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Indian Journal of Ecology (2020) 47 Special Issue (12): 200-205

Manuscript Number: 474
NAAS Rating: 4.96

Effect of Agricultural Sulfur on Availability of NPK in Soil, Growth and Yield of Corn (*Zea mays* L.)

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Abstract: A field experiment was carried out to study the effect of agricultural sulfur and date of application on availability of NPK in the soil, growth and yield of two cultivars of corn (5012 and Bohoth 106). Sulfur (95% S) was used with two levels (0, 2.5 Meq S ha^{-1}) with four dates of application 30, 60 and 90 day before the sowing. The applications of of sulfur at 60 day before sowing and cultivar Bohoth 106 had significantly increased the availability of nitrogen, phosphorus and potassium in the soil and plant growth indicators (plant height, leaf area, weight of 500 grains and grains yield). The availability of nitrogen, phosphorus, and potassium in the soil was 42.25, 33.87 and 225.46 mg kg^{-1} respectively, leaf area 0.928 m^2 with an increase 36.07 %. The weight of 500 grains was 118.47 g with an increase 68.32 % and grain yield was 208.4 g $plant^{-1}$ with an increase 53.68% compared to control.

Keywords: Agricultural sulfur, Nitrogen, Phosphorus, Potassium, Corn

The Iraqi soil contains carbonate minerals in soils up to 10-45%, because of alkaline conditions and high saturation of calcium and carbonate ions that are representing the main reason for worsening of this problem. However, several researchers pointed out to the possibility of using the agricultural sulfur as a reformer for alkaline calcareous soils, because sulfur can be oxidized to sulfuric acid by a series of biological and chemical processes within the soil environment, and sulfuric acid increases the solubility of lime in the soil and reducing the pH conditions of the soil. Besides that, reducing pH condition positively effect on the availability of many nutrients in the soil, therefore, increasing the yield of various crops (Al-Rawi et al 2001, Al-Tememe 2003, Al-Ezzawi 2006). Sulfur is one of the essential nutrients for formation of protein and amino acids within plant cells. In addition, it contributes the creation of different compounds such as vitamin B group (Biotine and Thiamine), glutathione, and building and renovation of plant cells protoplasm and also essential in nitrate reduction. Furthermore, plays a vital role in the composition of the chlorophyll without entering in the chlorophyll structure (Ali et al 2014). Al-Ezzawi (2006) found a substantial decrease in soil pH which increased phosphorus availability in the soil, dry matter weight, and yield of maize. The production of large amounts of agricultural sulfur in Iraq which reach more than one million tons per year, it can utilize to increase the availability of the nutrients in the soil and contributing to agricultural production development. Therefore this study aimed to determine the effect of adding agricultural sulfur on the availability of each of nitrogen, phosphorus, and potassium in the soil and their impact on growth and yield of two maize cultivars.

MATERIAL AND METHODS

A field experiment was carried out during 2012-2013 in Ramadi-Anbar-Iraq to study the effect of agricultural sulfur in different dates on the availability of NPK in soil, growth and yield of two cultivars of Maize (5012 and Bohoth 106). The experiments were designed with randomized complete block design within three replicates in silt loam soil. Soil samples at (0-30 cm) depth were taken before planting for chemical and physical analysis (Table 1). The plot size was 2m × 3m with 1m separation between each plot. Corn cultivars (5012 and Bohoth 106) which symbolized as C_1 and C_2, respectively were planted as 5 furrows for each experimental unit with a spacing of 20 cm between each plant and 75 cm between each furrow. The agricultural sulfur (95% S) (from Mishraq fields) (Table 2) was added (0, 2.5) Meq S ha^{-1} which symbolized as (S_0, S_1) within 4 dates (at the planting date, 30, 60 and 90 day before planting), which symbolized as T_1, T_2, T_3, and T_4, respectively. Nitrogen was applied as 320 kg N ha^{-1} using urea fertilizer (46% N) applied at three stage, phosphorus was applied as 100 kg P ha^{-1} using DAP fertilizer (21% P) and potassium as 180 kg K ha^{-1} using potassium sulphate fertilizer (41.5% K).

