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Evaluating the Efficiency of Potassium Fertilizer Sources and Levels on Sesame Growth and Yield in Two Different Gypsum Soils

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Sesame; potassium fertilizers; gypsum soil; sesame oil

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ABSTRACT

To investigate the effect of potassium fertilizer sources and level on sesame growth and yield in two different gypsum soils, two experiments were applied throughout the summer of 2022. The experiments included three factors, which were sources of potassium, potassium sulfate (K_{K2SO4}) and potassium chloride (K_{KCL}), potassium levels, 0 (K_{00}), 75 (K_{75}), 150 (K_{150}), and 300 (K_{300}) kg ha^{-1}, and levels of gypsum in the soil, 6.02 ($Soil_{06.02}$) and 15.87 ($Soil_{15.87}$) %. Completely Randomized Block Design (CRBD) with three replications was used to apply the experiments. The results indicated that K_{K2SO4} significantly impacted plant height (18%), plant dry weight (8%), branch no (11%), capsules no. (5%), 1000 seeds weight (13%), yield (13%), and oil percentage (9%) compared with K_{KCL}. Similarly, potassium at K_{300} was significantly higher compared with the other potassium levels. Also, gypsum $Soil_{15.87}$ significantly impacted plant height (11%), dry weight (11%), capsules no. (5%), 1000 seeds weight (19%), yield (11%), and oil percentage (12%) compared with gypsum soil with 6%. The interactions between the two study factors and among the three study factors effected significantly all the study traits. These results will be beneficial for sesame production and management in the Salahaldin area, Iraq.

تأثير مصدر ومستوى السماد البوتاسي في نمو وحاصل السمسم المزروع في تربتين جبسيتين

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الخلاصة

لدراسة تأثير مصادر سماد البوتاسيوم ومستواه في نمو وحاصل السمسم في تربتين جبسيتين مختلفتين، تم تطبيق تجربتين خلال الموسم الصيفي 2022. تضمنت التجربتين ثلاثة عوامل متمثلة بمصادر البوتاسيوم (كبريتات البوتاسيوم وكلوريد البوتاسيوم) ومستوى لبوتاسيوم (0 و 75 و 150 و 300 كغم هكتار$^{-1}$) ومستويات الجبس في التربة (6.02 و 15.87٪). تم استعمال تصميم القطاعات العشوائية الكاملة وبثلاثة مكررات لتطبيق التجربتين. أشارت النتائج إلى أن المصدر كبريتات البوتاسيوم اثر معنوياً في ارتفاع النبات (18%) والوزن الجاف للنبات (8%) وعدد الافرع (11%) وعدد الكبسولات (5%) ووزن 1000 بذرة (13%) والحاصل (13%) ونسبة الزيت (9%) مقارنة بمصدر كلوريد البوتاسيوم. وبالمثل، فقد اثر مستوى البوتاسيوم 300 كغم هكتار$^{-1}$ معنونيا في كل الصفات المدروسة بالمقارنة مع مستويات البوتاسيوم الأخرى. كما تبين ان بنسبة الجبس في التربة عندما كانت 15.87% أثرت معنوياً في ارتفاع النبات (11%) والوزن الجاف (11%) وعدد الكبسولات (5%) ووزن 1000 بذرة (19%) والحاصل (11%) ونسبة الزيت (12%) بالمقارنة مع التربة التي تحتوي على نسبة جبس 6%. إن التداخل بين عاملي الدراسة وبين عوامل الدراسة الثلاثة أثر معنوياً في جميع صفات الدراسة. ستسهم هذه النتائج في زيادة الوعي لدى المزارعين لغرض ادارة وانتاج محصول السمسم في محافظة صلاح الدين بالعراق.

الكلمات المفتاحية: سمسم، الأسمدة البوتاسية، الترب الجبسية، زيت السمسم.

INTROUCTION

Sesame (*Sesamum indicum* L.) is one of the high value crops that produces one of the highest quality oil in agricultural production (Li *et al.*, 2023). Also, its seed is highly valuable as the seed contains oil (42-50%) protein (25%), carbohydrate (16-18%) (Miah *et al*., 2015). Sesame seeds have extraordinary antioxidants caused by the presence of lignin and tocopherol (Li *et al.*, 2023). Its seed contains a decent amount of protein and amino acids (mainly methionine), a nutrient that has an anti-aging content. Also, sesame seeds are rich sources of many vitamins such as A, B1, B2, and E, as well as some fatty acids, for instance, oleic, linoleic, palmitic, and stearic acid (Dasharath *et al.*, 2007). Moreover, seeds have some elements, including calcium. Sesame oil contains unsaturated fatty acid (85%) and is highly stable, which reduces cholesterol, and can reduce coronary heart diseases (Choudhary *et al*., 2017; Al-Alwani *et al*., 2023). Due to its extraordinary skin-care and enhancing properties, sesame is considering the queen of oil seeds. Currently, consumers are considerably more attracted to buying sesame oil as a substitute for the other oil types as a result of less cholesterol and the property of unsaturated fatty acids in the daily diet (Tashiro *et al*., 1990). Oilcake is one of the sesame crop production that is consuming by a wide range of animals such as fish, poultry, cattle, sheep, and goats (Khan *et al*., 2009; Jamel and Badawi, 2019).

