Journal of Tropical Crop Science Vol. 13 No. 2, June 2026
www.j-tropical-crops.com

Received 1/28/2025; Revised 11/24/2025; Accepted 5/5/2026
https://doi.org/10.29244/jtcs.13.02.335-349

Optimizing Potassium Fertilization for Precision Nutrition: Effects on Growth, Physiology, and Seed Potassium Content of Two Soybean Varieties

Ratu Fatkhunnisa[1], Supijatno*[2], and Edi Santosa[2]

[1] Agronomy and Horticulture Study Program, Graduate School, IPB University, Indonesia
[2] Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University, Indonesia

*Corresponding author; email: supijatno@yahoo.com

Abstract

Potassium is an essential macronutrient that supports major physiological processes in plants and strongly influences soybean productivity. This study aimed to evaluate the effects of different potassium fertilization levels on plant physiology, yield performance, and seed nutritional composition in two soybean varieties, ‘Dena 1’ and ‘Denasa 1’.The research employed a factorial completely randomized group design with five potassium fertilizer levels (0, 15, 30, 45, and 60 kg K_2O/ha) and two soybean varieties (‘Dena 1’ and ‘Denasa 1’), with three replications. The results showed that the potassium dose significantly affected plant height and leaf number but did not influence photosynthetic rate or stomatal conductance. The ‘Dena 1’ variety exhibited better growth, greater leaf greenness, and faster generative development than ‘Denasa 1’. The optimal potassium dose of 45 kg/ha improved yield components, resulting in a 30.7% increase in seed weight and a 45.8% increase in the number of filled pods compared with the control. A positive correlation was found between plant potassium content and key physiological traits, such as photosynthesis and transpiration rates. Seed nutrition analysis showed that soybean varieties significantly influenced nitrogen and phosphorus levels at the R7 and R8 stages, whereas the potassium fertilization dose had no significant effect on seed nutrient concentrations. Nutrient levels increased from R6 to R7 before declining at R8, reflecting nutrient redistribution during seed filling. Overall, the results suggest that applying 45 kg K_2O/ha is an effective fertilization rate for enhancing soybean physiological performance and yield, while varietal characteristics remain the primary factor shaping seed nutritional composition.

Keywords: growth, potassium fertilizer, physiology, soybean, yield optimization

Introduction

Precision nutrition focuses on how individuals respond differently to food and nutrients, enabling the development of personalized, evidence-based dietary recommendations to prevent and manage chronic diseases (Stover & King, 2020; Toro-Martin et al., 2017). In clinical contexts, this approach is particularly important for chronic kidney disease , where regulating specific nutrient intake—especially potassium—is crucial for improving clinical outcomes. Potassium disorders are one of the most common electrolyte abnormalities in patients with chronic kidney disease, and maintaining serum potassium within the normal range is essential for patient stability. Furthermore, dietary potassium restriction remains a core strategy for managing chronic hyperkalemia (Sumida et al., 2023). Given this, understanding potassium levels in plant-based foods is increasingly relevant, as soybeans are an important dietary source of potassium and may require careful assessment in CKD dietary planning.

Soybeans are globally recognized as a

Received 1/28/2025; Revised 11/24/2025; Accepted 5/5/2026
https://doi.org/10.29244/jtcs.13.02.335-349

nutritionally important crop due to their high protein content, essential amino acids, and healthy lipids, making them a major source of plant-based protein for humans. Beyond their importance to human nutrition, soybean seed productivity and quality are strongly influenced by the availability of soil potassium. In agricultural practice, potassium is an essential macronutrient required by plants to support various physiological and biochemical processes. Although it does not have a structural role in plant metabolism, potassium functions as an enzyme activator critical for protein synthesis, carbohydrate metabolism, and the regulation of cellular osmotic pressure (Cui & Tcherkez, 2021). Additionally, potassium contributes to starch formation and translocation, regulates stomatal opening and closing, and enhances photosynthesis efficiency (Xu et al., 2020). These roles are vital for supporting the growth, development, and productivity of soybean seeds. Root epithelial and cortical cells take up K^+ from soil solution through mass flow and diffusion (Volf et al., 2018). Plant root cells absorb potassium ions (K^+) from the soil, against a concentration gradient across the plasma membrane of root cells. K^+ transporters facilitate high-affinity K^+ uptake when K^+ concentrations are low, while K^+ channels assist low-affinity K^+ uptake at high K^+ concentrations (Maathuis, 2009). K^+ ions are transported into root cells and subsequently pass through the endodermis and into the xylem parenchyma. K^+ channels and transporters located on the plasma membrane of parenchyma cells mediate the loading (release) of K^+ into the xylem, where K^+ ions are transported upward toward the plant shoots (Gaymard et al., 1998).

