Effect of Phosphate Fertilizer Levels on Grain Yield and Composition of Different Sorghum (Sorghum bicolor L.) Cultivars Grown in Gypsum Soil

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Abstract

This study was conducted during the spring season of 2025 at the Field Crops Research Station,

College of Agriculture, Tikrit University, to evaluate the effect of three levels of phosphate fertilizer (0, 100, and 200 kg ha ^{1}) on grain yield and its components in four Sorghum cultivars grown in gypsum soil. A Randomized complete block design (R.C.B.D) with three replications was used. The studied traits included dry grain yield, number of grains per head, 500-grain weight, and harvest index. The results showed that phosphate fertilization significantly increased dry grain yield, with the 200 kg ha ^{1} level recording the highest overall average of 186.13 g compared to 168.06 g in the nofertilization treatment. It also significantly increased the number of grains per head, reaching 1522.35 grains.head^{-1} at the same level compared to 1216.34 grains.head^{-1} in the control treatment respectively, the weight of 500 grains decreased with increasing phosphorus levels, with the no-fertilization treatment recording the highest average of 81.00 g compared to 71.49 g at the 200 kg ha ^{1} level. The results also showed significant differences between cultivars. The Lilo cultivar excelled the others in grain yield, while Bohooth 70 cultivar excelled the others in grain count and harvest index. The interaction between Bohooth 70 cultivar and the 200 kg ha ^{1} level resulted in the highest values for several studied traits. We conclude that improving Sorghum productivity in gypsum soils depends on selecting the appropriate cultivar and applying the correct level of phosphate fertilization.

Keywords: Sorghum, phosphate fertilization, grain yield, gypsum soil, cultivars.

Introduction:

Sorghum (*Sorghum bicolor L. Moench*) is one of the most important cereal crops in arid and semiarid regions due to its tolerance to harsh environmental conditions and its efficient use of limited resources, making it a crucial crop for achieving food security [5]. Sorghum grains ard eistinguished by

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their nutritional value, containing good proportions of protein, carbohydrates, and minerals. They are used in human and animal nutrition and various food industries. The productivity of this crop is affected by several factors, most notably mineral fertilization. Phosphorus is an essential element for improving plant growth and increasing grain yield through its role in energy transfer and activating vital processes within the plant. Phosphorus is one of the essential macronutrients for plant growth and plays a pivotal role in energy transfer (ATP), nucleic acid and phospholipid formation, root growth activation, and improved absorption of other nutrients. Numerous studies have shown that phosphorus deficiency leads to reduced vegetative growth, impaired root development, and decreased grain and feed quality. Recent studies indicate that phosphate fertilization contributes to improving the productive characteristics of Sorghum. Increased phosphorus levels promote grain set and increase grain weight [2]. Phosphorus also plays a significant role in improving grain quality by enhancing metabolic processes associated with the formation of bioactive compounds. Therefore, understanding the interaction between Sorghum and phosphate fertilization is a crucial step in developing sustainable agricultural management strategies and improving crop productivity and quality in environments with challenging climates and deficient soil fertility [3].

Study aims:

To evaluate the effect of phosphorus supplementation on grain yield and forage production in Sorghum grown in gypsum soil. To compare the response of different cultivars (four Sorghum cultivars) to phosphate fertilization.

To identify the most suitable cultivar for the region from among the cultivars used and the optimal level of phosphate fertilization.

Materials and Methods

A field experiment was conducted at the Field Crops Research Station of the College of Agriculture, Tikrit University, during the spring season of April 15, 2025. The station is located approximately 12 km from the center of Tikrit city in Salah al-Din province, at 34.6° East longitude and 34.6° North latitude, at an altitude of 129 meters above sea level. The aim of the experiment was to study the effect of using different levels of phosphorus fertilizer on improving the grain yield of Sorghum genotypes grown in gypsum soils. The experimental land was plowed using a rake plow, then smoothed and leveled to prepare a suitable seedbed. The experimental land was divided according to the field plan and included 36 experimental units distributed across three sectors, with 12 experimental units in each sector. The area of each experimental unit was 3 x 3 m², with 4 rows in each unit. The length of each row was 3 meters, thd eistance between rows was 0.75 m², and thd eistance between plants was 0.10 cm. And others. Before planting began, soil

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samples were taken for analysis to determine their physical and chemical properties at the Soil Sciencd eepartment laboratory, College of Agriculture, Tikrit University.

