

Effect of different levels of phosphate and potassium fertilizer on the growth and yield of sorghum (*Sorghum bicolor* L.)

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Abstract

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In Al-Bandar experimental field in Al-Muthanna Governorate, a field experiment was conducted in the spring of 2020 and 2021. The purpose of the research is to determine how much phosphate and potassium fertilizers affect the yield of sorghum and its constituent parts. The experiment was conducted using the Caviar variety and the RCBD with three replications. The experiment consisted of four fertilizer amounts: 0, 30, 60, and 120 kg K ha⁻¹ for potassium and 0, 40, and 80 kg P ha⁻¹ for phosphate. Following the arrival of the plant at 75% flowering, ten plants were randomly chosen from the test units, together with the subsequent parameters were measured: plant height, the index of leaf area, the yield of dry fodder (dry matter), the quantity of grains within each panicle, 1000 grains (g) and yield ton ha⁻¹. The results indicate that the potassium fertilization treatment exceeded 120 kg ha⁻¹ kg K ha⁻¹ in plant height 162.64–162.75 cm, stem diameter 12.77–12.59 mm, dry feed weight 13.29–12.77 tons ha⁻¹, green fodder weight 27.18–27.01 tons/ha, and several grains per head 2055.67 And 2134 grains, grain yield of 5.56 and 5.78 tons ha⁻¹, the fertilization treatment exceeded 80 kg P ha⁻¹ in plant height 177.44–177.11 cm, stem diameter 12.90–13.07 mm, dry feed weight 11.80–11.38 tons h⁻¹, and green fodder weight 25.94–25.87 tons ha⁻¹ The number of grains per head is 2063.25 and 2096.75 grains, and the grain yields are 5.73 and 5.82 tons ha⁻¹, respectively, in both seasons.

Keywords: sorghum; potassium; phosphate; yield

Introduction

Finding unconventional biofuel supplies, such as next-generation bioenergy crops, is one of the world's most pressing issues today. Sorghum (*Sorghum bicolor* (L.) Moench) is an economically viable crop that can adapt to a wide range of agroclimatic conditions and is a potential source of bioenergy. In addition to generating grain, sorghum aggregates sugar in its stem. This grain crop is becoming increasingly important in the global agricultural industry, as it can be used to produce a range of products, including chemical and biofuels, food, fuel, fiber, and feed. Leading tropical crop sorghum has more genes and a larger genome than sugarcane, the crop that holds the

most promise for producing biomass as efficiently as possible and serving as the world's leading source of ethanol. (Paterson et al., 2009). Short growth time, high Brix (%), high biomass output, and low water need (4000 m³/ha), as well as greater adaptability, are key criteria that draw extra attention to this bioenergy crop for scientific research (Reddy et al., 2005). Sorghum output has increased with phosphate fertilization; nevertheless, there are limited studies on the relationship between phosphorus (P) sources and effective fertilizer management in sorghum production. (Restelatto et al., 2017). A significant response of Sorghum to potassium is also reported by Sharma and Ramna (1993). In water-stress conditions, potassium affects sorghum's general parameters (Sharma and Ku-

mari, 1996). The different cultivars may exhibit independent responses to environmental factors (Alhassan et al., 2008). The purpose of this research is to investigate how different potassium and phosphate fertilizer levels affect sorghum and its component yields.

Materials and Methods

To investigate the impact of potassium and phosphate fertilizers on sorghum growth and yield, a field experiment was conducted in the Al-Muthanna Governorate (Al-Bandar region), southern Iraq, during the 2020 and 2021 seasons. Table 1 displays the physical and chemical characteristics of the soil. The RCBD was utilized in the experiment. The aim of this research is to Knowledge of effect Potassium and Phosphate Fertilizers on growth and feed yield of corn with three replications that included four levels of potassium fertilizer which are 0, 30, 60 and 120 kg K ha⁻¹ and three levels of phosphate fertilizer 0, 40, 80 kg P ha⁻¹. The experimental unit included four meadows, length of 4 m, the distance between one mower and another 0.75 cm, and between one seed and another 20 cm. Three seeds were planted in one jar, and after germination, only one plant remained in the jar. Fertilizer was added, 46% urea, at 200 kg ha⁻¹, with two batches, the first at planting and the second after 45 days of planting, and phosphate fertilizer when preparing the land in the form of triple superphosphate (Al-Tahir et al., 2013). Ten plants were randomly selected from the experimental units. Upon the arrival of the plant at 75% flowering, the following characteristics were measured, including plant height, leaf area index (leaf length * width * 0.75) according to Stickler et al. (1961), the average biomass yield (dry matter) (t ha⁻¹) from the harvest of one marrow. When the plants reached maturity (as indicated by yellowing), ten plants were randomly selected, including the number of seeds per panicle, the average weight of 1000 grains (g), and the grain yield. The Genstat 12 software was used to evaluate the data statistically.