Gypsum soil varies in nutrient value. Mostly, Salahaldin soil conceders as gypsum soil. Sesame crop production is facing some managing problems due to soil fertility in Salahaldin, Iraq. Gypsum soils are characterized as low fertility due to the lack of vegetation cover, so the solubility of calcium sulphate in the soil solution led to the creation of a nutritional imbalance in those types of soils (Cera *et al.*, 2023). These soils deteriorate from a deficiency in the quantity and availability of macro- and micro-nutrients, and the presence of high percentages of gypsum in these soils leads to a lack of availability of nutritional compounds such as potassium as a result of saturation of the soil solution with calcium and sulfate ions (Amezketa *et al.*, 2005). In order to increase and improve the quality of agricultural production in gypsum soils, different management methods must be followed, including adding chemical fertilizers to soils, which have less in most of the nutrients that plants need, such as potassium. Potassium mineral plays a major role in increasing the sesame yield due to the important role in the growth and yield of the plant, as it activates more than 80 enzymes to contribute to carrying out many important vital activities within the plant (Rawat *et al.*, 2016). Also, it works as an osmotic regulator for the cell, which the plant requirements to produce the energy molecule (ATP), which is important for the metabolic processes of the plant. Moreover, it contributes to activating the process of photosynthesis and the transfer of sugars from the source to the sink. Potassium, is also a major mineral that plays a role in increasing the absorption of nitrogen and thus increasing the protein content in the plant (Kaiser and Rosen, 2018). Furthermore, the presence of potassium can reduce the effect of some toxic compounds such as Putrescine and Agmatine, as well as reduce the plant's exposure to insects and diseases. Potassium can be beneficial to RNA formation in the plant (Souri and Hatamian, 2019). The general opinion until the mid-eighties of the last century was that Iraqi soils, including gypsum soils, like the rest of the dry and semi-arid soils, had a decent potassium content and did not require potassium fertilization. However, recent research proved the opposite that gypsum soils contain decent amounts of potassium, but its release is slow. Depending on the gypsum content, the fertilizer selection depends on the nutrient types, capability of solubility, and fertilizer cost (Hebebrand and Laborde, 2023). As sources of potassium in fertilizers, potassium sulphate K_2SO_4 and potassium chloride KC1 were used. Potassium sulphate fertilizer contains 41% potassium and 18% sulfur, which is considered an expensive fertilizer due to the high costs of its manufacture, in addition to the control of many countries over its industry and raw materials. It is preferred for most economic crops, especially those sensitive to chlorine, and it is also a good source of the sulfur nutrient (Das and Mandal, 2015). While potassium chloride fertilizer contains 50% potassium, potassium chloride is considering as a cheap fertilizer compared to potassium sulphate fertilizer. Although the salt index of this fertilizer is high as a result of it containing the chloride ion, many studies have shown that there is a high response to this fertilizer by crops.

Many studies have shown that different types of gypsum soil have affected sesame growth and yield. However, this is the first study that compared the growth and yield of types of sesame growing in two types of gypsum soils with levels of potassium fertilizers and two types of fertilizers as sources of potassium.

MATERIAL AND METHODS

Two field experiments were conducted in Alalm city, which is located east of Tikrit, Salahaldin governorate, Iraq, by using two types of soils with two different gypsum contents, as shown in their physical and chemical properties in table 1. Completely Randomized Block Design (CRBD) with three replications was used to apply the experiments factors, so there were 24 experimental units. The experiment included three factors, which were sources of potassium (two sources), potassium sulfate (K_{K2SO4}) and potassium chloride (K_{KCL}), potassium levels (four levels), 0 (K_{K00}), 75 (K_{K75}), 150 (K_{K150}), and 300 (K_{K300}) kg ha^{-1}, and levels of gypsum in the soil, 6.02 ($Soil_{06.02}$) and 15.87 ($Soil_{15.87}$) %. The experiment soils were plowed with two perpendicular plows, then smoothed and leveled to prepare a suitable bed for the seeds. Then the experiment soil was divided into experimental units with an area of 3 × 3.6 m. Four rows of plants were fit in each experiment unit. The distance between rows was 0.9 m, and between plants was 0.25 m. Three seeds were sown in 1-2 cm depth. The planting date was the 10th of May, 2022. Phosphate fertilizer was added in the calcium superphosphate form before planting by using 200 kg P ha^{-1}, nitrogen fertilizer in urea form was added by using 200 kg N ha^{-1} in two equal batches. The first one was before planting and the second one was added when the plants reached 25 cm height (Khattar, 2002). Plants were thinning by leaving one plant in each spot when plants reached 25 cm height. Weeds were removed manually three times during the experiments. Experiments fields were irrigated as needed. Fifty days after planting, five plants were taken from the middle lines of each experiment unit, then washed using distilled water, then placed in perforated paper bags and dried in an electric oven at a temperature of 65-70°C until the weight was constant to calculate the plant's dry weight. Plants harvested 131 day after planting. Ten plants from the middle lines for each experimental unit were randomly selected to measure plant height, from soil surface to the top of plant, (cm), branches number (no. $plant^{-1}$), capsules number (no. $plant^{-1}$), 1000 seeds weight (g), yield (kg ha^{-1}), and oil percentage (%).