Table (1) Physical and Chemical Properties of the Experimental Soil Before Planting and at a Depth of 30 cm.

Traits	values	Units
Ph	7.80	
EC (Electrical Conductivity of Soil)	2.35	$DS.m^{-1}$
Available Nitrogen	14.95	$mg.kg^{-1}$
Available Phosphorus	3.02	$mg.kg^{-1}$
Available Potassium	124.5	$mg.kg^{-1}$
Boron	0.01	$mg.kg^{-1}$
Gypsum	151	g.kg $Soil^{-1}$
Organic Matter	9.15	g.kg $Soil^{-1}$
Sand	618	g.kg $Soil^{-1}$
Clay	175	g.kg $Soil^{-1}$
Silt	210	g.kg $Soil^{-1}$
Soil texture		Sandy loam

Materials:

1. Genotypes

Four genotypes of Sorghum were used in this study. These were obtained from the Field Crops Department, College of Agriculture, Tikrit University.

Table (2) lists the names of the genotypes, their origins and Provenance

genotype	Origin	Source
Lilo	Iraq	Iraqi Variety
Giza	Egypt	Variety introduced to Iraq from Egypt
Bohooth	Sudan	Introduced from Sudan and registered and approved in 2016 by the Iraqi Ministry of Agriculture as a highyielding green fodder variety
J	Iraq	Genetic Composition, Selected

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2. Phosphate Fertilizer Levels

a. Level 1: No addition (0 $kg.ha^{-1}$).

b. Level 2: Add 100 $kg.ha^{-1}$

c. Level 3: Add 200 $kg.ha^{-1}$.

3. Studied Traits:

The following traits were studied by taking random samples of ten plants, recorded as an average, randomly selected from the two midlines of each experimental unit. The exception was flowering, which was measured from the top of the experimental unit.

The studied traits, their calculation methods, and units of measurement are:

1. Dry Grain Yield (g)

The number of heads of the original plant, including branches, was counted and totaled for ten plants, and the average was calculated [4].

2. Number of Grains per Head (grain. $Head^{-1}$)

The number of seeds per head was counted after drying the head, separating the seeds, and manually counting them [5].

3. Weight of 500 grains (g)

500 grains were randomly selected from the seeds of the ten plants whose head number was calculated, and from clean, impurity-free grains from each unit of the experiment. They were weighed using a sensitive electronic scale [6].

4. Harvest Index (%)

The harvest index was calculated by dividing the grain yield by the total biological yield and multiplying by 100. This index is a measure of the efficiency of converting vegetative growth into an economic yield [7].

Results and Discussion

Grain Yield (g)

The results in Table (3) show that increasing the level of phosphate fertilization led to a significant increase in dry grain yield. The 200 kg ha^{1} phosphorus level recorded the highest overall average yield of 186.13 g, compared to the control treatment which recorded 168.06 g. The 100 kg phosphorus level had an average yield of 179.24 g. This increase in dry grain yield at high phosphorus levels is attributed to the important physiological role of this element in improving the efficiency of vital processes within the plant, particularly energy synthesis, and increasing the efficiency of photosynthetic translocation from the leaves to the grains during the filling stage. This directly translates to an increase in dry grain weight. [2] demonstrated that moderate to high phosphorus fertilization led to a significant increase in dry grain weight due to improved photosynthetic efficiency and increased translocation of photosynthetic products to the grains.