Given the importance of potassium for soybean growth, understanding how potassium fertilization impacts seed quality and yield become essential for optimizing agricultural productivity. Past studies have consistently shown that Potassium application in soybeans enhances plant growth and yield. Applying potassium at a rate of 150 kg/ha increased seed yield by 29.6% compared to lower doses. Additionally, a dose of 109 kg/ha was more economically viable in soybean cultivation (Batista et al., 2020). The results of Khan et al. (2023) showed that phosphorus and potassium fertilization at 80 kg/ha can increase seed production, plant height, chlorophyll content, crown and root mass, while fertilization above 100 kg/ha can reduce seed quality, thereby reducing yield. To further optimize potassium utilization, various agronomic approaches, including potassium fertilization, soil management, and high-yielding soybean varieties, have been explored to maximize crop performance. According to Ahmed et al. (2020), the application of potassium fertilizer increases potassium levels in soybean plant tissues, thereby improving growth and yield. Potassium promotes biomass accumulation and the distribution of essential nutrients among plant parts, including roots, green biomass, and seeds.

Despite these findings, existing research rarely addresses how potassium requirements differ among soybean varieties with distinct genetic backgrounds. Information on the optimum potassium dose for varieties such as ‘Dena 1’ and ‘Denasa 1’ remains limited. This creates a knowledge gap, especially since varietal responsiveness affects nutrient uptake efficiency and yield. Therefore, this study aims to evaluate the effects of different potassium fertilization levels on the growth, yield components, and seed potassium content of two soybean varieties, ‘Dena 1’ and ‘Denasa 1’, to determine their optimum potassium requirements.

Materials and Methods

The research was conducted from July to September 2024 at Cikabayan Experimental Station, IPB University, Bogor, West Java, Indonesia. The research used a factorial completely randomized block design. The first factor was the soybean variety (V): ‘Dena 1’ and ‘Denasa 1’. The second factor was the dose of potassium fertilizer (K) consisting of 5 treatment levels, 0 kg K_2O/ha (0 kg/ha KCl), 15 kg K_2O/ha (25 kg/ha KCl), 30 kg K_2O/ha (50 kg/ha KCl), 45 kg K_2O/ha (75 kg/ha KCl), 60 kg K_2O/ha (100 kg/ha KCl). Each treatment consisted of three

Received 1/28/2025; Revised 11/24/2025; Accepted 5/5/2026
https://doi.org/10.29244/jtcs.13.02.335-349

replications, yielding 30 experimental units in total. A total of 360 soybean plants were used in this experiment. Each experimental unit consisted of 12 plants, from which 6 representative plants were selected as samples for data collection

Experimental Procedures

Soil as planting media was packed into polybags in amounts of up to 8 kg. Polybags measuring 40 cm x 40 cm were used. Polybags were placed 25 cm apart. Carbofuran-containing pesticide (Furadan 3G®) was added at a rate of 0.2 g around the planting hole. The fertilizer dose given was 22.5 kg N/ha (equivalent to 50 kg Urea/ha or 0.22 g per polybag), 18 kg P_2O_5/ha (equivalent to 50 kg SP-36/ha or 0.56 g per polybag), and KCl fertilizer according to the treatment (Ministry of Agriculture Regulation, 2022). The potassium fertilization treatments consisted of 15 kg K_2O/ha (0.0835 g per polybag), 30 kg K_2O/ha (0.165 g per polybag), 45 kg K_2O/ha (0.250 g per polybag), and 60 kg K_2O/ha (0.335 g per polybag). The first fertilization was applied at planting time, consisting of half the recommended dose of urea and KCl, and the full dose of SP-36. The second fertilization was given when the plants are 25-30 days old or before flowering. Maintenance activities consist of replanting, watering, fertilizing, and pest and disease control. Pests and diseases were controlled with Regent 50SC (a.i. fipronil), and weeds were controlled with Agil 100EC (a.i. propaquizafop), following company recommendations. Harvesting was done after about 90% of the leaves had senesced or 95% of the pods had reached maturity, as indicated by dryness, by cutting the whole plant at the base of the stem.