Table 1: Some physical, chemical, and fertility properties of soils traits that used for the experiments

Soil Traits	Gypsum Soil 6.02%	Gypsum Soil 15.87%	Measuring Units	Methods
Sand	509	544		
Clay	266	236	g Kg^{-1}	(Black,1965)
Loam	225	220		
Soil texture	**SCL**			
CEC	15.61	12.14	$Cmol_+$ kg^{-1}	(Black,1965)
pH(1:1)	7.62	7.39		(Page *et al*., 1982)
EC (1:1)	2.41	2.54	ds m^{-1}	
$CaSO_4$	6.02	15.87		(Lagerwerff *et al*., 1965)
Carbonate minerals	201	179	g Kg^{-1}	(Page *et al*., 1982)
Organic Matter	8.01	6.03		(Black,1965)
Available N	21.24	15.12		
Available P	6.11	3.79	mg Kg^{-1}	(Olsen *et al*., 1954)
Available K	120	106		(Black,1965)
Calcium (Ca)	5.02	9.11		
Magnesium (Mg)	1.72	1.13		
Potassium (K)	0.67	0.49		
Sodium (Na)	1.12	1.29	mmol L^{-1}	(Richard, 1954)
Sulphate (SO_4)	3.61	8.77		
Carbonate (CO_3)	Non	Non		
Bicarbonate (HCO_{3-})	0.22	0.31		
Chloride (Cl-)	0.92	0.76		

The data was analyzed according to the R.C.B. Design using the SAS program (V-9.4) (SAS Institute, Cary, NC, 2011). The means were compared according to the Duncan test at P = 0.05, so that was used to determining the significance of using treatment effects.

RESULTS AND DISSCUSION

Sesame crop responded positively to potassium fertilizer in relations of plant height. Significant response to applied K levels that used. The level K_{300} Kg ha^{-1} had significantly plant height (125.17 cm) compared with the other levels while the level K_{00} impacted negatively the plant height (80.77 cm) (table 2). There were a significant variation between the two sources of K, so the K_{K2SO4} source increased plant height to reach 107.81 cm compared to the K_{KCl} source that had 103.77 cm (table 2). $Soil_{15.87}$ improved significantly the plant height (111.71 cm) compared with the $Soil_{06.02}$, which was 99.87 cm. The two interactions among the experiments factors showed a significant differences. The interaction $Soil_{15.87} \times K_{300}$ impacted positively the plant height to reach 132.09 cm while the interaction $Soil_{06.02} \times K_{00}$ had the lowest plant height (79.33 cm). The interaction $K_{K2SO4} \times K_{300}$ effected significantly the plant height (128.73 cm) compared with the other interactions of the same group while the interaction $K_{K2SO4} \times K_{00}$ and $K_{KCl} \times K_{00}$

were significantly the lowest in plants height (80.77 cm). The interaction $Soil_{15.87}$ × K_{K2SO4} increased the plant height to reach 113.67 cm, which was significantly higher compared with the interactions of the same group while the interaction $Soil_{06.02}$ × K_{KCl} was significantly the lowest compared with the other interaction in the same group (table 2). The three factors interactions showed a significantly differences. The interaction $Soil_{15.87}$ × K_{K2SO4} × K_{300} effected plant height significantly and increased to reach 135.31 cm while the interaction $Soil_{06.02}$ × K_{K2SO4} × K_{00} and $Soil_{06.02}$ × K_{KCl} × K_{00} were significantly the lowest in plant height, which was 79.33 cm (table 2). Potassium is one of main nutrient that impact positively plants growth. Therefore, increasing the level of potassium can be increase the cells divisions and cause increasing plant height (Abdel-Rahman, 2014). Potassium sulphate fertilizer effected positively compared to potassium chloride fertilizer, and that could be due to the effect of the accompanying ion in lowering the soil pH. Potassium sulphate fertilizer showed higher effect and can be good choice for potassium fertilization and can be used in gypsum lands because it has a low salt index. It also contains the sulphur element that the plant needs and add it in basic and neutral soil conditions (Watsh *et al*., 2023).

Table 2. Effect of potassium sources and levels on sesame plant height (cm) grown in two types of gypsum soils.