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[8] also indicated that increased phosphorus levels improved yield components and contributed to higher dry grain productivity compared to the control treatment. The results show significant differences in dry grain yield among cultivars. The Lilo cultivar recorded the highest overall average at 185.15 g, followed by Bohooth 70 cultivar at 182.87 g, while the Giza cultivar recorded the lowest average at 168.46 g. This variation among cultivars is attributed to differences in genetic makeup, which determine a cultivar's efficiency in nutrient uptake, its ability to develop a vigorous vegetative system, and its efficiency in converting processed materials into plump grains with a higher dry weight. The interaction results showed that the cultivars' responses to phosphate fertilization levels were not uniform. The 'Bohooth 70' cultivar recorded the highest dry grain yield at 195.69 g at a phosphorus level of 200 kg ha ¹, compared to 168.45 g in the control treatment, indicating its high efficiency in utilizing added phosphorus. In contrast, the response of the 'Giza' cultivar was less pronounced, achieving only a limited increase in dry grain yield at high phosphorus levels, suggesting its relatively lower phosphorus utilization efficiency compared to the other cultivars.

Table (3) Effect of the interaction between Sorghum cultivars and phosphate fertilization levels (kg ha ¹) on dry grain yield

Cultivars	**Phosphorus levels**			**average cultivars**
	0 kg.ha^{-1}	100 kg.ha^{-1}	200 kg.ha^{-1}	
Lilo	174.50 a b	186.72 a b	194.24 a	185.15 a
Giza	161.08 c	172.51 a b c	171.80 a b c	168.46 b
J	168.24 b c	173.25 a b c	182.80 a b c	174.76 a b
Bohooth 70	168.45 b c	184.80 a b c	195.69 a	182.87 a
Average fertilizer	168.06 b	179.24 a b	186.13 a	177.18

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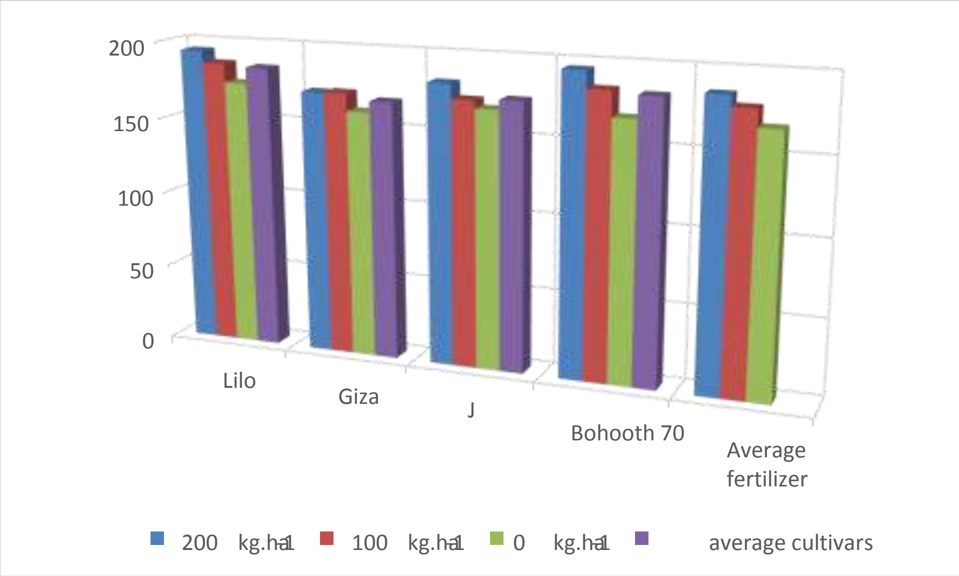

Figure (1): The effect of the interaction between sorghum cultivars and phosphorus fertilization

levels (0, 100, and 200 kg ha⁻ ¹) on averagd ery grain yield (g).