RESULTS AND DISCUSSION

Available nitrogen: The addition of agricultural sulfur application (Table 3) was significantly increased available nitrogen in soil (30.93 mg N kg^{-1}) with an increase of 48.91% than in control (20.77 mg N kg^{-1}), may be due to sulfuric acid formed as a result of the oxidation of agricultural sulfur, which increased the concentration of hydrogen ions, which leads to a decrease in soil pH and then reduce the loss of nitrogen by volatilization in the form of ammonia (NH3). Similar results are also observed by (Al-Aqili 2001, Al-Bayati et al 2006). The adding at 60 day before planting achieved the highest available nitrogen was (29.91 mg N kg^{-1}) with an increase of 31.64% compared to treatment (at the planting date) which gave the lowest nitrogen in soil was (22.72 mg N kg^{-1}). Cultivar Bohoth 106 resulted highest available nitrogen in soil was (27.04 mg N kg^{-1}) with an increase of 8.83 % compared to cultivar 5012 was (24.65 mg N kg^{-1}). The significant increase was observed in available nitrogen in interaction between adding agricultural sulfur at 60 day before planting and cultivar bohoth 106 was (42.25 mg N kg^{-1}). This increase could be related to the role of sulfuric acid, formed by agricultural sulfur oxidation, in decreasing soil pH due to hydrogen ions concentration then decreasing soil nitrogen loss that was also confirmed by (Al-Ezzawi 2006, Kaya et al 2009).

Available phosphorus: The addition of agricultural sulfur application (Table 4) was significantly increased available phosphorus in soil (25.74 mg P kg^{-1}) with an increase of 62.39 % than in control (15.85 mg P kg^{-1}), may be due to the sulfur oxidation process, chemically and biologically and the formation of sulfuric acid and an increase in the concentration and activity of hydrogen ion in the soil solution that led to the dissolution of some phosphorus compounds and then released the phosphorus held by the soil, that was also confirmed by (Jabr et al 2007). The adding at 60 day before planting achieved the highest available phosphorus was (23.16 mg P kg^{-1}) with an increase of 27.53% compared to treatment (at the planting date). Cultivar Bohoth 106 resulted highest available phosphorus in the soil was (22.94 mg P kg^{-1}) with an increase of 22.93% compared to cultivar 5012 was (18.66 mg P kg^{-1}). The significant increase was observed in available phosphorus in interaction between adding agricultural sulfur at 60 day before planting and cultivar bohoth 106 was (33.87 mg P kg^{-1}). This increase could be related to the decrement in soil pH due to adding the agricultural sulfur as well as the formation of sulfuric acid and an increment in hydrogen ions activity in the soil solution due to sulfur oxidation then dissolving some of phosphorus compounds and releasing the seized phosphorus in the soil thus increasing phosphorus availability, that was also confirmed by (Fontanetto et al 2000, Al-Adhami 2001, Al-Ezzawi 2006).

Available potassium: The addition of agricultural sulfur application (Table 5) was significantly increased available potassium in soil (209.54 mg K kg^{-1}) with an increase of 10.22 % than in control (190.10 mg K kg^{-1}), may be due to the role of sulfur in reducing soil pH as a result of its oxidation and formation of sulfuric acid, which leads to the dissolution of calcium carbonate and its substitution of potassium ions adsorbed on colloidal surfaces and the release of potassium to the soil solution, that was also confirmed by (Al-Agaili

Table 2. Properties of agricultural sulfur

pH	ECds m^{-1}	S (%)	Ca^{+2} (mg Kg^{-1})	C (%)	Clay (%)	Diameter (Mesh)
3.7	4.4	95	64	0.12	1.5	325

*Agricultural sulfur data was obtained from The General Company of Mishraq Sulfur

Table 3. Effect of level and adding date of agricultural sulfur on available nitrogen in soil mg N kg^{-1} soil

Agricultural sulfur level	Date of application agricultural sulfur	Cultivar		S*T
		C_1	C_2	
S_0	T_0	19.63	21.91	20.77
S_1	T_1	23.77	25.58	24.68
	T_2	28.51	23.88	26.19
	T_3	35.84	42.25	39.05
	T_4	30.59	37.00	33.79
LSD (0.05)		3.00		2.126
				Mean S
C*S	S_0	19.63	21.91	20.77
	S_1	29.68	32.18	30.93
LSD (0.05)		1.50		1.063
				Mean T
C*T	T_1	21.70	23.75	22.72
	T_2	24.07	22.89	23.48
	T_3	27.73	32.08	29.91
	T_4	25.11	29.45	27.28
LSD (0.05)		2.13		1.503
Mean C		24.65	27.04	
LSD (0.05)		1.06		

