings (1995). The pattern of comparison among treatments was rather similar to those regarding yields of grains and ears. These results are similar to those by Bader (2006) who found that the highest release of potassium was consistent up the end of composting process (feldspar +compost + SDB) after 90 days of incubation.

As a general result, the available potassium showed remarkably increase after 90 days at all treatments. These increases may be due to the microbial activity which has the ability to affect soil reaction in the soil microenvironment leading to solubilizing mineral K. This finding is in agreement with those obtained by Blum & Stillings (1995), Bader *et al.* (2006) and Merwad *et al*. (2013).



Treatments are K0: no –K; K1, K2, K3, K4 and K5 of KS 100%, 75% KS+25% KF, 50% KS + 50% KF, 25%KS + 75% KF and KF 100% (100% is 95 kg K ha^{-1})

Fig.1. Effect of potassium sulphate or potassium feldspar treated with silicate dissolving bacteria on available potassium during different periods after sowing.

Economical choice

Data presented in Table 5 show the most practical and economical treatment of potassium sulphate, K-feldspar and SDB applied on maize production (Mg ha^{-1}), calculated in LE and the price of one Mg (grains) is = 1500 LE and one Mg of stover dry weight is = 100 LE , on the other hand, the price cost of one Mg of potassium sulphate is = 7000 LE, one Mg of K-feldspar is = 800 LE and one liter of SDB is = one LE according to 2014 prices.

The flowing equation was used in each treatment to calculate:

Production (LE ha^{-1}) = { grains (Mg ha^{-1})* 1500 + Stover dry weight (Mg ha^{-1}) * 100)
Production cost (LE ha^{-1}) for treatment = {(Potassium sulphate kg ha^{-1} * 7) + (K- feldspar Kg ha^{-1} * 0.8) + SDB L/ Kg feldspar * 1 }
Revenue (LE ha^{-1}) = {Production (LE ha^{-1}) – Production cost (LE ha^{-1})}

Data presented in Table 5 show the effect of different sources of potassium fertilizers (potassium sulphate and K- feldspar with SDB) on maize production (Mg ha^{-1}). The application of 50% potassium sulphate plus 50% K- feldspar + SDB exhibited the maximum revenue (11271 LE ha^{-1}) compared to 100% potassium sulphate (9379 LE ha^{-1}).

TABLE 5. Effect of potassium sulphate and potassium feldspar treated with silicate dissolving bacteria on maize revenues

Treatment	Production (LE)	Production Costs (LE)	Revenue (LE)
K0	6139	000	6139
K1	11045	1666	9379
K2	8683	1589	7094
K3	12783	1512	11271
K4	7568	1435	6133
K5	9192	1359	7833
Means	9235	1260	7975

Treatments are K0: no –K; K1, K2, K3, K4 and K5 of KS 100%, 75% KS+25% KF, 50% KS + 50% KF, 25% KS + 75% KF and KF 100% (100% is 95 kg K ha^{-1}).

In general, addition of 50% potassium sulphate plus 50% K- feldspar + SDB showed favorable effects on maize production and maximum revenue as compared to K1, K2, K4 and K5 with an increase 20, 58, 83 and 44% , respectively.

Conclusion

There were positive effects of application of K- feldspar in combination with SDB mixed with K-sulphate at a ratio of 1:1 (50% potassium sulphate + 50% K-feldspar) in production of maize yield and uptake of NPK. The treatment of (K3) gave the highest values of available potassium in soil compared to other treatments. Using the naturally deposited materials of K-feldspar combined with SDB would be beneficial for farmers and save high costs of chemical fertilizers.

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كفاءة سلفات البوتاسيوم والفلسبار البوتاسى المعامل بالبكتريا المذيبة للسيليكات على محصول وامتصاص العناصرالغذائية لنباتات الـــذرة

عبدالرحمن محمد أمين مرواد
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أجريت تجربة حقلية خلال موسم 2014 بههيا محافظة الشرقية – مصر لدراسة اضافة 95 كجم بوتاسيوم/ هكتار الى الذرة من سلفات البوتاسيوم او الفلسبار البوتاسى المعامل بالبكتريا المذيبة للسيليكات منفردة او مخلوطاً فى نسب مختلفة. أعطت معاملة 50٪ سلفات بوتاسيوم + 50٪ فلسبار بوتاسوى أعلى القيم فى طول النبات ، مساحة الورقة ، طول الكوز، قطر الكوز، محصول الكيزان ، المادة الجافة للحطب والحبوب ، النيتروجين والفوسفور والبوتاسيوم الممتص ، محتوى البروتين والمحصول البيولوجى بينما أعطت معاملات الكنترول و25٪ سلفات بوتاسيوم + 75٪ فسلبار بوتاسى أقل القيم . أدت إضافة 50٪ سلفات بوتاسيوم + 50٪ فلسبار بوتاسوى زيادة فى المادة الجافة للحطب والحبوب تراوحت بين 40 إلى51 ٪ و 87 إلى 118٪ على التوالى. أعطت معاملة 50٪ سلفات بوتاسيوم + 50٪ فلسبار بوتاسوى أعلى قيم لبوتاسيوم التربة الميسر عند 45، 90 و 180 يوم (295 ، 375 و 247 ملجم كجم$^{-1}$ على التوالى) بينما أعطت معاملة الكنترول أقل القيم (63 ، 58 و 51 ملجم كجم$^{-1}$ على التوالى).