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The investigation of nitrogen, phosphorus, and potassium fertilizer on the productivity of various *Sorghum bicolor* varieties

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Abstract. *Handayanta E, Barido FH, Samanhudi. 2024. The investigation of nitrogen, phosphorus, and potassium fertilizer on the productivity of various* Sorghum bicolor *varieties. Biodiversitas 25: 2763-2768.* Sorghum (*Sorghum bicolor* L. Moench) is a unique cereal crop characterized by its regenerative capacity post-harvest, with varieties including Super, Suri, Numbu, and Keller. This investigation sought to elucidate the impact of varying fertilizer levels on the forage productivity of these sorghum varieties. The experiment employed was a Completely Randomized Design (CRD) with a 4×5 factorial arrangement and three replications. The first factor comprised the sorghum varieties (V1 = Super, V2 = Suri, V3 = Numbu, V4 = Keller), while the second factor pertained to the levels of NPK fertilizer (P0 = 0 kg/ha, P1 = 173 kg/ha, P2 = 346 kg/ha, P3 = 519 kg/ha, P4 = 692 kg/ha). Data were subjected to Analysis of Variance (ANOVA), and significant differences were further analyzed using the Duncan Multiple Range Test (DMRT). The study concluded that while there was no interaction between the sorghum variety and NPK fertilization levels, the sorghum variety significantly influenced ($P<0.05$) protein and crude fat production but not dry matter and crude fiber production ($P>0.05$). The NPK fertilization levels significantly affected ($P<0.05$) the production of dry matter, protein, fat, and crude fiber. The study deduced that a 692 kg/ha fertilization dose yielded the highest dry matter, protein content, crude fat, and crude fiber production.

Keywords: Fertilizer, plant production, proximate, sorghum

INTRODUCTION

Sorghum has been long cultivated as an alternative food or feed source globally. This versatile grain crop species from the Poaceae family, under the subfamily of Panicoideae possesses an outstanding adaptability mechanism, allowing them to grow well in harsh conditions and extreme climatic environments (Borrell et al. 2021). The genus of sorghum which also widely known as broomcorn, durra, great millet, milo, or guinea corn encompasses 25 acknowledged species, though certain classifications propose as many as 32 species. These species are found in diverse regions such as Australia, the Pacific Islands, Southeast Asia, East Asia, South Asia, and Africa. The main cultivated species, *Sorghum bicolor* L. Moench, is accompanied with the high protein content at 10-12%, good source of essential minerals, like the potassium, calcium, iron, magnesium, and abundant in vitamin E, B complex, and antioxidants (Masenya et al. 2021). Various sorghum species can reach 2.4 meters in tall, wherein in each of large bushy flowerheads can contain more than 3,000 seeds. Wide varieties of this *S. bicolor* are reportedly capable of withstanding waterlogging, limited soil nutrition, and resistance against parasites. Thus, up to date, numerous studies suggested this plan to be incorporated as a staple feed source in the livestock industry (Tonapi et al. 2020; Masenya et al. 2021).

Fertilization constitutes a fundamental aspect of horticultural practices, primarily aimed at rectifying deficiencies in essential macronutrients, namely Nitrogen (N), Phosphorus (P), and Potassium (K). These elements are indispensable for plant growth and development. However, the primary challenge hindering optimal growth and yield in cultivated plants is the limited availability of NPK in the soil (Khaitov and Abdiev 2018). Consequently, the application of supplemental fertilizers becomes a necessity in crop cultivation. Given the escalating global food demand, it is postulated that an increase in fertilizer application rates is imperative (Samanhudi et al. 2017). The fertilizer is mainly utilized in that so-called low-diminished soil fertility. The NPK are essential nutrition to majorly support and optimize the quantity and quality of sorghum production. The N is vital nutrition and a building block for plant growth, mainly composed of amino acids, proteins, chlorophyll, and nucleic acids. Adequate N compounds within the soil stimulate vigorous vegetative growth, such as leaf development, stem elongation, and overall plant expansion (Mardhikasari et al. 2020).