Table 1. Chemical and physical properties of soil before planting

Textural	pH 1:01	EC ds m^{-1}	CEC c mol kg^{-1}	O.M Gm Kg^{-1}	Carbonate minerals Gm Kg^{-1}	N Mg Kg^{-1}	P Mg Kg^{-1}	K Mg Kg^{-1}	$SO_4^{=}$ Mg Kg^{-1}
Silt Loam	7.33	3.1	20.5	10.1	262	39	7.1	246	394.8

2001, El-Kholy 2013). The adding at 60 day before planting achieved the highest available potassium was (204.52 mg K kg^{-1}) with an increase of 5.52% compared to treatment (at the planting date) which gave the lowest potassium in soil was (193.81 mg K kg^{-1}). Cultivar Bohoth 106 resulted highest available potassium in soil was (202.96 mg K kg^{-1}) with an increase of 3.24 % compared to cultivar 5012 was (196.58 mg K kg^{-1}). The significant increase was observed in available potassium in interaction between adding agricultural sulfur at 60 day before planting and cultivar bohoth 106 was (225.46 mg K kg^{-1}). This increase could be related to the role of agricultural sulfur in decreasing soil pH due to forming sulfuric acid by the biological oxidation which led to dissolved the compound carrying potassium in the soil as well as increasing hydrogen ions activity that released by sulfur oxidation process and competing adsorbed potassium ion then releasing potassium into soil solution, that was also confirmed by Al-Ezzawi (2006).

Plant height: The addition of agricultural sulfur application (Table 6) significantly increased the plant height was (219.35 cm) with an increase of 24.31% than in control, that could be related to in improving soil fertility as a result of oxidation of sulfur and the formation of a acid solution and the concomitant increase in the solubility of some nutrients and in addition to reducing nitrogen loss by volatilization, whose rates increase in the basal medium, Similar results were reported by Al-Bayati et al (2009).

The adding at 60 day before planting achieved the highest plant height was (206.38 cm) with an increase of 10.64% compared to treatment (at the planting date). Cultivar Bohoth 106 resulted highest plant height was (204.04 cm) with an increase of 6.40% compared to cultivar 5012 was (191.75 cm). The significant increase was observed in plant height in interaction between adding agricultural sulfur at 60 day before planting and cultivar bohoth 106 was (244.84 cm). This increase could be related to the role of the agricultural sulfur in supplying plants with nutrients and increasing the average of plant growth as well as it enters in many compounds in the plant especially protein compounds and its role in decreasing soil pH then increasing soil nutrients available for plants which contribute to increasing carbon synthesis and increasing division, elongation, and growth of the cells which positively increasing plant height (Havlin et al 2014, Jabir et al 2017).

Leaf area: The addition of agricultural sulfur application (Table 7) significantly increased the highest leaf area was (0.831 m^2) with an increase of 20.43 % than in control, that could be related to reducing the value of soil pH and increasing the readiness of nutrients and their absorption by the plant has positively reflected in the increase in the division

Table 4. Effect of level and adding date of agricultural sulfur on available phosphorus (mg P kg^{-1} soil)

Agricultural sulfur level	Date of application agricultural sulfur	Cultivar		S*T
		C_1	C_2	
S_0	T_0	14.44	17.27	15.85
S_1	T_1	17.92	22.99	20.46
	T_2	21.88	27.11	24.50
	T_3	27.06	33.87	30.46
	T_4	24.63	30.45	27.54
LSD (0.05)		3.16		2.232
				Mean S
C*S	S_0	14.44	22.87	15.85
	S_1	17.27	28.60	25.74
LSD (0.05)		1.58		1.116
				Mean T
C*T	T_1	16.18	20.13	18.16
	T_2	18.16	22.19	20.18
	T_3	20.75	25.57	23.16
	T_4	19.54	23.86	21.70
LSD (0.05)		2.23		1.578
Mean C		18.66	22.94	
LSD (0.05)		1.12		

Table 5. Effect of level and adding date of agricultural sulfur date on available potassium mg K kg^{-1} soil