Results and Discussion

Plant height (cm)

Results of Table 2 indicated was a significant of adding phosphorus in the characteristic of plant height and for the

two seasons 2021-2020, as the treatment P3 gave the highest average of plant height and for the two seasons, 171.54 cm and 169.86 cm, respectively, with an increase of 9.8 and 24.96% over control treatment, treatment P2 came In the second place, with an increase of 10.86 and 23%, compared to the control treatment that gave the lowest mean of plant height 137.27, 138.09 cm respectively. P impacts on the balance of phytohormones must be taken into consideration when interpreting the effects of P application on plant growth and development (Marschner, 1986). Accordingly, shoot development is a result of elevated cytokinin compared to auxin levels (Fosket, 1994). P supply has an impact on cytokinin synthesis and export, albeit less so than when N applications are involved (Salama and Wareing, 1979). The low levels of endogenous cytokinins in birch seedlings under conditions of nitrogen and phosphorus deficiency suggest that the availability of these growth regulators under these conditions may limit average growth rates (Horgan and Wareing, 1980). Zones of rapid cell division are associated with both primary and secondary growth (Taiz and Zeiger, 1991), and cytokinin has been proposed as a potential primary hormone for plant cell division (Fosket, 1994). By combining the study's findings with those from other studies, we can speculate that P's effect on plant height may be cytokinin-mediated. These findings support the findings of Al-Tahir et al. (2013) and Elmedani (1997), which indicate that plant height increases with increasing phosphate fertilizer levels.

As for the addition of potassium fertilizer, an increase in plant height was observed, with a significant difference, as the treatment K4 and K3 gave the highest average of plant height of 162.75 and 153.68 cm, respectively, compared with the control treatment that gave the lowest average of plant height of 146.80 cm, and the average of increase to 6.23 and 11 63% in the first season and 10.86% 6.18% in the second season of the treatments k3 and k4 for the control treatment sequentially The reason for the increase in plant height with the increase in the potassium level is attributed to the role of potassium in activating the photosynthesis process, increasing the division of living cells of the plant and encouraging the growth of meristematic tissues. The results showed a significant superiority of phosphorus over potassium treatments, resulting in a notable increase in plant height.

Table 1. Some physical and chemical characteristics of the soil of the experiment field in Al Bandar station (Al-Muthanna Governoaverage)

Soil structure			K	P	N	EC(ds.m)	PH	Season
Sand, %	Clay, %	Silt, %						
38	24.82	38	0.75	8.12	18	4.5	8.1	2014
37.3	24	39	0.9	8	16	4.45	7.72	2015

Table 2. Effect of phosphate and potassium fertilizer levels on plant height (cm) and for the two seasons 2020-2021

Season	2020				2021			
plant height (cm)	P1	P2	P3	means	P1	P2	P3	Means
K1	132.66	143.54	160.86	145.69	133.96	146.67	159.76	146.80
K2	136.76	146.50	165.60	149.62	135.09	149.83	162.97	149.30
K3	136.27	150.64	177.44	154.78	137.90	152.64	177.11	155.88
K4	143.40	162.24	182.27	162.64	145.40	163.24	179.60	162.75
means	137.27	150.73	171.54	153.18	138.09	153.10	169.86	153.68
L.s.d 0.05	K	P	K*P		K	P	K*P	
	3.492**	3.024**	6.04*		4.32**	3.74**	7.49*	