Proper N management directly impacts sorghum output and grain quality, while the inadequacy of N causes stunted growth and lower grain yields (Leghari et al. 2016). Another essential element, phosphorus, plays an important function in cell energy transfer. It is a component of Adenosine Triphosphate (ATP), the plant's energy currency. The adequate P quantity promotes robust root development, which improves nutrient uptake and water absorption that consequently affect the floral and seed development, grain size, seed vigor, and overall reproductive performance. Phosphorus promotes stress tolerance, allowing sorghum to resist harsh conditions such as drought and low soil fertility (Lambers 2022). Another essential element, potassium, generally known as K, is mainly required for the growth and development of sorghum. This element is essential in osmosis regulation, maintains cell stiffness, and helps the plant stand upright. In addition, the K helps transport water within plant cells, impacts all metabolic processes and plant development, and promotes nutrition movement from roots to different regions of the plant. A previous study reported that potassium helps produce high-quality sorghum grains, thus resulting in an increased harvest yield (Tittal et al. 2021).

Diminished soil fertility, attributable to nutrient exhaustion and land degradation, significantly impedes Indonesia's agricultural productivity. The soil quality in cultivated lands is witnessing consistent degradation due to shortened fallow periods and inefficient utilization of inputs (Nugroho et al. 2017). The primary factors contributing to this deterioration in soil fertility include nutrient depletion, extended periods of cultivation, suboptimal management of crop residues, and reduced crop rotation. A significant proportion of semi-arid soils in Indonesia exhibit severe deficiencies in plant nutrients, specifically in bioavailable phosphorus, total nitrogen, and organic carbon, all of which fall into the low category. Consequently, there is a notable decline in crop production rate (Sebnie et al. 2020).

Moreover, “micro-dosing" refers to applying minimal quantities of fertilizer during planting or as a top dressing around three to four weeks post-emergence. This method is advantageous in reducing input and investment costs while enhancing yields and fertilizer use efficiency. The strategic placement of the fertilizer, approximately 5 cm adjacent to the seeds, ensures a high uptake rate, thereby making it an efficient mode of fertilizer administration (Permana et al. 2018). When juxtaposed with traditional application techniques such as basal application and top dressing, micro-dosing of fertilizers has been observed to augment double yields and increase farmers' income by 52% to 134%, according to Sebnie et al. (2020). Up to date, studies on the incorporation effect of NPK fertilizer on various sorghum species are scarce. Buah et al. (2012) suggested that the NPK did increment on production yield of *S. bicolor* at the range of 47-69%. Besides, Hussein and Alva (2014) elaborated that the incorporation of high NPK concentration significantly releases the sorghum from drought stress, thus increasing the plant biomass in a significant matter. Nevertheless, prior studies were limited by the utilization of single species, and there were no specific studies that investigated the chemical composition of various sorghum species after NPK fertilizer treatments. Therefore, according to the above premises, this study aimed to investigate the impact of applying NPK fertilizer on the various sorghum varieties, including Super, Suri, Numbu, and Keller.

MATERIALS AND METHODS

Sample preparation

The research was carried out in the geographical confines of Cabeyan Village, Bendosari Sub-district, Sukoharjo District, Indonesia with an average temperature of ± 28°C and relative humidity of ± 77%, and concurrently at the Animal Feed and Nutrition Laboratory of the Study Program of Animal Husbandry, Faculty of Agriculture, Universitas Sebelas Maret, Surakarta, Central Java, Indonesia, conducting from April to September 2022. The investigative materials incorporated sweet sorghum varieties, namely Super, Suri, Numbu, and Keller, in conjunction with NPK fertilizer (Phonska, Indonesia), supplemented by a fundamental compost fertilizer based on the protocol by Buah et al. (2012). The instrumental apparatus employed in this study comprised hoes and machetes for tillage, along with a comprehensive set of laboratory equipment designed for proximate analysis to ascertain nutrient content.