Agricultural sulfur level	Date of application agricultural sulfur	Cultivar		S*T
		C_1	C_2	
S_0	T_0	189.07	190.95	190.01
S_1	T_1	195.19	200.01	197.60
	T_2	201.00	214.05	207.53
	T_3	212.58	225.46	219.02
	T_4	207.62	220.37	214.00
LSD (0.05)		8.85		6.225
				Mean S
C*S	S_0	189.07	204.10	190.10
	S_1	190.95	214.97	209.54
LSD (0.05)		4.42		3.127
				Mean T
C*T	T_1	192.13	195.48	193.81
	T_2	195.04	202.50	198.77
	T_3	200.83	208.21	204.52
	T_4	198.35	205.66	202.00
LSD (0.05)		6.23		4.423
Mean C		196.58	202.96	
LSD (0.05)		3.13		

and elongation of cells, and then the increase in the leafy area of the plant, and these results are consistent with (Bektash and Kadhem 2002, Havlin et al 2014).

The adding at 60 day before planting achieved the highest leaf area was (0.792 m^2) with an increase of 9.54% compared to treatment (at the planting date) which gave the lowest leaf area (0.723 m^2). Cultivar Bohoth 106 resulted highest leaf area was (0.781 m^2) with an increase of 5.54% compared to cultivar 5012 was (0.740 m^2). The significant increase was observed in leaf area in interaction between adding agricultural sulfur at 60 day before planting and cultivar bohoth 106 was (0.928 m^2). This increase could be related to the increment in the added levels of the agricultural sulfur led to decrease soil pH in the rhizosphere then increasing the availability of macro nutrients NP and the micro nutrients which were important for plant growth and this positively increased the division and elongation and thus increasing plant leaf area, this agreed with (Al-Adhami, 2001, Al-Ani, 2003, Jabir et al 2017).

Weight of 500 grains: The addition of agricultural sulfur application (Table 8) significantly increased the highest weight of 500 grains was (93.83 g) with an increase of 24.44 % than in control, that could be related to the increase in the characteristics of vegetative growth (leaf area and chlorophyll content), which led to an increase the period required to grain fullness that reflected in grain weight, this was consistent with (El.Fahdawi and Khalil, 2011, Hussein 2016). The adding at 60 day before planting achieved the highest weight of 500 grains was (89.45 g) with an increase of 10.99% compared to treatment (at the planting date) which gave the lowest leaf area (80.59 g). Cultivar Bohoth 106 resulted highest weight of 500 grains was (92.94 g) with an increase of 22.13% compared to cultivar 5012 was (76.28 g). The significant increase was observed in weight of 500 grains in interaction between adding agricultural sulfur at 60 day before planting and cultivar bohoth 106 was (118.47 g). This increase could be related to the increment in the plant dry weight due to adding the agricultural sulfur to the soil which positively increased grains number then increasing the weight of 500 grains and this explained Sulfur importance in the continuation of plant metabolic processes of fat carbohydrates, and proteins formation and assembled them in the seeds, and this results agreed with (At-Temimi 2003).

Grains yield: The addition of agricultural sulfur application (Table 9) significantly increased the highest grains yield was (173.9 g $plant^{-1}$) with an increase of 25.46% than in control, that could be related to the effect of agricultural sulfur in increasing yield components (rows number, grains number per row and weight of grains), which led to increase plant grains yield. This result was consistent with (Dibaba et al

Table 6. Effect of level and adding date of the agricultural sulfur on plant height for two cultivars of corn cm

Agricultural sulfur level	Date of application agricultural sulfur	Cultivar		S*T
		C_1	C_2	
S_0	T_0	171.56	181.34	176.45
S_1	T_1	190.17	203.00	196.59
	T_2	212.67	225.90	219.28
	T_3	227.77	244.84	236.31
	T_4	217.17	233.25	225.21
LSD (0.05)		9.26		6.546
				Mean S
C*S	S_0	171.56	181.34	176.45
	S_1	211.95	226.75	219.35
LSD (0.05)		4.63		3.273
				Mean T
C*T	T_1	180.87	192.17	186.52
	T_2	192.12	203.62	197.87
	T_3	199.67	213.09	206.38
	T_4	194.37	207.30	200.83
LSD (0.05)		6.55		4.629
Mean C		191.75	204.04	
LSD (0.05)		3.27		

Table 7. Effect of level and adding date of the agricultural sulfur on maize leaf area (m^2)