Stem diameter (mm)

The results of Table 3 indicated that there were significant differences in the characteristic of the stem diameter, as the addition of phosphorous led to a significant increase of both seasons, as the treatment P3 gave the highest average stem diameter of 12.9 and 13.09 mm respectively for the two seasons, with an increase of 21.92 and 21.24% with the control treatment. It gave the lowest average of 10.58 and 10.78 mm, respectively. It also caused an increase in the averages of potassium addition to an increase in the diameter of the stem, with a significant difference, as the treatment K4 and K3 gave the highest average of stem diameter was 12.77 and 11.77 mm respectively in the first season, compared to the control treatment that gave 10.68 As for the second season, treatment K4 and K2 outperformed and gave 12.59 and 12.03 mm, respectively, compared with the control treatment that gave 11.03 mm. The growth of the meristematic tissue and thus the increase in the diameter of the stem is consistent with (Al-Bourky et al), as the results of the analysis showed that there was no significant overlap between phosphorus and potassium treatments in the characteristic of stem diameter in the first season, while significant differences appeared. The effect of the interaction of phosphorus and potassium treatments in the second season may indicate the interconnection of these two elements in plant growth.

Dry Feed Weight (ton h⁻¹)

It is evident from Table 4 that there are significant differences

in the average weight of dry feed with an increase in phosphorous levels, as the treatment exceeded P3 and gave 11.80 and 11.38 (tons. h⁻¹) for the two seasons respectively, and an increase of which was compared to the control treatment P0, which gave the lowest average of 10.58 and 9.57 (tons. h⁻¹) This is in agreement with the findings of Cobb et al. (2016) and Erasmo and Petilli (1997); Abdelhalim et al. (2019) that the addition of phosphorus led to an increase in the weight of the dry feed, that the increase in potassium levels led to a significant increase in the weight of the dry feed and outperformed the treatment K3. In the quality of dry fodder, it gave the highest mean of 13.29 and 12.38 tons. ha⁻¹ for both seasons, respectively, with an increase of % compared with the control treatment that gave the lowest average of 9.36 and 8.78 (tons. ha⁻¹). The growth in stem diameter and height is the cause of the rise in dry plant fodder's weight. The analysis's findings regarding the effect of potassium for both seasons and the interaction revealed a substantial overlap between the phosphorus and potassium treatments, which significantly raised the feed's dry weight.

Green fodder (ton h⁻¹)

The results of Table 5 indicate that there are significant differences in the average weight of green fodder with an increase in phosphorus levels, as the treatment P3 outperformed the green fodder for both seasons and gave 25.91 and 25.87 tons. h⁻¹, respectively, compared with the control treatment that gave the lowest average of 24.09 and 24.23

Table 3. Effect phosphate and potassium fertilizer levels on stem diameter (mm) and for the two seasons 2018-2019

Season	2020				2021			
Stem Diameter	P1	P2	P3	Means	P1	P2	P3	Means
K1	9.38	10.68	11.97	10.68	9.71	11.01	12.38	11.03
K2	9.94	11.57	13.11	11.54	10.27	11.86	13.95	12.03
K3	11.33	11.39	12.59	11.77	11.91	11.37	12.20	11.83
K4	11.65	12.76	13.91	12.77	11.24	12.77	13.75	12.59
means	10.58	11.60	12.90	11.69	10.78	11.75	13.07	11.87
L.s.d 0.05	K	P	K*P		K	P	K*P	
	1.261*	1.092**	Ns		0.732**	0.634**	1.268*	

Table 4. The effect of phosphate and potassium fertilizer levels on dry feed weight (tons h⁻¹) and for the two seasons 2020–2021