The research methodology employed a Completely Randomized Design (CRD) with a factorial pattern of 4×5 and was replicated thrice. The first factor encompassed the variety of sorghum, which included V1 = Super variety, V2 = Suri variety, V3 = Numbu variety, and V4 = Keller variety. The second factor pertained to the levels of NPK fertilizer, which included P0 = 0 kg/ha, P1 = 173 kg/ha, P2 = 346 kg/ha, P3 = 519 kg/ha, and P4 = 692 kg/ha. Meanwhile, the research process was divided into several stages: land preparation, planting, thinning and stitching, fertilization, irrigation, weed control (weeding), Control of Plant-Disturbing Organisms (CPO), an act of control to diminish the disturbance effect that caused by organism. The CPO can be conducted through various methods, namely pest and pathogens management, soil solarization, targeted plant removal, and forecasting attacks. It was then followed by harvesting and conducting the proximate analysis.

Land and plant preparation

The land preparation involved the removal of weeds, hoeing, and bed formation. Planting was conducted using a 60×20 cm spacing with four seeds per planting hole. A basic fertilizer in the form of chicken manure was applied at the onset of planting, followed by compound NPK fertilizer 30 days post-planting (HST). Thinning involved retaining one plant per planting hole, and replanting was conducted if the seeds exhibited abnormal growth or mortality. Irrigation was performed every three days using a trench inundation system. Weed and OPT control was executed both mechanically and chemically. Harvesting was conducted when the flag leaves turned yellow, and the seeds hardened (sorghum at 90 HST).

Proximate composition

The determination of proximate composition from various sorghum samples was according to the Association of Official Analytical Chemists (AOAC) (AOAC 2012). The moisture percentage was recorded from 1 g sample after oven drying at 105°C for 24 hours. Crude protein content was measured according to the Kjeltec system procedure (2200 Kjeltec Auto Distillation Unit, Foss, Hillerød, Denmark). Crude fat was extracted by the Soxhlet extraction method for 48 hours, and the crude ash content was obtained after burning in a muffle furnace (LEF-115S, Daihan Labtech Co., Ltd., Namyangju, Korea) at 550°C. All analyses were performed in triplicate.

Statistical analysis

The data procured were subjected to rigorous analysis utilizing R version 3.6.1 (The R-foundation for Statistical Computing, Vienna, Austria), specifically employing a two-way analysis of variance methodology. The boundary for statistical significance was established at a p-value of 0.05. Subsequently, the statistical significances of each group were perpetually evaluated through the application of Duncan's multiple-range tests. This comprehensive approach ensured a robust and thorough examination of the data.

RESULTS AND DISCUSSION

Production of dry matter

The conducted research, which encompassed four types of sorghum verity and four distinct fertilizer treatments, primarily focused on dry matter production, revealed no interaction between the two factors under consideration, namely the variety of sorghum and fertilizer types. The production of dry matter was not contingent on the variety of the plant but was significantly influenced by the application of fertilizer. This effect was observed across all types of sorghum, irrespective of the variety, as the variety primarily affected the plant's nutrient absorption capacity. Temeche et al. (2021) stated applying fertilizer at the appropriate dosage can lead to high, optimal, and efficient production. As indicated in Table 1, the range of dry matter production was between 1,368.73 kg/ha and 2,579.44 kg/ha. Temeche et al. (2021) elaborated that an appropriate dose of fertilizers can produce around 2.62 tons of dry matter per hectare. This yield can be attributed to some cultivated land containing minimal nutrients.

As per the data in Table 1, the Super variety of sorghum demonstrated the highest dry matter production, with an average yield reaching 2,322.42 kg/ha. The factorial pattern analysis of variance, as depicted in Table 1, indicated that the factor of plant variety did not significantly influence ($P>0.05$) the dry matter content. This could be attributed to the relatively uniform plant root nutrient absorption across different treatments, resulting in a consistent response across various varieties. The nutrients absorbed by the plants, supplied by the soil via the roots, are typically assimilated as negative and positive ions, which are generally bound to soil complexes.