Number of grains per head (grain. head¹)

The results in Table (4) show that the 200 kg ha ¹ phosphate fertilization level achieved the highest overall average number of grains, reaching 1522.35 grains/head, significantly exceeding the 100 kg ha¹ level, which reached 1393.28 grains/head. The control treatment (no phosphate application) recorded the lowest average, at 1216.34 grains/head. This superiority is attributed to the vital role of phosphorus in stimulating flower formation, improving fertilization efficiency, and reducing the rate of flower abortion. Furthermore, phosphorus plays a role in increasing the translocation of photosynthetic products to the reproductive organs, which directly impacts the number of grains formed per head. [8] indicated that increasing phosphorus levels led to a significant increase in the number of grains in cereal crops as a result of improved reproductive growth. [2] also demonstrated that moderate to high phosphorus levels improve flower set efficiency and increase the number of grains per head. The results showed significant differences between cultivars, with the 'Bohooth 70' cultivar recording the highest overall average number of grains at 1574.37 grains/head, while the 'J', 'Giza', and 'Lilo' cultivars recorded lower averages

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ranging from 1285.44 to 1335.81 grains/head. The superiority of the 'Bohooth 70' cultivar is attributed to its higher genetic predisposition to producing a greater number of fertile flowers and its better ability to utilize nutrients, particularly phosphorus, compared to the other cultivars. The interaction results showed that the highest number of grains was recorded in the 'Bohooth 70' cultivar at a phosphorus level of 200 kg ha ¹, reaching 1766.70 grains/head, a clear and significant advantage over the other interaction treatments. In contrast, the Lilo cultivar, treated without added phosphorus, recorded the lowest value at 1107.50 grains per head. This indicates that Bohooth 70 cultivar has a high capacity to utilize added phosphorus, while low phosphorus levels limit the grainsetting efficiency of some cultivars. [9] also demonstrated that genetic makeups differ in phosphorus utilization efficiency, and that highly fertilization-efficient cultivars exhibit a

greater response to higher phosphorus levels, leading to increased grain count and improved yield components.

Table (4) Effect of the interaction between Sorghum cultivars and phosphate fertilization levels (kg ha ¹) on the number of grains per head (grain/head).

Cultivars	**Phosphorus levels**			**average cultivars**
	0 kg.ha^{-1}	100 kg.ha^{-1}	200 kg.ha^{-1}	
Lilo	1107.50 e	1309.50 d c	1439.33 c	1285.44 b
Giza	1195.07 e	1319.07 d	1426.87 c	1313.67 b
J	1180.01 e	1370.93 d c	1456.87 c	1335.81 b
Bohooth 70	1382.80 c d	1573.60 b	1766.70 a	1574.37 a
Average fertilizer	1216.34 c	1393.28 b	1522.35 a	1377.32

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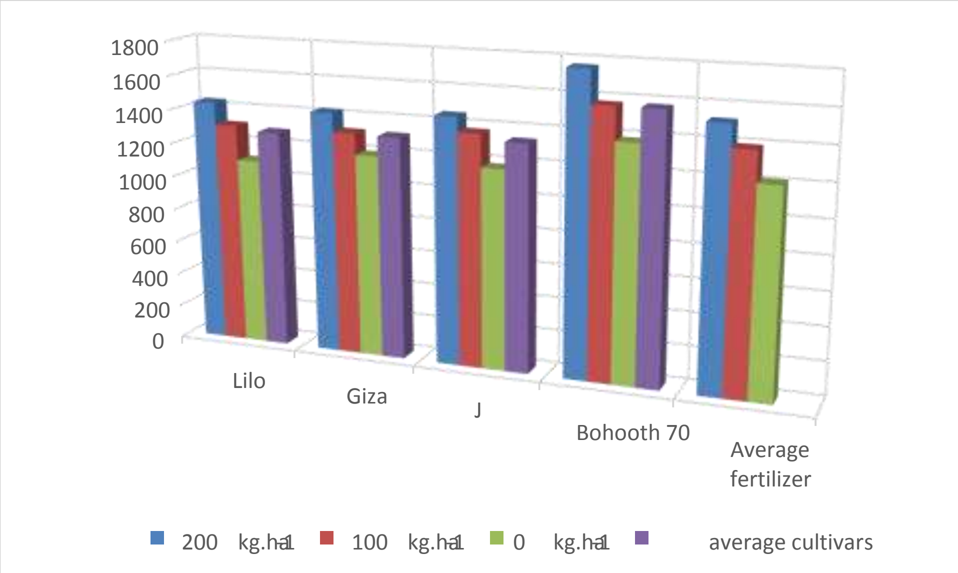