Season	2020				2021			
The dry weight of the feed	P1	P2	P3	Means	P1	P2	P3	Means
K1	8.69	9.46	9.94	9.36	8.37	8.83	8.96	8.72
K2	9.09	9.95	10.55	9.86	9.09	9.48	9.89	9.49
K3	11.73	11.73	12.47	11.98	10.11	11.89	12.81	11.60
K4	12.82	12.82	14.23	13.29	10.69	12.59	13.85	12.38
means	10.58	10.99	11.80	11.12	9.57	10.70	11.38	10.55
L.s.d 0.05	K	P	K*P		K	P	K*P	
	0.42**	0.36**	0.73*		0.187**	0.162**	0.325**	

tons. h⁻¹, respectively, and this is consistent with what was found Phosphorous is involved in most of the vital processes of plants, including the breakdown of carbohydrates and other substances Resulting from photosynthesis to release the energy needed for biological processes and in the formation of cell membranes Plant membranes such as plasma membranes, mitochondria, chloroplasts, and gap membranes by forming phospholipids such as lecithin. It also contributes to the formation of DNA (Important in the process of Ribonucleic acid, RNA), carrying the genotypes and Deoxyribonucleic acid, Protein composition, and the composition of some energy-rich compounds, such as Adenosine triphosphate (ATP). Energy is formed as a result of photosynthesis by photophosphorylation

To breathe in the process of oxidative phosphorylation and NADPH₂, which gives an estimated energy of about 52 000 calories. Mole- (Amandeep, 2012). The addition of potassium fertilizer also increased the weight of green fodder, with a significant difference, as the treatment exceeded K4 for both seasons, yielding 27.18 and 27.01 tons. ha⁻¹ compared to the control treatment, which gave the lowest average. It was 22.39 and 23.03 tons. ha⁻¹, respectively. The increase in the average green fodder weight may be attributed to the increase in the efficiency of the photosynthesis process, the manufacture of foodstuffs and their storage in the

shoots, as well as the stimulation of many enzymes that lead to an increase in the resulting shoots. Adding potassium fertilizer is consistent with what Mutlag et al., (2015) found. As for the overlap, the effect of phosphorus and potassium was significant in the weight of green fodder for both seasons.

Number of grains per panicle¹

The results of Table 6 indicate that there are significant differences in the characteristic of the number of pills per panicle when adding levels of phosphorus, as the treatment exceeded P2 and P3 and gave the highest averages of 1931.75 and 2063.25 in the first season 2002.75 and 2096.75 for the second season, respectively, with an increase of 36.18 and 45.45% in the first season 52.73 and 59.9% in the second season. The increase in the number of grains in the panicle may be attributed to the positive effect of phosphorus on increasing growth characteristics, which leads to an increase in the efficiency of photosynthesis and the production of its products, thereby preparing the emerging grains to meet the requirements of processed food, which contributes significantly. It is effective in its durability and fullness, as well as its impact on increasing the percentage of fertility in flowers. Ali et al., (2007) and Dar et al., (2018) also found that the addition of phosphorus significantly increased the number of grains in the spike of the wheat crop.

Table 5. The effect of phosphate and potassium fertilizer levels on green fodder weight (tons ha⁻¹) and for the two seasons 2020–2021

Season	2020				2021			
Green fodder	P1	P2	P3	Means	P1	P2	P3	Means
K1	21.48	22.12	23.56	22.39	22.39	22.80	23.89	23.03
K2	23.26	23.97	24.34	23.86	23.26	23.66	23.70	23.54
K3	25.43	26.42	27.40	26.42	25.43	26.42	27.39	26.41
K4	26.19	27.02	28.33	27.18	25.84	26.70	28.50	27.01
means	24.09	24.88	25.91	24.96	24.23	24.90	25.87	25.00
L.s.d 0.05	K	P	K*P		K	P	K*P	
	0.56**	0.49**	Ns		0.29**	0.25**	0.51**	

Table 6. The effect of phosphate and potassium fertilizer levels on the number of grains (head) and for the two seasons 2020–2021

Season	2020				2021			
Number of grains	P1	P2	P3	Means	P1	P2	P3	Means
K1	1272.00	1767.00	1919.00	1652.67	1306.00	1800.00	1953.00	1686.33
K2	1066.00	1953.00	1956.00	1658.33	678.00	2004.00	1989.00	1557.00
K3	1539.00	1994.00	2021.00	1851.33	1430.00	2027.00	2054.00	1837.00
K4	1797.00	2013.00	2357.00	2055.67	1831.00	2180.00	2391.00	2134.00
means	1418.50	1931.75	2063.25	1804.50	1311.25	2002.75	2096.75	1803.58
L.s.d 0.05	K	P	K*P		K	P	K*P	
	259**	224.3**	Ns		300**	322**	Ns	