As indicated in Table 1, the P4 fertilizer dosage (692 kg/ha) exhibited the most pronounced effect, with an average dry matter production of 2,579.44 kg/ha. The application of NPK fertilizer factors significantly influenced ($P<0.05$) the dry matter content. The control treatment without fertilizer application (P0) significantly differed from the P1-P4 fertilizer treatments. This substantiates that NPK fertilizer can enhance sorghum dry matter production. However, there was no significant difference in the increase observed with applying P1-P4 levels of NPK fertilizer. Regardless of the level of fertilizer added, the results remained consistent and insignificant due to the propensity of elements such as nitrogen, phosphorus, and potassium to be easily leached into the soil. Consequently, the nutrient content in the soil remains constant despite an increase in fertilizer. Additionally, leaching, a process where a nutrient is lost from the soil due to excess water, results in the nutrient being dissolved or washed away from the soil (O'Connor et al. 2021). The leaching of certain nutrients from the soil leads to plants not receiving adequate nutrients, disrupting growth, photosynthesis, starch, and protein synthesis (Alkharabsheh et al. 2021).

Production of crude protein

The study revealed no interaction between the variety factor and the fertilizer factor; applying fertilizers did not influence crude protein production in sorghum plant varieties. This can be attributed to different plant varieties' distinct characteristics resulting from diverse genotypes (Johansson et al. 2020; Swarup et al. 2021). In terms of nutrient absorption from the soil, the application of increased doses of fertilizer will yield consistent results if the absorption properties of the plants remain the same; as per the research findings in Table 2, crude protein production ranged from 80.99 to 165.96 kg/ha.

The data presented in Table 2 indicates that the Keller variety (V4) exhibited the highest crude protein production, averaging 156.76 kg/ha. However, this output was not significantly different from the Super, Suri, and Nmbu varieties. A factorial pattern analysis of variance revealed that plant variety factors significantly influenced ($P<0.05$) the crude protein content. Interestingly, no significant difference was observed in the characteristics of the Numbu (V3) and Super (V1) sorghum varieties. However, these two varieties significantly differed from the Suri (V1) and Keller (V4) varieties. The latter two varieties exhibited similar characteristics. It is mentioned that these two sorghum varieties are one of the most cultivated sorghum types with heights ranging from around 200 cm and leaf counts of around 12. These characteristics distinguished them from the Nmbu and Super varieties. Baye et al. (2022) posited that the genetic factors of sorghum are key determinants of plant growth and yield. Consequently, the genes in each sorghum plant seed of different varieties will result in distinct plant appearances. These differences can potentially influence the growth and quality of sorghum crops, underscoring the importance of genetic diversity in crop production and its potential impact on yield and quality.

Table 1. Dry matter production of sorghum (kg/ha)

Variety	Treatment					Average
	0 kg/ha	173 kg/ha	346 kg/ha	519 kg/ha	692 kg/ha	
Super	1215.91	2478.23	2765.09	2498.57	2654.30	2322.42 ^{ns}
Suri	1388.52	2241.95	1878.08	2309.84	2649.68	2093.62 ^{ns}
Numbu	1411.10	2517.14	1913.50	1839.01	2533.96	2042.94 ^{ns}
Keller	1459.40	2163.87	2407.40	2647.88	2479.81	2231.67 ^{ns}
Average	1368.73 ^{a}	2350.30 ^{b}	2241.02 ^{b}	2323.83 ^{b}	2579.44 ^{b}	

Note: ^{a,b} different superskripts in the same column shows a significant difference (P<0.05); ^{ns} (non-significant) *P-value*: <0.05

Table 2. Crude protein production of sorghum (kg/ha)

Variety	Treatment					Average
	0 kg/ha	173 kg/ha	346 kg/ha	519 kg/ha	692 kg/ha	
Super	61.45	135.86	151.59	136.98	145.52	126.28 ^{a}
Suri	98.44	164.41	137.73	169.39	194.31	152.86 ^{b}
Numbu	65.63	147.77	112.34	107.96	148.76	116.49 ^{a}
Keller	98.42	152.91	170.12	187.12	175.24	156.76 ^{b}
Average	80.99 ^{a}	150.24 ^{b}	142.95 ^{b}	150.36 ^{b}	165.96 ^{b}	