Gypsum %	K sources	K Levels, Kg ha^{-1}				Gypsum % × K sources AV.
		0	**75**	**750**	**300**	
$Soil_{06.02}$	**K_2SO_4**	79.33 l	96.24 i	110.11 fg	122.15 d	**101.96 c**
	KCl	79.33 l	91.22 j	106.23 h	114.34 e	**97.78 d**
$Soil_{15.87}$	**K_2SO_4**	82.21 k	111.08 f	126.06 c	135.31 a	**113.67 a**
	KCl	82.21 k	108.11 gh	119.78 d	128.87 b	**109.74 b**
						K sources AV.
K levels × K sources AV.	**K_2SO_4**	80.77 g	103.66 e	118.09 c	128.73 a	**107.81 a**
	KCl	80.77 g	99.67 f	113.01 d	121.61 b	**103.77 b**
						Gypsum %AV.
Gypsum % × K Levels AV.	**$Soil_{06.02}$**	79.33 g	93.73 e	108.17 d	118.25 c	**99.87 b**
	$Soil_{15.87}$	82.21 f	109.6 d	122.92 b	132.09 a	**111.71 a**
Potassium Levels AV.		**80.77 d**	**101.66 c**	**115.55 b**	**125.17 a**	

According to Duncan's test at level 0.05 probability, there were no significant differences among means had the same letters

Fifty days after planting time, significant higher dry weight was observed by the different among K levels. Potassium at K_{300} increased sesame dry weight positively compared with the other K levels while the control treatment K_{00} showed the lowest value of dry weight. Increasing the amount of $K_{(0-300)}$ increased the sesame dry weight (table 3). There was a significant variation between the two sources of K, so the K_{K2SO4} source increased dry weight to reach 46.21 gm plant^{-1} compared to the K_{KCl} source that had 42.67 g plant $^{-1}$ (table 3). $Soil_{15.87}$ improved significantly the dry weight (47.07 g plant^{-1}) compared with the $Soil_{06.02}$, which was 41.82 g plant^{-1} (table 3). The two interactions among the experiments factors indicated a significant differences. The interaction

$Soil_{15.87} \times K_{300}$ impacted positively the dry weight to reach 57.97 g $plant^{-1}$ while the interaction $Soil_{06.02} \times K_{00}$ had the lowest dry weight (29.12 g $plant^{-1}$). The interaction $K_{K2SO4} \times K_{300}$ effected significantly the dry weight (56.62 g $plant^{-1}$) compared with the other interactions of the same group while the interaction $K_{K2SO4} \times K_{00}$ and $K_{KCl} \times K_{00}$ were significantly the lowest in dry weight (32.13 g $plant^{-1}$). The interaction $Soil_{15.87} \times K_{K2SO4}$ increased the dry weight to reach 49.02 g $plant^{-1}$, which was significantly higher compared with the interactions of the same group while the interaction $Soil_{06.02} \times K_{KCl}$ was significantly the lowest in dry weight (40.24 g $plant^{-1}$) compared with the other interaction in the same group (table 3).The three factors interactions presented a significantly variations. The interaction $Soil_{15.87} \times K_{K2SO4} \times K_{300}$ effected dry weight significantly and increased to reach 60.66 g $plant^{-1}$ while the interaction $Soil_{06.02} \times K_{K2SO4} \times K_{00}$ and $Soil_{06.02} \times K_{KCl} \times K_{00}$ were significantly the lowest in sesame dry weight, which was 29.12 g $plant^{-1}$ (table 3). Increasing the amount of potassium was more effective for dry weight and that might be because it's attributed to the enhanced photosynthetic and plant water as well as it is noted that significant correlations between the producing dry weight and gas exchange traits and retaining ability (Fang *et al.*, 2023). Also, at the influence of the cation exchange process, a high level of gypsum led to the release of potassium into the soil solution, especially when the potassium content was very low, and that might be held dry weight accumulation in sesame.

Table 3. Effect of potassium sources and levels on sesame dry weight (g) grown in two types of gypsum soils.

Gypsum %	K sources	K Levels, Kg ha^{-1}: 0	75	750	300	Gypsum % × K sources AV.
$Soil_{06.02}$	**K_2SO_4**	29.12 i	42.12 f	49.79 d	52.58 c	**43.40 c**
	KCL	29.12 i	38.11 g	43.85 f	49.87 d	**40.24 d**
$Soil_{15.87}$	**K_2SO_4**	35.14 h	46.27 e	54.01bc	60.66 a	**49.02 a**
	KCL	35.14 h	41.88 f	48.13 de	55.27 b	**45.11 b**
						K sources AV.
K levels × K sources AV.	**K_2SO_4**	32.13 f	44.20 d	51.90 b	56.62 a	**46.21 a**
	KCL	32.13 f	40.00 e	45.99 cd	52.57 b	**42.67 b**
						Gypsum %AV.
Gypsum % × K Levels AV.	**$Soil_{06.02}$**	29.12 g	40.12 e	46.82 c	51.23 b	**41.82 b**
	$Soil_{15.87}$	35.14 f	44.08 d	51.07 b	57.97 a	**47.07 a**
Potassium Levels AV.		**32.13 d**	**42.10 c**	**48.95 b**	**54.60 a**	

According to Duncan's test at level 0.05 probability, there were no significant differences among means had the same letters