Figure (2): This figure shows the effect of the interaction between sorghum cultivars and different phosphorus fertilization levels (0, 100, and 200 kg ha⁻ ¹) on the number of grains per head

Weight of 500 grains (per head)

The results in Table (5) showed that the 500 showed that the 0 kg ha ¹ treatment resulted in

grain weight (g) trait was significantly affected the highest overall average weight of 500

by the cultivars and levels of phosphate grains, at 81.00 g, followed by the100 kg ha ¹ fertilization, as well as by the interaction treatment with an average of 75.12 g, while thebetween them. The Lilo cultivar recorded the 200 kg ha ¹ treatment yielded the lowest highest overall average weight of 500 grains, average at 71.49 g. This trend indicates that reaching 84.35 g, significantly surpassing the increasing the phosphorus level led to a gradual rest of the cultivars. It was followed by the J decrease in grain weight. This is

recorded the highest individual weight of 500 grains at 91.74 g at 0 kg ha^{-1},

attributed to cultivar with an average of 76.45 g, then Giza the increased number of grains formed as a with an average of 74.86 g, while Bohooth 70 result of phosphorus stimulating flowering and cultivar recorded the lowest average of 67.82 g. fruit set, causing competition among the grains This variation is attributed to the genetic for photosynthetic products during the filling differences between the cultivars in grain filling stage. This is known as the trade-off between efficiency, vent capacity, and their ability to grain number and weight, as demonstrated by utilize photosynthetic products during the grain [10,11] Regarding the interaction between filling stage, which was indicated by [2,10] when cultivar and fertilization level, the Lilo cultivar studied the factors controlling grain

which was not significantly different from its treatment at 100 kg ha^{-1}, which

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recorded 82.85 g. However, the weight decreased at 200 kg ha-1 to 78.45 g. In the J cultivar, the highest value was 82.90 g at 0 kg ha^{-1}, followed by 73.48 g at 100 kg ha-1, and then 72.98 g at 200 kg ha-1. This indicates that increasing the phosphorus level did not improve grain filling in this cultivar, but rather led to a decrease in their relative weight due to the increased number of grains. The results for the Giza cultivar showed values of 78.56 g at 0 kg ha-1 and 76.01 g at 100 kg ha-1, while they decreased to 70.01 g at 200 kg ha-1. These results are consistent with what [12] stated, namely that high phosphorus levels may increase the numerical characteristics of the yield at the expense of weight characteristics. Bohooth 70 cultivar recorded the lowest values overall, reaching 70.81 g at 0 kg ha-1 and 68.14 g at 100 kg ha-1, and decreasing to 64.52 g at 200 kg ha-1, indicating its limited efficiency in maintaining grain weight with increased yield load. These results clearly indicate that increasing the level of phosphate fertilization, particularly to 200 kg ha ¹, led to a decrease in the weight of 500 grains in all cultivars. This is because phosphorus helps increase the number of grains by stimulating reproductive growth. However, this expansion in the number of ducts leads to thd eistribution of photosynthetic products across a larger number of grains, thus reducing thd ery matter content per grain. This aligns with the physiological explanation provided by [10]. This trend is consistent with what [11] reported, explaining that an imbalance between the source (leaves) and thd euct (grains) during the later stages of growth leads to a decrease in the weight of individual grains, even when the plant's nutritional conditions are improved. Recent studies on Sorghum have shown that high phosphorus levels increase the number of grains and heads, but may reduce grain weight due to increased production load on the plant [2] Furthermore, the varying responses of different cultivars to phosphorus levels in this trait reflect genetic differences in phosphorus uptake and internal transport efficiency, as well as in the ability to regulate thd eistribution of photosynthetic products between vegetative and reproductive parts.