Note: ^{a,b,} different superscripts in the same row and column show significant differences (P<0.05); ^{ns} (non-significant) *P-value*: <0.05

Table 3. Crude fat production of sorghum (kg/ha)

Variety	Treatment					Average
	0 kg/ha	173 kg/ha	346 kg/ha	519 kg/ha	692 kg/ha	
Super	29.13	72.89	81.33	73.49	78.07	66.98 ^{b}
Suri	24.94	52.44	43.93	54.03	61.98	47.47 ^{a}
Numbu	33.40	74.03	56.28	54.09	74.53	58.47 ^{b}
Keller	26.70	52.46	58.36	64.19	60.12	52.36 ^{a}
Average	28.54 ^{a}	62.96 ^{b}	59.98 ^{b}	61.45 ^{b}	68.67 ^{b}	

Note: ^{a,b,} different superscripts in the same row and column show significant differences (P<0.05); ^{ns} (non significant) *P-value*: <0.05

Table 2 reveals that the P4 fertilizer dose (692 kg/ha) had the most pronounced effect, with an average dry matter production of 165.96 kg/ha. The application of NPK fertilizer also significantly influenced (P<0.05) crude protein production. Interestingly, the control treatment without fertilizer (P0) significantly differed from those with P1-P4 treatments. However, no significant difference was observed between the P1-P4 treatments. This suggests that while the absence of fertilizer has a noticeable impact, the variations in fertilizer types (P1-P4) do not significantly alter the outcome. Ahmed et al. (2020) noted that plants absorb nitrogen from fertilizers as nitrate, easily leached by rainwater, irrigation water, and sprinkling. Consequently, regardless of the quantity of fertilizer added, the nitrogen content attached to the soil does not increase. This highlights the challenges of nutrient retention in soil and the importance of efficient fertilizer management strategies.

Production of crude fat

The research analysis yielded intriguing findings regarding the interplay between the variety and fertilizer factors. It was observed that there was no interaction between these two factors in the production of crude fat. This suggests that the genetic influences inherent in different varieties predominantly determine the production of crude fat, irrespective of the application and increase in the fertilizer level administered. This is because fertilizers universally provide nutrients to the soil, influencing plant growth and development across all varieties. Therefore, their impact on crude fat production appears minimal compared to the genetic factors. Table 3 further corroborates this, showing that the production of crude fat from the four sorghum varieties under different fertilization levels ranged from 28.54 to 68.67 kg/ha. This underscores the importance of genetic diversity in crop production and its potential impact on yield and quality.

Table 3 shows the 'Super' variety exhibited the maximum crude fat yield, averaging 66.98 kg/ha. The factorial pattern analysis of variance, as outlined in the same table, indicates a significant influence (P<0.05) of the plant variety on the crude fat yield. The 'Keller' (V4) and 'Suri' (V2) varieties demonstrated a distinctly higher crude fat percentage compared to the 'Nambu' (V3) and ‘Super' (V1) varieties. This discrepancy can be attributed to the higher stem and leaf production in the V3 and 'Super' varieties instead of the 'Super' and 'Suri' varieties. The fat content in plants is subject to variation based on the plant species, sunlight intensity and duration, and nutrient availability (Briat et al. 2020; Pant et al. 2021). Therefore, plant type and environmental factors contribute to the crude fat yield.

According to the data in Table 3, applying P4 fertilizer at a dose of 692 kg/ha resulted in the highest crude fat yield, averaging 68.67 kg/ha. Therefore, applying NPK fertilizers also had a significant impact (P<0.05) on the production of crude fat. The table illustrates that there was no significant difference in the crude fat yield with the increase in the levels of P1-P4 NPK fertilizers; however, the control group without fertilizer application (P0) showed a significant difference compared to the P1-P4 fertilizer treatments. This can be attributed to the varying plants' abilities to absorb nutrients from the soil and the soil's capacity to retain nutrients from rainwater and irrigation. Chen et al. (2020) support this observation, stating that during the vegetative phase, plants generate more than they consume. The surplus assimilation is stored in the vegetative part as a reserve compound. Therefore, applying NPK fertilizers enhances leaf production, increasing fat yield from photosynthesis.