Sesame crop impacted certainly to potassium fertilizer in relations of branch number. Significant responses to applied K levels that used. The level K_{300} Kg ha^{-1} had significantly branch number (7.35 no. $plant^{-1}$) compared with the other levels while the level K_{00} impacted negatively sesame branch number (4.61 no. $plant^{-1}$) (table 4). The two sources of K showed a significant variation, so the K_{K2SO4} source increased branch number to reach 6.47 no. $plant^{-1}$ compared to the K_{KCl} source that had 5.74 no. $plant^{-1}$ (table 4). $Soil_{15.87}$ improved significantly the sesame branch number (6.54 no. plant^{-1}) compared to the $Soil_{06.02}$, which was 5.67 no. plant^{-1}. Two factors interactions among the experiments factors indicated a significant differences. The interaction $Soil_{15.87}$ × K_{300} impacted positively the branch numbers to reach 7.79 no. plant^{-1} while the interaction $Soil_{06.02}$ × K_{00} had the lowest sesame branch number (4.12 no. plant^{-1}). The interaction K_{K2SO4} × K_{300} effected significantly the branch number (7.95 no. plant^{-1}) compared with the other interactions of the same group while the interaction K_{K2SO4} × K_{00} and K_{KCl} × K_{00} were significantly the lowest in sesame branch number (4.61 no. plant^{-1}). The interaction $Soil_{15.87}$ × K_{K2SO4} increased sesame branch number (6.82 no. plant^{-1}), which was significantly higher compared with the interactions of the same group, while the interaction $Soil_{06.02}$ × K_{KCl} was significantly the lowest (5.21 no. plant^{-1}) in sesame branch number compared with the other interaction in the same group (table 4). The three factors interactions presented a significantly variances. The interaction $Soil_{15.87}$ × K_{K2SO4} × K_{300} effected sesame branch number significantly and increased to reach 8.35 no. plant^{-1} while the interaction $Soil_{06.02}$ × K_{K2SO4} × K_{00} and $Soil_{06.02}$ × K_{KCl} × K_{00} were significantly the lowest in branch number, which was 4.12 no. plant^{-1} (table 4). The higher level of potassium and K_2SO_4 source of potassium and gypsum soil with 15.87 % increased the growth and development for sesame plant. Therefore, their two and three interactions were impacted significantly the sesame development, which was reflected by increasing the branches number. Similar results were found by Reddy *et al.* (2022) and Dasmahapatra *et al.* (1990). Increasing the addition of potassium fertilizer led to a significant increase in all sesame traits and that might be related to an effective role in providing enzymes and cell divisions (Havlin *et al.,* 2005).

Table 4. Effect of potassium sources and levels on sesame branch number (no. plant^{-1}) grown in two types of gypsum soils.

Gypsum %	K sources	K Levels, Kg ha^{-1} 0	75	750	300	Gypsum % × K sources AV.
$Soil_{06.02}$	K_2SO_4	4.12 j	5.85 f-h	6.97 b-d	7.55 b	**6.12 b**
	KCL	4.12 j	4.91 g-i	5.51 g-i	6.29 d-g	**5.21 c**
$Soil_{15.87}$	K_2SO_4	5.09 hi	6.52 c-f	7.31 bc	8.35 a	**6.82 a**
	KCL	5.09 hi	5.98 e-g	6.73 b-d	7.22 bc	**6.26 b**
						K sources AV.
K levels × K sources AV.	K_2SO_4	4.61 f	6.19 d	7.14 b	7.95 a	6.47 a
	KCL	4.61 f	5.45 e	6.12 d	6.76 c	5.74 b
						Gypsum %AV.
Gypsum % × K Levels AV.	$Soil_{06.02}$	4.12 e	5.38 d	6.24 c	6.92 b	5.67 b
	$Soil_{15.87}$	5.09 d	6.25 c	7.02 b	7.79 a	6.54 a
Potassium Levels AV.		4.61 d	5.82 c	6.63 b	7.35 a	

According to Duncan's test at level 0.05 probability, there were no significant differences among means had the same letters

Sesame capsules number per plant affected significantly by potassium fertilizer levels. Significant responses to applied K levels that used. The level K_{300} Kg ha^{-1} impacted significantly capsules number per plant to reach 59.69 no. $plant^{-1}$ compared with the other levels while the level K_{00} impacted negatively sesame capsule number per plant (50.23 no. $plant^{-1}$) (table 5). Two sources of potassium (K) showed a significant variation by impacting capsule number per plant, so the K_{K2SO4} source increased capsule number to reach 56.26 no. $plant^{-1}$ compared to the K_{KCl} source that had 53.61 no. $plant^{-1}$ (table 5). $Soil_{15.87}$ improved significantly the sesame capsule number (56.35 no. $plant^{-1}$) compared to the $Soil_{06.02}$, which was 53.51 no. $plant^{-1}$.