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Table (5) : Effect of the interaction between Sorghum cultivars and phosphate fertilization levels (kg ha^{1}) on the weight of 500 grains (one head).

cultivars	Phosphorus levels			average cultivars
	0 kg.ha^{-1}	100 kg.ha^{-1}	200 kg.ha^{-1}	
Lilo	91.74 a	82.85 a b	78.45 b c	84.35 a
Giza	78.56 b c	76.01 b c d	70.01 c d	74.86 b
J	82.90 b c	73.48 b c d	72.98 b c d	76.45 b
Bohooth 70	70.81 b c d	68.14 c d	64.52 D	67.82 c
Average fertilizer	81.00 a	75.12 a b	71.49 B	75.87

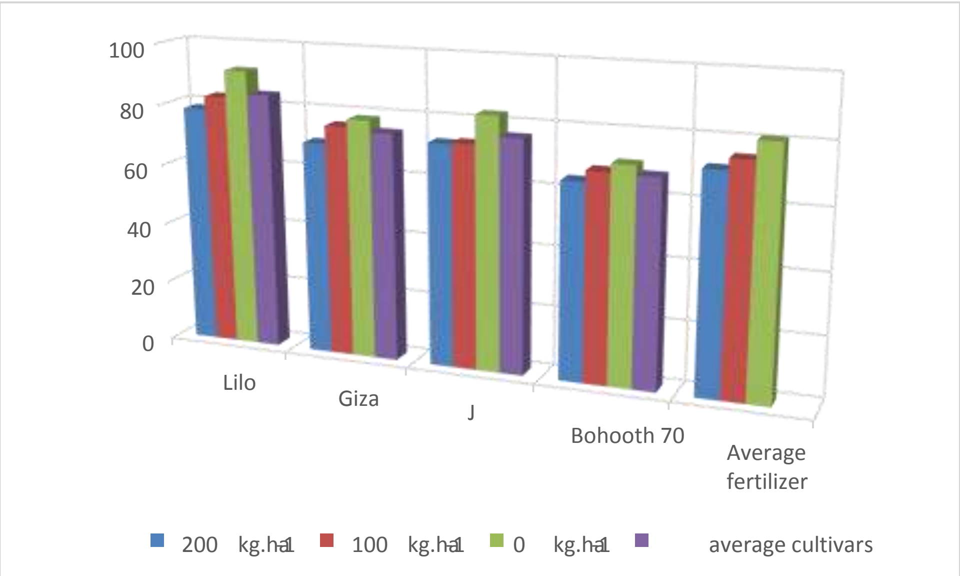

Figure (3): This figure shows the effect of the interaction between sorghum cultivars and different phosphorus fertilization levels (0, 100, and 200 kg ha^{-1}) on the weight of 500 grains (g).

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Harvest Index %

cultivar and the levels of phosphate fertilization, as well as the interaction between

The results in Table (6) show that the harvest them. This reflects thd eifferent efficiency of index (%) was significantly affected by both the the cultivars in converting total dry matter into

grain yield under different phosphorus levels. At the cultivar level, Bohooth 70 cultivar recorded the highest overall average harvest index at 44.91%, significantly outperforming the other cultivars. The Lilo cultivar recorded an average of 35.88%, followed by the Giza cultivar at 34.23%, and then the J cultivar, which recorded the lowest average at 33.53%. The superiority of Bohooth 70 cultivar is attributed to its higher efficiency in distributing photosynthetic products towards the grain compared to the foliage. This is related to genetic differences in downstream strength and the regulation of the relationship between the source and downstream, as indicated by [10,11] As for the effect of phosphate fertilization levels, the results showed that the treatment of no addition (0 kg ha-1) achieved the highest overall average harvest index of 38.73%, and did not differ significantly from the treatment of 100 kg ha-1, which recorded 36.51%, while the averagd eecreased at the level of 200 kg ha1 to 36.18%. This trend indicates that increasing phosphorus levels did not