Table 4. Crude fiber production of sorghum (kg/ha)

Variety	Treatment					Average
	0 kg/ha	173 kg/ha	346 kg/ha	519 kg/ha	692 kg/ha	
Super	560.63	1268.27	1415.08	1278.68	1358.38	1176.21 ^{ns}
Suri	648.53	1232.42	1032.39	1269.74	1456.55	1127.93 ^{ns}
Numbu	684.67	1302.99	990.52	951.96	1311.69	1048.37 ^{ns}
Keller	756.40	1285.20	1429.85	1572.68	1472.85	1303.40 ^{ns}
Average	662.56 ^{a}	1272.22 ^{b}	1216.96 ^{b}	1268.27 ^{b}	1399.87 ^{b}	

Note: ^{a,b,} different superscripts in the same row and column show significant differences ($P<0.05$); ^{ns} (non-significant) *P-value*: <0.05

Production of crude fiber

As depicted in Table 4, the study findings indicate that the interplay between varietal factors and fertilizer application does not significantly influence crude fiber production. This is primarily because the impact of fertilizer application on crude fiber yield remains consistent across different varieties. The research data reveals that the crude fiber yield from the four examined sorghum varieties, under varying fertilization levels, ranged between 662.56 kg/ha and 1,399.87 kg/ha. This suggests that the crude fiber production is more likely to be influenced by the fertilization levels rather than the varietal differences.

As indicated in Table 4, the 'Keller' variety demonstrated the maximum crude fiber yield, with an average production reaching 1,303.40 kg/ha. The factorial pattern analysis of variance revealed that the plant variety factors did not significantly influence ($P>0.05$) the crude fiber yield. This can be attributed to the genetic characteristics of the sorghum plants, which exhibit relative uniformity in crude fiber production. The nutrient absorption by the plants, facilitated by the soil through the roots, occurs in the form of both negative and positive ions; these ions are typically associated with complex ions in the soil. Therefore, crude fiber production is more likely influenced by the soil's nutrient content rather than the plant variety.

Table 4 revealed that applying P4 fertilizer at a dosage of 692 kg/ha exhibited the most pronounced impact, with an average crude fiber yield of 1,399.87 kg/ha. The factorial influence of NPK fertilizer application was significant ($P<0.05$) on the production of crude fiber. Despite the absence of a significant difference in the increasing P1-P4 NPK fertilizer levels, a marked distinction was observed between the control treatment (P0) without fertilizer application and the P1-P4 fertilizer treatments. Nitrogen, absorbed by plants from fertilizers in the form of nitrate, is susceptible to leaching by rainwater, irrigation water, and sprinkling, thereby rendering the nitrogen content in the soil invariant irrespective of the quantity of fertilizer added. Clauw et al. (2024) posited that as plants mature, particularly during the generative phase, the stem-to-leaf ratio increases, diminishing food value. With the progression of plant age, there is a decrease in protein, mineral, and soluble carbohydrate content while the crude fiber and lignin content increase. This is attributed to the secretion of secondary cell walls by the protoplasm post cessation of cell growth, with the xylem serving as a plant support. The protoplasm and its contents dissipate following the secretion of cell walls, leaving behind only the cell walls. In essence, plant maturity is associated with increased cell wall thickness. The application of NPK fertilizers enhances the growth of sorghum, thereby increasing the fiber content therein (McGinnis and Painter 2020).