The two factors interactions among the experiments factors illustrated a significant differences for capsule number per plant. The interaction $Soil_{15.87} \times K_{300}$ impacted positively the capsule numbers to reach 60.82 no. $plant^{-1}$ while the interaction $Soil_{06.02} \times K_{00}$ had the lowest sesame capsule number (48.21 no. $plant^{-1}$). The interaction $K_{K2SO4} \times K_{300}$ effected significantly sesame capsule number per plant (61.43 no. $plant^{-1}$) compared with the other interactions of the same group while the interaction $K_{K2SO4} \times K_{00}$ and $K_{KCl} \times K_{00}$ were significantly the lowest in sesame capsule number (50.23 no. $plant^{-1}$). The interaction $Soil_{15.87} \times K_{K2SO4}$ increased sesame capsule number (55.07 no. $plant^{-1}$), which was significantly higher compared with the interactions of the same group, while the interaction $Soil_{06.02} \times K_{KCl}$ was significantly the lowest in capsule number per plant (52.13 no. $plant^{-1}$) compared with the other interaction in the same group (table 5).

The three factors interactions affected significantly sesame capsule number per plant. The interaction $Soil_{15.87} \times K_{K2SO4} \times K_{300}$ impacted sesame capsule number significantly and increased to reach 62.84 no. $plant^{-1}$ while the interaction $Soil_{06.02} \times K_{K2SO4} \times K_{00}$ and $Soil_{06.02} \times K_{KCl} \times K_{00}$ were significantly the lowest in capsule number, which was 48.21 no. $plant^{-1}$ (table 5). Increasing the capsules number results from the increasing the K levels and using K_2SO_4 as source of K. that might be related the K role in cell division as well as the sulphate that reduce the pH of soil and made the nutrients in soil available for absorption (Li *et al.*, 2023). Using K_2SO_4 as source of potassium can decrease the soil pH which could create an acidic environment and that might be led to made the other nutrition's available to plant.

Table 5. Effect of potassium sources and levels on sesame capsule number (no. $plant^{-1}$) grown in two types of gypsum soils.

Gypsum %	**K sources**	**K Levels, Kg ha^{-1}**				**Gypsum % × K sources AV.**
		0	**75**	**750**	**300**	
$Soil_{06.02}$	**K_2SO_4**	48.21 i	53.87 f	57.46 c	60.01 b	**54.89 c**
	KCL	48.21 i	50.12 h	53.09 fg	57.11 c	**52.13 d**
$Soil_{15.87}$	**K_2SO_4**	52.24 g	56.42 cd	59.00 b	62.84 a	**57.63 a**
	KCL	52.24 g	53.98 ef	55.28 de	58.79 b	**55.07 b**
						K sources AV.
K levels × K sources AV.	**K_2SO_4**	50.23 e	55.15 c	58.23 b	61.43 a	56.26 a
	KCL	50.23 e	52.05 d	54.19 c	57.95 b	53.61 b
						Gypsum %AV.
Gypsum % × K Levels AV.	**$Soil_{06.02}$**	48.21 d	52.24 c	55.28 b	58.56 ab	53.51 b
	$Soil_{15.87}$	52.24 c	55.22 bc	57.14 b	60.82 a	56.35 a
Potassium Levels AV.		50.23 d	53.60 c	56.21 b	59.69 a	

According to Duncan's test at level 0.05 probability, there were no significant differences among means had the same letters

Sesame 1000 seeds weight affected significantly by potassium fertilizer levels. Significant responses to applied K levels that used. The level K_{300} Kg ha^{-1} showed higher1000 seeds weight (6.12 g) compared with the other levels while the level K_{00} impacted negatively sesame 1000 seeds weight (4.09 g) (table 6). Two sources of potassium showed a significant variation by impacting 1000 seeds weight, so the K_{K2SO4} source increased capsule number to reach 5.62 g compared to the K_{KCl} source that had 4.97 g (table 6). $Soil_{15.87}$ impacted significantly the sesame 1000 seeds weight (5.83 g) compared to the $Soil_{06.02}$, which was 4.74 g. The two factors interactions among the experiments factors affected a significantly changes for 1000 seeds weight. The interaction $Soil_{15.87} \times K_{300}$ impacted positively the sesame 1000 seeds weight to reach 6.56 g while the interaction $Soil_{06.02} \times K_{00}$ had the lowest sesame 1000 seeds weight (3.25 g). The interaction $K_{K2SO4} \times K_{300}$ effected significantly sesame 1000 seeds weight (6.57 g) compared with the other interactions of the same group while the interaction $K_{K2SO4} \times K_{00}$ and $K_{KCl} \times K_{00}$ were significantly the lowest in sesame 1000 seeds weight (4.09 g). The interaction $Soil_{15.87} \times K_{K2SO4}$ increased sesame 1000 seeds weight (6.14 g), which was significantly higher compared with the interactions of the same group, while the interaction $Soil_{06.02} \times K_{KCl}$ was significantly the lowest in 1000 seeds weight (4.40 g) compared with the other interaction in the same group (table 6). The three factors interactions affected significantly sesame 1000 seeds weight. The interaction $Soil_{15.87} \times K_{K2SO4} \times K_{300}$ impacted sesame capsule number 1000 seeds weight significantly and increased to reach 6.94 g while the interaction $Soil_{06.02} \times K_{K2SO4} \times K_{00}$ and $Soil_{06.02} \times K_{KCl} \times K_{00}$ were significantly the lowest in sesame 1000 seeds weight, which was 3.25 g (table 6). Increasing the weight of 1000 seeds of sesame imitated the increasing the K levels and using K_2SO_4 as source of K. that might be related the K role in cell division and growth and development as well as the sulphate (K_2SO_4) that reduce the amount of pH inside the soil and made the other importance nutrients available for absorption (Kathiresan, 2000; Li *et al*., 2023).