Vegetative Phase

Soybean growth stages are described as R1 to R8, where R1 = Flowering begins at each node on the main stem, one flower blooms. R2 = Full bloom, which refers to flowering that occurs when the flower blooms on one of the first two leaves on the main stem. R3 = The initial pod formation of 3/16 inch long at one of the top four nodes with a fully developed trifoliate leaf. R4 = A fully developed pod, ¾ inch long, on one of the top four nodes with a fully developed trifoliate leaves. R5 = The pods are beginning to fill with seeds; 1/8-inch-long seeds can be found in the pods at one of the four top nodes, which have fully developed and have three leaves. R6 = A full green seed that fills the space inside the pod at one of the four top nodes, which has fully developed and has trifoliate leaves. R7 = Early maturity, when a typical pod on the main stem changes color to dark brown. R8 = Full maturity, when that 95% of the pods on the main stem have turned a deep brown color.

Plant height (cm), number of trifoliate leaves, and number of productive branches were measured on sample plants at 6 and 8 weeks after planting (WAP), representing the vegetative growth phase. Physiological parameters, including leaf greenness, photosynthesis rate, transpiration rate, and stomatal conductance. Leaf greenness was measured on the third leaf sample from the shoot and measured using the SPAD tool in the R2 phase (Proklamasiningsih et al., 2012). Photosynthesis rate, transpiration rate, and stomatal conductance were measured during the R2 phase using LI-COR 6400 on the third leaf from the shoot (Volf et al. 2022).

Nutrient Uptake

Analysis of N, P, K, Ca, and Mg levels in plants was conducted when 50% of soybean plants were in the R6 and R7 phases, and seed analysis was conducted during the R6, R7, and R8 phases. Determination of N levels using the Kjeldahl method, P by spectrophotometry, and K, Ca, Mg, and Na using AAS. Seed protein content was analyzed during the R6, R7, and R8 phases. Determination of total protein content by the semi-micro Kjeldahl method. Nutrient uptake of N, P, K, Ca, and Mg was calculated using the following formula:

$$\text{Nutrient uptake} = \frac{\text{nutrient content}}{100\%} \times \text{dry weight (g)}$$

Received 1/28/2025; Revised 11/24/2025; Accepted 5/5/2026
https://doi.org/10.29244/jtcs.13.02.335-349

Reproductive Phase

Yield components observed included flower emergence time (days), pod filling time (days), harvest time (days), productivity (ton/ha), number of filled pods, number of empty pods, root dry weight (g), crown dry weight (g), weight per 100 seeds (g), and seed weight per plant. Flowering time (days) is calculated as the number of days until 50% of the population has flowered. Pod filling time (days) is observed when pods on the main stem contain seeds measuring 2 mm x 1 mm. Harvest time (days) is observed when the pods are fully filled, and 95% have reached the color of fully ripe pods, which is blackish-brown. The number of filled and empty pods is determined after the plants have been harvested by separating and counting them. Root and crown dry weight (g) is observed by uprooting one non-sample plant in each experimental plot. Then, the plants were dried using an oven at 70 °C within 48 hr (Pratiwi & Artari, 2018). The weight per 100 seeds (g) was measured at harvest time by taking 100 seeds from the sample plants. Seed weight per plant was measured by weighing the seeds of each plant.

Data Analysis

Data were analyzed using analysis of variance (ANOVA) in SAS at the 5% significance level. If ANOVA showed significant differences, the analysis was continued with Duncan's multiple range test (DMRT) at α = 5%.

Results and Discussion

Plant Growth

Varietal differences had a significant effect on plant height and the number of trifoliate leaves. 'Dena 1' showed better growth than 'Denasa 1' (Table 1), which has a plant height of 41.98 cm, the number of leaves is 22.59, and the number of branches is 4.73. According to Yang et al. (2020), genetic and environmental factors, such as average day length, average maximum temperature, and pH, significantly affect soybean plant height traits.