necessarily lead to an increase in the harvest index. High phosphorus levels may promote vegetative growth at the expense of the relative allocation of dry matter to the grain. Analysis of the interaction between cultivar and fertilization level revealed the highest individual value of the harvest index in the 'Bohooth 70' cultivar, reaching 45.62% at 200 kg ha^{1}, 44.49% at 100 kg ha^{1}, and 44.62% at 0 kg ha^{1}, with no significant differences between these levels. This demonstrates the stability of this cultivar in its dry matter distribution efficiency, regardless of the phosphate fertilization level. This stability is due to its high physiological efficiency in nutrient filling and transport processes within the plant. The Lilo cultivar showed the highest value of the harvest index at the 0 kg ha-1 level, which reached 43.22%, while the values decreased at 100 kg ha-1 to 33.27%, and then to 31.16% at 200 kg ha-1, indicating that the increase in the phosphorus level led to a relativd eecrease in the efficiency of converting dry matter into grains in this cultivar, and this is likely due to an increase in vegetative growth at the expense of reproductive components, which is consistent with what [13] indicated, that high levels of phosphorus may promote vegetative growth and affect thd eistribution of photosynthetic products.

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The Giza cultivar recorded values of 37.13% at 0 kg ha¹, 33.12% at 100 kg ha ¹, and 32.45% at 200 kg ha ¹, while the J cultivar recorded its highest value at 35.46% at 200 kg ha ¹, compared to 35.15% at 100 kg ha¹ and 29.96% at 0 kg ha¹. This indicates that cultivars respond differently to phosphorus levels depending on their genetic capacity to utilize nutrients and achieve a balance between vegetative growth and economic yield, as confirmed by [10,11] . In general, the harvest index does not depend solely on increased phosphate fertilization, but is primarily determined by the interaction between the cultivar's genetic makeup and the appropriate fertilization level.

Table (6) Effect of the interaction between Sorghum cultivars and phosphate fertilization levels (kg ha-1) on the harvest index %

cultivars	**Phosphorus levels**			**average cultivars**
	0 kg.ha^{-1}	100 kg.ha^{-1}	200 kg.ha^{-1}	
Lilo	43.22 a	33.27 c d e	31.16 f e	35.88 b
Giza	37.13 b	33.12 c d e	32.45 f d e	34.23 b c
J	29.96 f	35.15 b c d	35.49 b c	33.53 c
Bohooth 70	44.62 a	44.49 a	45.62 a	44.91 a
Average fertilizer	38.73 a	36.51 a	36.18 b	37.14

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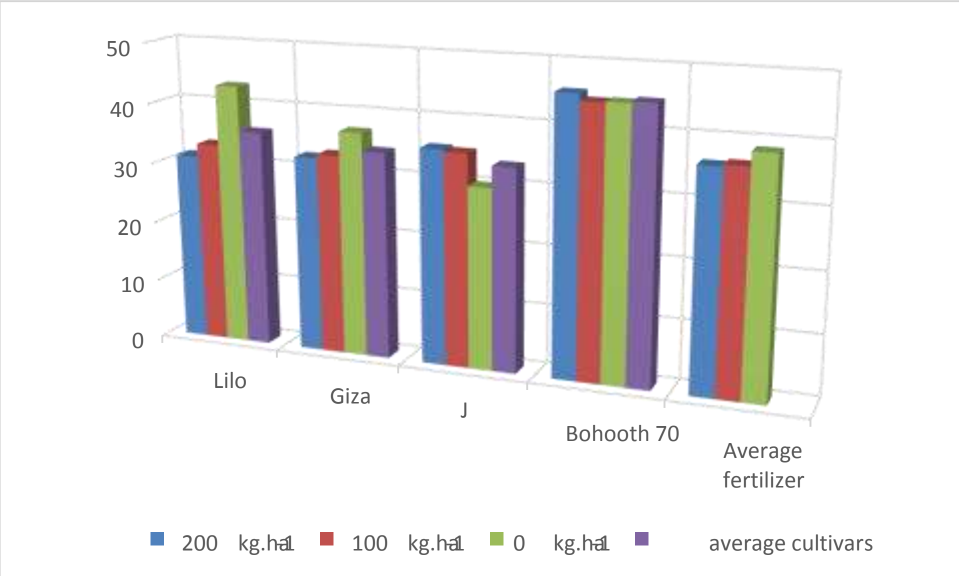