Table 6. Effect of potassium sources and levels on sesame 1000 seeds weight (g) grown in two types of gypsum soils.

Gypsum %	**K sources**	**K Levels, Kg ha^{-1}**				**Gypsum % × K sources AV.**
		0	**75**	**750**	**300**	
$Soil_{06.02}$	**K_2SO_4**	3.25 f	5.11 d	5.81 c	6.19 bc	**5.09 c**
	KCL	3.25 f	4.23 e	4.95 d	5.15 d	**4.40 d**
$Soil_{15.87}$	**K_2SO_4**	4.92 d	6.08 c	6.61 ab	6.94 a	**6.14 a**
	KCL	4.92 d	5.21 d	5.82 c	6.18 bc	**5.53 b**
						K sources AV.
K levels × K sources AV.	**K_2SO_4**	4.09 f	5.60 c	6.21 b	6.57 a	5.62 a
	KCL	4.09 f	4.72 d	5.39 c	5.67 c	4.97 b
						Gypsum %AV.
Gypsum % × K Levels AV.	**$Soil_{06.02}$**	3.25 f	4.67 e	5.38 c	5.67 c	4.74 b
	$Soil_{15.87}$	4.92 d	5.65 c	6.22 b	6.56 a	5.83 a
Potassium Levels AV.		4.09 d	5.16 c	5.80 b	6.12 a	

According to Duncan's test at level 0.05 probability, there were no significant differences among means had the same letters

Potassium fertilizer levels impacted sesame yield significantly. The responses to applied K levels that used had a significant effect. The level K_{300} Kg ha^{-1} showed higher yield, which was 2244 kg ha^{-1} compared with the other levels while the level K_{00} impacted negatively sesame yield, which was 1396 kg ha^{-1} (table 7). Two sources of potassium showed a significant variation by impacting sesame yield, so the K_{K2SO4} source increased yield (1975 kg ha^{-1}) compared to the K_{KCl} source that had 1734 kg ha^{-1} (table 7). $Soil_{15.87}$ impacted significantly the sesame yield to reach 1965 kg ha^{-1} compared to the $Soil_{06.02}$, which was 1734 kg ha^{-1} (table 7).The two factors interactions among the experiments factors affected a significantly the changes for sesame yield. The interaction $Soil_{15.87} \times K_{300}$ impacted positively the sesame yield to reach 2334 kg ha^{-1} while the interaction $Soil_{06.02} \times K_{00}$ had the lowest sesame yield (1271 kg ha^{-1}). The interaction $K_{K2SO4} \times K_{300}$ effected significantly sesame yield (2378 kg ha^{-1}) compared with the other interactions in the same group while the interaction $K_{K2SO4} \times K_{00}$ and $K_{KCl} \times K_{00}$ were significantly the lowest in sesame yield (1396 kg ha^{-1}). The interaction $Soil_{15.87} \times K_{K2SO4}$ increased sesame yield (2091 kg ha^{-1}), which was significantly higher compared with the interactions of the same group, while the interaction $Soil_{06.02} \times K_{KCl}$ was significantly the lowest in sesame yield (1628 kg ha^{-1}) compared with the other interaction in the same group (table 7).The three factors interactions affected significantly sesame yield. The interaction $Soil_{15.87} \times K_{K2SO4} \times K_{300}$ impacted sesame yield significantly and increased to reach 2458 kg ha^{-1} while the interaction $Soil_{06.02} \times K_{K2SO4} \times K_{00}$ and $Soil_{06.02} \times K_{KCl} \times K_{00}$ were significantly the lowest in sesame yield, which was 1271 kg ha^{-1} (table 7). Seed yield showed the impact of experiments factors on the other traits. Therefore increasing the plant height (table 2) could be increase the capsule number and altimetry the seed yield. Similar results were found by Havlin (2005), Kathiresan et al. (2000), and Malic (2004) Shehu (2010).

Table 7. Effect of potassium sources and levels on sesame yield (kg ha^{-1}) grown in two types of gypsum soils.