The results of Table 6 indicated that the increase in potassium levels had a significant effect on the number of pills in the panicle. The treatment exceeded K3 and K4, as it yielded 1851.33 and 2055.67, respectively, in the first season, and resulted in increases of 12.02% and 24.38%, respectively, in the first season, with additional increases of 8.9% and 26.54%. This may be attributed to the direct effect of potassium in controlling plant hormones related to flower formation, pollination, and fertilization, which is consistent with findings by Al-Maghribi (2004) and Al-Ani (2011).

Weight of 1000 grains (g)

It is noticed from the results of Table 7 that there is a significant effect only in the first season of phosphate fertilization, as treatment P3 outperformed both treatments P2 and P1, reaching 24.96 g, with an increase of 3.2%, and no significant differences appeared in the second season, and this is consistent with Gemenet et al. (2016). As for the potassium fertilization treatment, there were no significant differences in the weight of 1000 grains in both seasons. Regarding the interaction between phosphorus and potassium levels, the 1000 tablets did not yield significant results.

Grain yield (tons h⁻¹)

Table 8 shows that there were significant differences in the grain yield with an increase in phosphorus levels, as the treatment exceeded P3 and gave 5.73 and 5.82 tons. h⁻¹ for the two seasons, respectively, compared with the control treatment P0, which gave the lowest average of 4.46 and 4.75 tons. h⁻¹. The reason for the increase in grain yield was the increase in phosphate fertilizer levels, which increased the number of grains in the panicle and the weight of 1000 grains. This finding is consistent with those of Abu et al. (1990), Al-Khafaji et al. (2000); Al-Fahdawi et al. (2008), which also indicate a significant increase. In the yield of cereals and for different crops, increasing phosphorus from 0 to 52 kg P ha⁻¹.

The results of Table 8 indicated that the addition of potassium fertilizer led to a significant increase in the yield of grains, as the treatment exceeded K4 and K3 and gave the highest average of 5.56 and 5.47 tons. ha⁻¹, respectively, compared with the control treatment that gave the lowest averages of 4.51 and 4.62 tons. ha⁻¹ respectively, that the increase in the level of potassium addition led to an increase in the grain yield due to the positive role of potassium in increasing the leaf area, the number of panicle grains and the weight of the grain, and it was positively reflected in the

Table 7. The effect of phosphate and potassium fertilizer levels on the weight of 1000 grains (g) and for the two seasons 2020–2021

Season	2020				2021			
Weight of 1000 grains	P1	P2	P3	Means	P1	P2	P3	Means
K1	23.89	24.70	25.44	24.68	23.55	24.39	25.17	24.37
K2	24.89	25.04	24.59	24.84	24.52	24.63	24.64	24.60
K3	23.70	24.25	24.63	24.19	24.63	24.68	25.04	24.78
K4	24.19	24.56	25.16	24.64	24.61	24.74	25.34	24.90
means	24.17	24.64	24.96	24.59	24.33	24.61	25.05	24.66
L.s.d 0.05	K	P	K*P		K	P	K*P	
	ns	0.522*	ns		Ns	ns	ns	

Table 8. The effect of phosphate and potassium fertilizer levels on grain yield (tons h⁻¹) and for the two seasons 2020-2021

Season	2020				2021			
Grain yield	P1	P2	P3	Means	P1	P2	P3	Means
K1	4.20	4.42	4.91	4.51	4.34	4.55	4.97	4.62
K2	4.25	5.06	5.69	5.00	4.42	4.83	5.83	5.03
K3	4.70	5.55	6.16	5.47	5.14	5.68	6.02	5.61
K4	4.68	5.83	6.17	5.56	5.12	6.02	6.47	5.87
means	4.46	5.22	5.73	5.14	4.75	5.27	5.82	5.28
L.s.d 0.05	K	P	K*P		K	P	K*P	
	0.44**	0.38**	ns		0.516**	0.44**	ns	

increase in the grain yield per unit area, and this is consistent with the findings (Al-rawi and Al-Dulaimi, 2023).