Figure (4): This figure shows the effect of the interaction between sorghum cultivars and different

phosphorus fertilization levels (0, 100, and 200 kg ha^{-1}) on the harvest index (%).

Conclusions .

- Phosphate fertilization significantly
- level registering the highest productivity compared to the no-phosphate treatment.

- Grain yield components (number of grains per head) improved with increasing phosphorus levels, indicating the role of phosphorus in promoting reproductive growth and increasing fruit set efficiency.

- Higher phosphorus levels led to an increase in the number of

increased dry grain yield, with the 200 kg ha¹

grains but a decrease in individual grain weight (500 grains), due to competition among grains for photosynthetic products.

- Cultivars showed significant differences in grain yield and its components, as follows:

- The Lilo cultivar had the highest grain yield. Bohooth 70 cultivar had the highest grain number and

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harvest index, while the Giza cultivar was the least productive.

- Bohooth 70 cultivar recorded the highest phosphorus utilization efficiency, especially at the higher phosphorus level, indicating a high genetic capacity for nutrient utilization. 6. A high phosphorus level did not consistently lead to an increase in the harvest index, as a decrease was sometimes observed due to increased vegetative growth at the expense of grain yield.
- 7. The interaction between cultivars and phosphorus levels had a significant effect, confirming that crop responsd eepends on the compatibility between cultivar and fertilization level.
- Recommendations
- It is recommended to use phosphate
fertilization at a rate of 200 kg ha¹ to increase grain yield in Sorghum grown in gypsum soils.
- Planting Bohooth 70 or Lilo cultivars is preferabld eue to their superior grain yield and efficient response to phosphate fertilization.
- It is essential to achieve a balance in phosphate fertilization to avoid increasing the number of grains at the expense of grain weight and to obtain the best possible yield.
- Adopting integrated fertilization programs (phosphorus + other elements) is necessary to improve nutrient utilization efficiency and increase production.
- Conduct future studies on:
- Higher or different levels of phosphorus

• Integrated fertilization (NP) or (NPK)

• Evaluate performance under different environmental conditions

6. Focus on selecting the appropriate cultivar with the appropriate fertilizer level as a key factor in increasing grain productivity.

Conclusion

The results of this study show that phosphate fertilization is a key factor in improving the productivity of cereal Sorghum grown in gypsum soils. It led to a significant increase in grain yield and its components, particularly the number of grains per head. The highest yield was achieved at a level of 200 kg ha ¹, reflecting the vital role of phosphorus in promoting the physiological processes associated with grain formation and filling.

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The results also showed a clear variation among cultivars in their response to phosphate fertilization. Some cultivars excelled others in grain yield and others in yield components, indicating the importance of genetic makeup in determining nutrient utilization efficiency. The interaction between cultivar and fertilization level also demonstrated that achieving maximum productivity depends not only on fertilization but also on selecting the appropriate cultivar with the correct fertilizer level.

Although increasing phosphorus levels improved grain count, it led to a relativd eecrease in grain weight, indicating the need for balanced fertilization management to ensure optimal nutrient distribution within the plant. Therefore, improving Sorghum productivity in gypsum soils requires integrated strategies that include selecting high-yielding cultivars and applying appropriate phosphate fertilization levels to achieve maximum productivity and agricultural sustainability.

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