Gypsum %	**K sources**	**K Levels, Kg ha^{-1}**				**Gypsum % × K sources AV.**
		0	**75**	**750**	**300**	
$Soil_{06.02}$	**K_2SO_4**	1271 j	1784 g	2077 d	2298 b	**1858 b**
	KCL	1271 j	1501 i	1729 h	2009 e	**1628 c**
$Soil_{15.87}$	**K_2SO_4**	1521 i	2057 de	2329 b	2458 a	**2091 a**
	KCL	1521 i	1702 h	1919 f	2209 c	**1838 b**
						K sources AV.
K levels × K sources AV.	**K_2SO_4**	1396 g	1921 d	2203 c	2378 a	1975 a
	KCL	1396 g	1602 f	1824 e	2109 b	1734 b
						Gypsum %AV.
Gypsum % × K Levels AV.	**$Soil_{06.02}$**	1271 f	1643 d	1903 c	2154 b	1743 b
	$Soil_{15.87}$	1521 e	1880 c	2124 b	2334 a	1965 a
Potassium Levels AV.		1396 d	1761 c	2014 b	2244 a	

Potassium fertilizer levels impacted sesame oil percentage significantly. The level K_{300} Kg ha^{-1} indicated higher oil percentage, which was 52.93 % compared with the other levels while the level

K_{00} impacted negatively sesame oil percentage, which was 41.18 % (table 8). Two sources of potassium showed a significant variation by impacting sesame oil percentage, so the K_{K2SO4} source increased oil percentage (50.38%) compared to the K_{KCl} source that had 45.61 % (table 8). $Soil_{15.87}$ impacted significantly the sesame oil percentage to reach 50.99 % compared to the $Soil_{06.02}$, which was 45.00 % (table 8). The two factors interactions among the experiments factors affected a significantly the changes for sesame oil percentage. The interaction $Soil_{15.87} \times K_{300}$ impacted positively the sesame oil percentage to reach 55.76 % while the interaction $Soil_{06.02} \times K_{00}$ had the lowest sesame oil percentage (38.12 %). The interaction $K_{K2SO4} \times K_{300}$ affected significantly sesame oil percentage (56.26 %) compared with the other interactions in the same group while the interaction $K_{K2SO4} \times K_{00}$ and $K_{KCl} \times K_{00}$ were significantly the lowest in sesame oil percentage (41.18 %). The interaction $Soil_{15.87} \times K_{K2SO4}$ increased sesame oil percentage (53.35 %), which was significantly higher compared with the interactions of the same group, while the interaction $Soil_{06.02} \times K_{KCl}$ was significantly the lowest in sesame oil percentage (42.59 %) compared with the other interaction in the same group (table 8). The three factors interactions affected significantly sesame oil percentage. The interaction $Soil_{15.87} \times K_{K2SO4} \times K_{300}$ impacted sesame oil percentage significantly and increased to reach 59.01 % while the interaction $Soil_{06.02} \times K_{K2SO4} \times K_{00}$ and $Soil_{06.02} \times K_{KCl} \times K_{00}$ were significantly the lowest in oil percentage, which was 38.12 (table 8). In the same way the oil percentage follow the same role like the other testing traits. Potassium (K) plays a key role in plant regulatory development including plant-water relation, osmoregulation, and internal cation-anion balance. It also has considerable impact on enzyme activation involved in the formation of organic substances, oil synthesis, respiratory and photosynthetic metabolism (Lauchli and Pfluger 1979; Wyn Jones et al. 1979; Shehu, 2010; Le Bot et al., 2021), and that could be the main reason for increasing the oil percentage.

Table 8. Effect of potassium sources and levels on sesame oil percentage (%) grown in two types of gypsum soils.

Gypsum %	K sources	K Levels, Kg ha^{-1}				Gypsum % × K sources AV.
		0	**75**	**750**	**300**	
Soil$_{06.02}$	**K_2SO_4**	38.12 j	46.37 g	51.59 d	53.50 c	**47.40 c**
	KCL	38.12 j	41.14 i	44.40 h	46.71 fg	**42.59 d**
Soil$_{15.87}$	**K_2SO_4**	44.23 h	52.37 d	57.78 b	59.01 a	**53.35 a**
	KCL	44.23 h	47.54 f	50.24 e	52.51 cd	**48.63 b**
						K sources AV.
K levels × K sources AV.	**K_2SO_4**	41.18 f	49.37 c	54.69 b	56.26 a	50.38 a
	KCL	41.18 f	44.34 e	47.32 d	49.61 c	45.61 b
						Gypsum %AV.
Gypsum % × K Levels AV.	**Soil$_{06.02}$**	38.12 f	43.76 e	48.00 d	50.11 c	45.00 b
	Soil$_{15.87}$	44.23 e	49.96 c	54.01 b	55.76 a	50.99 a
Potassium Levels AV.		41.18 d	46.86 c	51.00 b	52.93 a	

According to Duncan's test at level 0.05 probability, there were no significant differences among means had the same letters

CONCLUSION

Increasing potassium level that applied to soil increased the growth and yield for sesame crop. The soil with 15.87 % gypsum improved growth traits such as plant height and dry weight as well as yield traits such as sesame 1000 seeds weight, yield, and oil percentage. Sesame crop showed significant responses to the potassium sources and increased all the experiments traits by using K_2SO_4 as source of potassium. The two factor interactions $Soil_{15.87} \times K_{300}$, $K_{K2SO4} \times K_{300}$, and $Soil_{15.87} \times K_{K2SO4}$ were improved the sesame crop production as well as the three factors interaction $Soil_{15.87} \times K_{K2SO4} \times K_{300}$.

CONFLICT OF INTEREST

The author declares no conflicts of interest associated with this manuscript.

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