The effect of potassium dose had no significant effect on plant height, number of trifoliate leaves, or number of productive branches. Increasing potassium fertilizer rates significantly increased plant height, number of leaves, and number of productive branches compared with 0 kg/ha. Silva and Uchida (2000) stated that the presence of potassium is very important for plant growth because potassium is known as an enzyme activator that drives metabolism. In addition, potassium-deficient plants will exhibit slow, stunted growth because potassium is required for photosynthesis and protein synthesis. The potassium fertilizer dose of 45 kg/ha produced the highest plant height at the age of 8 weeks (41.71 cm), the dose of 60 kg/ha produced the highest number of trifoliate leaves (20.13), and the dose of 30 kg/ha produced the highest number of productive branches (5.00). The results of research by Parveen et al. (2016) showed that a dose of 75 kg K^+/ha was more effective at reducing the negative impact of salinity at 6 dS/m, in both salt-tolerant and salt-sensitive soybean genotypes.

The interaction between variety and potassium fertilizer dose had no significant effect on the number of trifoliate leaves at 8 weeks of age (Table 2). 'Dena 1' and 'Denasa 1' varieties showed different responses to increasing doses of potassium fertilizer. In the 'Dena 1' variety, a potassium fertilizer dose of 30 kg/ha can give the highest number of trifoliate leaves of 26.50 leaves. On the other hand, the potassium fertilizer dose of 75 kg/ha produced the highest number of leaves on the 'Denasa 1' variety, which was 16.27 leaves. This shows that each variety has an optimal fertilizer dose that increases the number of trifoliate leaves. According to Hu et al. (2019), optimal nitrogen and potassium supply to plants leads to increased leaf area and net photosynthetic rate, thereby increasing crop yield.

Journal of Tropical Crop Science Vol. 13 No. 2, June 2026
www.j-tropical-crops.com
Received 1/28/2025; Revised 11/24/2025; Accepted 5/5/2026
https://doi.org/10.29244/jtcs.13.02.335-349

Table 1

Effects of Variety and Potassium Fertilizer on Plant Height, Number of Trifoliate Leaves, and Number of Productive Branches of Soybean Plants

Treatment	Plant height (cm)		Number of trifoliate leaves		Number of productive branches	
	6 WAP	8 WAP	6 WAP	8 WAP	6 WAP	8 WAP
Variety						
‘Dena 1’	30.65 a	41.98 a	14.09 a	22.59 a	3.41 a	4.73 a
‘Denasa 1’	24.24 b	32.27 b	10.55 b	13.88 b	3.39 a	4.60 a
Potassium fertilizer (kg/ha)						
0	25.21 b	32.78 c	10.90 b	14.33 c	2.92 c	4.27 c
15	28.06 a	34.65 c	12.00 ab	17.03 bc	3.08 abc	4.38 bc
30	27.53 a	38.22 b	12.37 ab	19.58 ab	3.47 ab	5.00 a
45	28.96 a	41.71 a	13.23 a	20.10 a	3.80 a	4.97 ab
60	27.46 a	38.27 b	13.10 ab	20.13 a	3.73 a	4.70 abc

Note. Values followed by different letters in the same column differ significantly according to the DMRT at α = 5%. WAP: weeks after planting.

Table 2

Effects of Interactions Between Variety and Potassium Fertilizer Dose on the Number of Trifoliate Leaves 8 Weeks After Planting

Variety	Potassium fertilizer (kg/ha)	Number of trifoliate leaves
‘Dena 1’	0	17.00 c
	15	21.00 b
	30	26.50 a
	45	23.93 ab
	60	25.20 a
‘Denasa 1’	0	11.67 d
	15	13.73 cd
	30	12.67 cd
	45	16.27 c
	60	15.07 cd

Note. Values followed by different letters in the same column differ significantly according to the DMRT at α = 5%.

Plant Physiology

The study on leaf greenness levels showed a significant effect on soybean varieties, whereas the potassium fertilizer dose did not. Variety ‘Dena 1’ has a higher level of leaf greenness, with a value of 42.00, compared to ‘Denasa 1’ variety (Table 3). This difference indicates that the ‘Dena 1’ variety has a better ability to produce and maintain chlorophyll, which plays an important role in photosynthesis and leaf brightness. In addition, the application of potassium fertilizer results in higher leaf greenness than does its absence. According to Meenakshi et al. (2023), potassium fertilization increases photosynthetic pigment levels and

Journal of Tropical Crop Science Vol. 13 No. 2, June 2026
www.j-tropical-crops.com

Received 1/28/2025; Revised 11/24/2025; Accepted 5/5/2026
https://doi.org/10.29244/jtcs.13.02.335-349

helps plants withstand drought stress.