Agricultural sulfur level	Date of application agricultural sulfur	Cultivar		S*T
		C_1	C_2	
S_0	T_0	0.682	0.698	0.690
S_1	T_1	0.717	0.794	0.756
	T_2	0.763	0.851	0.807
	T_3	0.861	0.928	0.895
	T_4	0.852	0.882	0.867
LSD (0.05)		0.019		0.013
				Mean S
C*S	S_0	0.682	0.698	0.690
	S_1	0.798	0.864	0.831
LSD (0.05)		0.01		0.0065
				Mean T
C*T	T_1	0.690	0.756	0.723
	T_2	0.723	0.775	0.749
	T_3	0.772	0.813	0.792
	T_4	0.767	0.790	0.779
LSD (0.05)		0.01		0.0092
Mean C		0.740	0.781	
LSD (0.05)		0.01		

Table 8. Effect of level and adding date of the agricultural sulfur on weight of 500 grains (g)

Agricultural sulfur level	Date of application agricultural sulfur	Cultivar		S*T
		C_1	C_2	
S_0	T_0	70.38	80.41	75.40
S_1	T_1	77.03	94.53	85.78
	T_2	80.41	101.88	91.15
	T_3	88.52	118.47	103.50
	T_4	82.77	107.01	94.89
LSD (0.05)		9.81		6.937
				Mean S
C*S	S_0	70.38	80.41	75.40
	S_1	82.18	105.47	93.83
LSD (0.05)		4.91		3.469
				Mean T
C*T	T_1	73.71	87.47	80.59
	T_2	75.40	91.15	83.27
	T_3	79.45	99.44	89.45
	T_4	76.58	93.71	85.14
LSD (0.05)		6.94		4.905
Mean C		76.28	92.94	
LSD (0.05)		3.47		

Table 9. Effect of level and adding date of the agricultural sulfur on plant grains yield (g plant^{-1})

Agricultural sulfur level	Date of application agricultural sulfur	Cultivar		S*T
		C_1	C_2	
S_0	T_0	135.6	141.7	138.6
S_1	T_1	168.0	152.8	160.4
	T_2	158.8	168.4	163.6
	T_3	175.4	208.9	192.2
	T_4	161.0	197.8	179.4
LSD (0.05)		18.59		13.15
				Mean S
C*S	S_0	135.6	141.7	138.6
	S_1	165.8	182.0	173.9
LSD (0.05)		9.30		6.57
				Mean T
C*T	T_1	151.8	147.2	149.5
	T_2	147.2	155.1	151.1
	T_3	155.5	175.3	165.4
	T_4	148.3	169.7	159.0
LSD (0.05)		13.15		9.30
Mean C		150.7	161.8	
LSD (0.05)		6.57		

2014, Jassim and Mohammed 2019). The adding at 60 day before planting achieved the highest grains yield was (165.4 g plant^{-1}) with an increase of 10.63 % compared to treatment (at the planting date), which gave the lowest grains yield (149.5 g plant^{-1}). Cultivar Bohoth 106 resulted highest grains yield was (161.8 g plant^{-1}) with an increase of 7.36% compared to cultivar 5012 was (150.7 g plant^{-1}). The significant increase was observed in grains yield in interaction between adding agricultural sulfur at 60 day before planting and cultivar bohoth 106 was (208.4 g plant^{-1}). This increase could be related to the role of the agricultural sulfur in the availability of some nutrients in the soil due to decreasing soil pH as well as the role of sulfur, as nutrient needed by plant at the growth, in increasing leaf area elongation and leaf area index and its role in increasing plant height and chlorophyll formation as well as increasing the surface exposed to the light, absorption and converting it into dry matter which positively increased grains fill, this results agreed with (Ahmed 2016, Sánchez et al 2019).

CONCLUSIONS

In general, the results showed that the significant increase was observed with application of interaction between adding agricultural sulfur at 60 day before planting and cultivar bohoth 106 in the availability of nitrogen, phosphorus, and potassium in soil and plant growth indicators (plant height, leaf area, weight of 500 grains and grains yield). This is due to the role of agricultural sulfur as a nutrient for calcareous soils in general and Iraqi soils in particular in reducing soil pH and Ec and increasing readiness of nitrogen, phosphorus and potassium in the soil and thus increasing their content in the plant and its moral effect in increasing all the characteristics of growth and plant yield.

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Received 06 June, 2020; Accepted 10 August, 2020