Conclusion

In this study, phosphate and potassium fertilizers have been shown to have positive effects on growth characteristics. The increase in levels of both fertilizers in both seasons led to an increase in plant height, stem diameter, and dry feed weight. At reproductive stages, phosphate and Potassium led to a significant response and superiority in terms of number of grains per panicle, weight of 1000 grains, and grain yield. The effect of both fertilizers had a highly significant effect on feed, increasing both dry feed weight and green feed weight. That showed how important it is to use compound fertilizers with phosphate and potassium to get maximum benefit and enhance the growth of corn.

References

- Abdelhalim, T. S., Kamal, N. M. & Hassan, A. B. (2019). Nutritional potential of wild sorghum: Grain quality of Sudanese wild sorghum genotypes (*Sorghum bicolor* L. Moench). *Food Sci. Nutr.*, 7(4), 1529 – 1539.
- Abu, D., Youssef, M. & Al-Younes, M. A. (1990). Plant Nutrition Guide. Ministry of Higher Education and Scientific Research. University of Baghdad. *Mosul University Press*, Iraq.
- Al-Bourky, R. H., Mahmoud, M. R. & Ali, S. T. (2021). Effect of spraying with nano silica and water salinity levels on growth and yield of wheat. *IOP Conference Series: Earth and Environmental Science*, 923(1), 012058. doi: 10.1088/1755-1315/923/1/012058.
- Al-Ani, A. A. S. (2011). Effect of zinc foliar and potassium fertilizer on growth, yield, and quality of two cultivars of Sorghum (*Sorghum bicolor* L. Moench) (M.Sc. thesis). College of Agriculture, Anbar University.
- Alhassan, U., Yeye M. Y., Aba, D. A. & Alabi, S. O. (2008). Correlation and path coefficient analyses for agronomic and malting quality traits in some sorghum (*Sorghum bicolor* (L.) Moench) genotypes. *Journal of Food, Agriculture and Environment.*, 6(3&4), 285 – 288.
- Ali, M. A., Jabran, K., Awan, S. I., Abbas, A., Zulkiffal, M., Acet, T. & Rehman, A. (2007). Morpho-physiological diversity and its implications for improving drought tolerance in grain sorghum at different growth stages. *Australian Journal of Crop Science*, 5(3), 311 – 320.
- Al-Maghribi, N. M. H. (2004). *The effect of potassium and phosphate fertilizer on growth and production of Sorghum bicolor L. Moench irrigated with different water salinity* (Ph.D. dissertation). Department of Soil, College of Agriculture, University of Baghdad.
- Al-Khafaji, A A, Hammadi, K. B. & Fayyad, N. M. (2000). The effect of adding foamy sulfur on the growth and yield of maize (*Zea mays* L.) in calcareous sedimentary soil. *Iraqi Agricultural Sciences Journal*, 31(1), 17 – 26.
- Al-rawi, M. B. N. & Al-Dulaimi, O. I. M. (2023). Effect of Potassium Silicate Spray and Water Stress on Yield and Yield Components of Sorghum. In: *IOP Conference Series: Earth and Environmental Science*, 1252(1), 012028. *IOP Publishing*.
- Al-Tahir, Faisal, M., Al-Refai, Sh. I. & Hashem, Kh. I. (2013). Performance of sorghum genotype under dry Iraqi conditions. *Association of Agricultural Technology in Southeast Asia*. Bangkok, 633 – 642.
- Amandeep, S. (2012). Forage quality of sorghum (*Sorghum bicolor*) as influenced by irrigation, N levels, and harvesting stage. *Indian Journal of Science Research*, 3(2), 67 – 72.
- Al-Fahdawi, W A S T. (2008). Effect of Levels of Agricultural Sulfur and Compound Fertilizer DAP on Grain Yield and Its Components of Sorghum. Master Thesis. Baghdad University. College of Agriculture, Department of Field Crops.
- Cobb, A. B., Wilson, G. W. T., Goad, C. L., Bean, S. R., Kaufman, R. C. & Herald, T. J. (2016). The role of arbuscular mycorrhizal fungi in grain production and nutrition of sorghum genotypes: enhancing sustainability through plant-microbial partnership. *Agric. Ecosyst. Environ.*, 233, 432 – 440. doi: 10.1016/j.agee.2016.09.024.
- Erasmio, E. A. L. & Pitelli, R. A. (1997). Effects of the application of fertilizer with phosphorus in the relationship between Sorghum and purple nutsedge. *I. Initial growing. Planta daninha*, 15(2), 114 – 121.
- Elmedani, Y. H. E. (1997). The effect of phosphate rocks, triple super phosphate and their combinations on the performance of *Sorghum bicolor* var. *dura* (L.) x sorghum Sudanese (piper) (stapf)[Sudan].
- Fosket, D. E. (1994). Plant growth and development: A molecular