Different varieties and doses of potassium fertilizer did not affect stomatal conductance, photosynthetic rate, and transpiration rate. However, potassium fertilizer can increase stomatal conductance, photosynthetic rate, and transpiration rate. Stomata regulate the uptake of CO_2 and H_2O via transpiration between plants and the atmosphere, playing an important role in the response to climate change (Haworth et al., 2021). The results of research by Wasaya et al. (2021), stated that the application of potassium to the leaves can increase the photosynthetic rate and chlorophyll content in corn, resulting in 10% higher grain yield.

Production and Yield

The treatment of the two varieties had no significant effect on flowering time, whereas pod filling and harvesting time were significantly affected. 'Dena 1' tends to take a faster time to flower, pod filling, and harvest, with times ranging from 33.73 DAP to 87.53 HST, while the 'Denasa 1' variety tends to take longer, at 34.53 DAP to 87.53 DAP (Table 4). This could be due to differences in physiological characteristics among varieties in their responses to nutrient availability and generative development. The dose of potassium fertilizer did not significantly affect flowering time, pod filling, or harvest. At a potassium fertilizer dose of 45 kg/ha, plants started flowering, and pod filling tended to be faster at 32.67 DAP and 53.17 DAP than at other doses. This shows that increasing the potassium fertilizer Dose to 45 kg/ha can accelerate flowering time and pod filling. According to Sharma et al. (2013), potassium plays an important role in regulating enzyme activity and stabilizing protein synthesis, which is particularly important during the early- to mid-seed-filling stage. Meanwhile, a potassium fertilizer Dose of 15 kg/ha tends to accelerate harvest time. At a potassium fertilizer Dose of 0 kg/ha, flowering, pod filling, and harvesting tended to be longer than in plants treated with potassium fertilizer.

The different varieties tested had a significant effect on productivity, seed weight per plant, and root dry weight. 'Dena 1' variety has the highest value for the variables of productivity (3.29 ton/ha), seed weight per plant (12.91 g), and root dry weight (2.20 g) (Table 5). The different doses of potassium fertilizer produced insignificant effects on all parameters. However, the 45 kg/ha dose of potassium fertilizer was significantly different from the 0 kg/ha Dose,

Table 3

Effect of Variety and Potassium Fertilizer on Leaf Greenness Value, Stomatal Conductance, Photosynthetic Rate, and Transpiration Rate in the R2 Phase

Treatment	Leaf greenness	Stomatal conductance ($mol\ H_2O/m^2/s^1$)	Photosynthetic rates ($\mu mol\ CO_2/m^2/s$)	Transpiration rates ($mmol\ H_2O/m^2/s$)
Variety				
'Dena 1'	42.00 a	0.29	10.82	0.0036
'Denasa 1'	40.11 b	0.30	13.45	0.0043
Potassium fertilizer (kg/ha)				
0	39.01 b	0.22	10.97	0.0030
15	41.23 a	0.27	10.37	0.0034
30	41.43 a	0.27	12.74	0.0040
45	41.94 a	0.43	14.38	0.0055
60	41.69 a	0.29	12.20	0.0039

Note. Values followed by different letters in the same column differ significantly according to the DMRT at α = 5%.

Received 1/28/2025; Revised 11/24/2025; Accepted 5/5/2026
https://doi.org/10.29244/jtcs.13.02.335-349

where the 45 kg/ha dose had the highest value for productivity (3.49 ton/ha), number of filled pods (31.33), seed weight per plant (13.95 g), and crown dry weight (7.17 g). According to Ahmed et al. (2020), potassium deficiency can reduce seed filling, possibly by impairing the translocation of sugars to growing parts of the plant, thereby decreasing yield.