The study concluded upon careful examination of the research findings, it can be inferred that there is no discernible interaction between the factors of forage sorghum varieties and the NPK fertilizer application levels. The specific sorghum variety and the extent of fertilizer application predominantly influence the productivity of forage sorghum. The administration of fertilizer at a dosage of 692 kg/ha has culminated in producing dry matter, crude protein, fat, and crude fiber, which tended to be the highest across all sorghum varieties. This underscores the pivotal role of appropriate fertilizer application in optimizing the yield of crucial components in forage sorghum.

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REFERENCES

Ahmed M, Rauf M, Akhtar M, Mukhtar Z, Saeed NA. 2020. Hazards of nitrogen fertilizers and ways to reduce nitrate accumulation in crop plants. Environ Sci Pollut Res Intl 27 (15): 17661-17670. DOI: 10.1007/s11356-020-08236-y.

Alkharabsheh HM, Seleiman MF, Battaglia ML, Shami A, Jalal RS, Alhammad BA, Almutairi KF, Al-Saif AM. 2021. Biochar and its broad impacts in soil quality and fertility, nutrient leaching and crop productivity: A review. Agronomy 11 (5): 993. DOI: 10.3390/agronomy11050993.

AOAC. 2012. Official Method of Analysis: Association of Analytical Chemists. 19th Edition, Washington DC.

Baye W, Xie Q, Xie P. 2022. Genetic architecture of grain yield-related traits in sorghum and maize. Intl J Mol Sci 23 (5): 2405. DOI: 10.3390/ijms23052405.

Borrell A, van Oosterom E, George-Jaeggli B, Rodriguez D, Eyre J, Jordan DJ, Mace E, Singh V, Vadez V, Bell M, Godwin ID, Cruickshank A, Tao Y, Hammer GL. 2021. Sorghum. Crop Physiology Case Histories for Major Crops: 196-221. Academic Press. DOI: 10.1016/B978-0-12-819194-1.00005-0.

Briat J-F, Gojon A, Plassard C, Rouached H, Lemaire G. 2020. Reappraisal of the central role of soil nutrient availability in nutrient management in light of recent advances in plant nutrition at crop and molecular levels. Eur J Agron 116: 126069. DOI: 10.1016/j.eja.2020.126069.