- approach. University of California Academic Press, Irvin, 694.
- Gemenet, D. C., Leiser, W. L., Beggi, F., Herrmann, L. H., Vadez, V., Rattunde, H. F., Weltzien, E., Hash, C. T., Buerkert, A. & Haussmann, B. I.** (2016). Overcoming phosphorus deficiency in west African pearl millet and sorghum production systems: promising options for crop improvement. *Front. Plant Sci.*, 7, 1389. doi: 10.3389/fpls.2016.01389.
- Horgan, J. M. & Wareing, P. F.** (1980). Cytokinins and the growth responses of seedlings of *Betula pendula* Roth, and *Acer pseudoplatanus* L. to nitrogen and phosphorus deficiency. *Journal of Experimental Botany*, 31, 525 – 532.
- Dar, R. A., Dar, E. A., Kaur, A. & Phutela, U. G.** (2018). Sweet sorghum-a promising alternative feedstock for biofuel production. *Renew. Sust. Energ. Rev.*, 82, 4070 – 4090. doi: 10.1016/j.rser.2017.10.066.
- Marschner, H.** (1986). *Mineral Nutrition Of Higher Plants*. University of Adelaide, Academic Press, London, 694.
- Mutlag, N. A., Kadhum, F. A. & Saleem, Q. A.** (2015). Effect of deficit irrigation and potassium fertilizer on grain yield of sorghum. *The Iraqi Journal of Agricultural Sciences*, 46(5), 247 – 257.
- Paterson, A., Bowers, J. & Bruggmann, R.** (2009). *The Sorghum bicolor genome and the diversification of grasses*. *Nature*, 457, 551 – 556. <https://doi.org/10.1038/nature07723>.
- Reddy, B. V. S., Ramesh, S., Sanjana Reddy, P. & Ramaiah, B.** (2005). Sweet sorghum: A potential alternative raw material for bioethanol and bioenergy. *International Sorghum and Millets Newsletter*, 46, 79 – 86.
- Restelatto, R., Menezes, L. F. G. de, Paris, W., Sartor, L. R., Martin, T. N., Herrera, W. F. B. & Pavinato, P. S.** (2017). Sorghum and black oat forage production and its nutritive value under phosphate levels. *Revista Semina: Ciências Agrárias*, 38, 429 – 442.
- Salama, A. M. S. E.-D. & Wareing, P. F.** (1979). Effects of mineral nutrition on endogenous cytokinins in plants of sunflower (*Helianthus annuus* L.). *Journal of Experimental Botany*, 30, 971 – 981.
- Sharma, P. S. & Ramna, S.** (1993). Response of sorghum to nitrogen and potassium in Alfisol. *J. Potash. Res.*, 9(27), 171 – 175.
- Sharma, P. S. & Kumari, T. S.** (1996). Effect of potassium under water stress on growth and yield of sorghum in Vertisol. *J. Potash. Res.*, 12(3), 319 – 325.
- Stickler, F. C., Wearden, S. & Pauli, A. W.** (1961). Leaf area determination in grain sorghum 1. *Agronomy Journal*, 53(3), 187 – 188.
- Taiz, L. & Zeiger, E.** (1991). *Plant physiology: Mineral nutrition*. The Benjamin Cummings Publishing Co., Inc. Redwood City, 100 – 119.

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