The interaction between variety and potassium fertilizer dose had a significant effect on the variables: number of filled pods, weight of filled pods, seed weight per plant, and dry weight of stover (Figure 1). The combination treatment of the 'Denasa 1' variety with a potassium fertilizer dose of 45 kg/ha tended to have a high value for the number-of-filled-pods parameter (32.78). The combination treatment of the 'Dena 1' variety with a potassium fertilizer dose of 45 kg/ha tends to have high values for the parameters seed weight per plant (14.67 g) and crown dry weight

Table 4

Effects of Soybean Variety and Potassium Fertilizer on the Time to Flower, Time to Pod Filling Phase, and Time to Harvest

Treatment	Days to flowering phase (R1) (DAP)	Days to pod filling phase (R5) (DAP)	Days harvest (R8) (DAP)
Variety			
'Dena 1'	33.73 a	53.13 a	81.67 a
'Denasa 1'	34.53 a	54.87 b	87.53 b
Potassium fertilizer (kg/ha)			
0	35.00 a	55.00 a	85.33 a
15	34.50 ab	54.17 ab	83.83 c
30	34.50 ab	53.83 ab	84.33 bc
45	32.67 c	53.17 b	84.67 bc
60	34.00 b	53.83 ab	84.83 ab

Notes. Values followed by different letters in the same column differ significantly according to the DMRT at α = 5%. DAP = days after planting.

Table 5

Effect of Variety and Potassium Fertilizer on Soybean Yield Components

Treatment	Productivity (tons/ha)	Number of field pods	Number of empty pods	Seed weight per plant (g)	Weight of 100-seeds (g)	Shoot dry weight (g)	Root dry weight (g)
Variety							
'Dena 1'	3.29 a	24.89	0.71 a	12.53 a	9.40	5.60	2.20 a
'Denasa 1'	2.72 b	26.19	1.46 a	11.89 b	9.87	5.33	1.93 b
Potassium fertilizer (kg/ha)							
0	2.76 b	21.50 c	1.22	10.67 c	8.17	4.44 c	2.03
15	2.74 b	24.58 bc	0.92	12.06 b	8.00	4.95 bc	1.93
30	2.78 b	24.50 bc	0.95	11.83 b	10.50	4.83 bc	2.17
45	3.49 a	31.33 a	1.11	13.95 a	11.17	7.17 a	2.20
60	3.28 ab	25.78 b	1.22	12.55 b	10.33	5.94 b	2.01

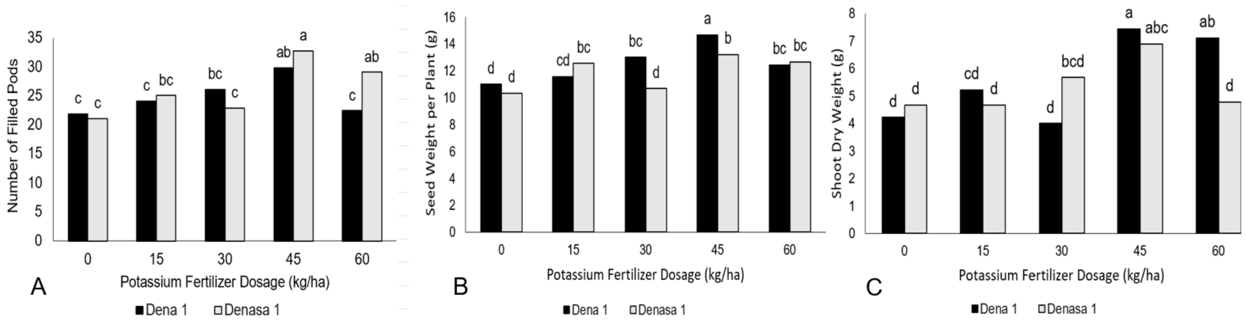
Notes. Values followed by different letters in the same column differ significantly according to the DMRT at α = 5%.

Journal of Tropical Crop Science Vol. 13 No. 2, June 2026
www.j-tropical-crops.com

Received 1/28/2025; Revised 11/24/2025; Accepted 5/5/2026
https://doi.org/10.29244/jtcs.13.02.335-349

Figure 1

Interaction Effects of Variety and Potassium Fertilizer Dose on the Number of Filled Pods, Seed Weight per Plant, and Shoot Dry Weight



Notes. Values followed by different letters in the same column differ significantly according to the DMRT at α = 5%. A: the number of filled pods; B: seed weight per plant; C: shoot dry weight.

(7.44 g). According to Bossolani et al. (2022), the application of K_2O at 70-80 kg/ha improved the soybean yield and nutrition.