Buah SSJ, Kombiok JM, Abatania LK. 2012. Grain sorghum response to NPK fertilizer in the Guinea Savanna of Ghana. J Crop Improv 26 (1): 101-115. DOI: 10.1080/15427528.2011.61.
Chen KE, Chen HY, Tseng CS, Tsay YF. 2020. Improving nitrogen use efficiency by manipulating nitrate remobilization in plants. Nat Plants 6 (9): 1126-1135. DOI: 10.1038/s41477-020-00758-0.
Clauw H, Van de Put H, Sghaier A, Kerkaert T, Debonne E, Eeckhout M, Steppe K. 2024. The impact of a six-hour light–dark cycle on wheat ear emergence, grain yield, and flour quality in future plant-growing systems. Foods 13 (5): 750. DOI: 10.3390/foods13050750.
Hussein MM, Alva AK. 2014. Growth, yield and water use efficiency of forage sorghum as affected by NPK fertilizer and deficit irrigation. Am J Plant Sci 5: 2134-2140. DOI: 10.4236/ajps.2014.513225.
Johansson E, Branlard G, Cuniberti M, Flagella Z, Hüsken A, Nurit E, Peña RJ, Sissons M, Vazquez D. 2020. Genotypic and environmental effects on wheat technological and nutritional quality. In: Igrejas G, Ikeda TM, Guzmán C (eds). Wheat Quality for Improving Processing and Human Health. Springer International Publishing, Cham, Switzerland. DOI: 10.1007/978-3-030-34163-3_8.
Khaitov B, Abdiev A. 2018. Performance of chickpea (*Cicer arietinum* L.) to bio-fertilizer and nitrogen application in arid condition. J Plant Nutr 41 (15): 1980-1987. DOI: 10.1080/01904167.2018.1484134.
Lambers H. 2022. Phosphorus acquisition and utilization in plants. Annu Rev Plant Biol 73: 17-42. DOI: 10.1146/annurev-arplant-102720-125738.
Leghari SJ, Wahocho NA, Laghari GM, Laghari AH, Bhabhan GM, Talpur KH, Ahmed T, Wahocho SA, Lashari AA. 2016. Role of nitrogen for plant growth and development: A review. Adv Environ Biol 10 (9): 209-218.
Mardhikasari S, Yunus A, Samanhudi. 2020. Modification of media for banana *in vitro* propagation with foliar fertilizer and coconut water in CV. Rajabulu. Caraka Tani: J Sustain Agric 35 (1): 23-32. DOI: 10.20961/carakatani.v35i1.27756.
Masenya K, Thompson GD, Tekere M, Makhalanyane TP, Pierneef RE, Rees DJ. 2021. Pathogen infection influences a distinct microbial community composition in sorghum RILs. Plant Soil 463: 555-572. DOI: 10.1007/s11104-021-04875-3.
McGinnis MJ, Painter JE. 2020. Sorghum: History, use, and health benefits. Nutr Today 55 (1): 38-44. DOI: 10.1097/NT.0000000000000391.
Nugroho PA, Widyastuti Y, Samanhudi, Yunus A. 2017. Growth response of *Artemisia annua* by effect of types and composition of organic fertilizer in lowland. J Agric Sci Technol 7 (5): 339-345. DOI: 10.17265/2161-6264/2017.05.006.
O'Connor J, Hoang SA, Bradney L, Dutta S, Xiong X, Tsang DCW, Ramadass K, Vinu A, Kirkham MB, Bolan NS. 2021. A review on the valorisation of food waste as a nutrient source and soil amendment. Environ Pollut 272: 115985. DOI: 10.1016/j.envpol.2020.115985.
Pant P, Pandey S, Dall'Acqua S. 2021. The influence of environmental conditions on secondary metabolites in medicinal plants: A literature review. Chem Biodivers 18 (11): e2100345. DOI: 10.1002/cbdv.202100345.
Permana HH, Widyastuti Y, Samanhudi, Yunus A. 2018. Response of *Artemisia annua* L. to shade and manure fertilizer application in lowland altitude. IOP Conf Ser: Earth Environ Sci 142: 012043. DOI: 10.1088/1755-1315/142/1/012043.
Samanhudi, Pujiasmanto B, Yunus A, Supyani, Suntoro, Widijanto H, Prabowo SM. 2017. The effect of manure and mycorrhiza application to the soil microbes biodiversity in terms of increasing soybean yield in marginal land in Indonesia. Bulg J Agric Sci 23 (6): 994-1003.
Sebnie W, Mengesha M, Girmay G, Feyisa T, Asgedom B, Beza G, Dejene D. 2020. Evaluation of micro-dosing fertilizer application on sorghum (*Sorghum bicholor* L) production at Wag-Lasta Areas of Amhara Region, Ethiopia. Sci Rep 10 (1): 6889. DOI: 10.1038/s41598-020-63851-6.
Swarup S, Cargill EJ, Crosby K, Flagel L, Kniskern J, Glenn KC. 2021. Genetic diversity is indispensable for plant breeding to improve crops. Crop Sci 61 (2): 839-852. DOI: 10.1002/csc2.20377.
Temeche D, Getachew E, Hailu G. 2021. Effects of nitrogen fertilizer quantity and time of application on sorghum (*Sorghum bicolor* L.) moench) production in lowland areas of North Shewa, Ethiopia. Intl J Agron 2021 (1): 3019528. DOI: 10.1155/2021/3019528.
Tittal M, Mir RA, Jatav KS, Agarwal RM. 2021. Supplementation of potassium alleviates water stress-induced changes in *Sorghum bicolor* L. Physiol Plant 172 (2): 1149-1161. DOI: 10.1111/ppl.13306.
Tonapi VA, Talwar HS, Are AK, Bhat BV, Reddy CR, Dalton TJ. 2020. Sorghum in the 21st Century: Food, Fodder, Feed, Fuel for a Rapidly Changing World. Springer, Singapore. DOI: 10.1007/978-981-15-8249-3.