Nutrient and Protein Content

Shoot N, P, K, and Ca are significantly different between varieties across all phases, except for Mg levels in the R7 phase (Table 6). The application of different potassium fertilizer Doses did not significantly affect the nitrogen, phosphorus, potassium, calcium, and magnesium levels at any observation phase. ‘Denasa 1’ variety had the highest levels of nitrogen, phosphorus, calcium, and magnesium in both R6 and R7 phases, while the highest potassium levels were found in the ‘Dena 1’ variety. The application of different doses of potassium fertilizer produced different nutrient levels in plants, including nitrogen nutrient levels in the R6 phase ranging from 2.29%-2.62% and R7 phase 1.10%-1.73%, phosphorus nutrient R6 phase 0.19%-0.24% and R7 phase 0.08%-0.12%, potassium nutrient R6 phase 0.97%-1.28% and R7 phase 0.56%-0.99%, calcium nutrient R6 phase 1.45%-1.79% and R7 phase 1.99%-2.41%, and magnesium nutrient R6 phase 0.21%-0.29% and R7 phase 0.19%-0.28%. Research by Sultana et al. (2023), conducted under varying environmental conditions, showed differences in nutrient concentrations, including nitrogen (1.3%-1.9%), phosphorus (0.22%-0.27%), and potassium (1.44%-1.46%).

Nitrogen, phosphorus, potassium, and magnesium nutrient levels tended to decrease from the R6 to R7 phase for variety and potassium fertilizer treatments, while calcium increased. This decrease was mainly due to the remobilization of nutrients from leaves to seeds. Islam et al. (2016) showed that across all plants, the rate of nitrogen accumulation peaked at the R5 stage (early seed filling) and then gradually decreased. At the R6 stage, the rate of nitrogen accumulation in seeds exceeded the rate of nitrogen accumulation in the whole plant. This means that in addition to the nitrogen directly provided by roots and root nodules, some of the nitrogen in seeds must come from other plant parts.

The nitrogen and phosphorus nutrient levels in the seeds of the two varieties showed significant effects at the R7 and R8 phases, respectively (Table 7). The treatment of potassium fertilizer did not show significant differences in the nutrient levels of nitrogen, phosphorus, potassium, calcium, and magnesium across observation phases. The levels of nitrogen, phosphorus, potassium, and magnesium in ‘Dena 1’ tend to increase in the R6 to R7 phases, except for calcium. The ‘Denasa 1’ variety showed an increase in nitrogen, potassium, and magnesium nutrients from R6 to R7 at each

Received 1/28/2025; Revised 11/24/2025; Accepted 5/5/2026
https://doi.org/10.29244/jtcs.13.02.335-349

soybean seed stage, except for phosphorus and calcium. This is because the seeds received nutrient translocation from other plant parts. Physiological processes that increase seed nutrient content include nutrient accumulation after the start of seed filling by direct partitioning into developing seed tissue, or remobilization of nutrients from leaf, stem, flower, or pod tissue (Bender et al., 2013). Meanwhile, nutrient levels in the R7 to R8 phase decreased across all nutrients in 'Denasa 1' and 'Dena 1'. This can be caused by drought during pod maturity. Research by Du et al. (2020) reported that nitrogen concentration decreased under drought stress at 15, 30, and 45 days after flowering.

The protein content of the 'Dena 1' and

Table 6

Effects of Variety and Potassium Fertilizer on Nitrogen, Phosphorus, Potassium, Calcium, and Magnesium Levels in Soybean Shoots

Treatment	Shoot N (%)		Shoot P (%)		Shoot K (%)		Shoot Ca (%)		Shoot Mg (%)	
	R6	R7	R6	R7	R6	R7	R6	R7	R6	R7
Variety										
'Dena 1'	2.23 b	1.15 b	0.20 b	0.08 b	1.25 a	0.93 a	1.34 b	1.41 b	0.22 b	0.21
'Denasa 1'	2.69 a	1.59 a	0.24 a	0.11 a	1.04 b	0.68 b	2.06 a	2.96 a	0.30 a	0.25
Potassium fertilizer (kg/ha)										
0	2.29	1.10	0.19	0.09	0.97	0.56	1.45	1.99	0.21	0.19
15	2.56	1.47	0.24	0.10	1.16	0.76	1.79	2.10	0.29	0.28
30	2.62	1.37	0.24	0.10	1.08	0.83	1.74	2.13	0.26	0.22
45	2.39	1.17	0.22	0.08	1.24	0.86	1.77	2.41	0.28	0.23
60	2.46	1.73	0.22	0.12	1.28	0.99	1.73	2.26	0.26	0.22

Note. Values followed by different letters in the same column differ significantly according to the DMRT at α = 5%. R6 = full seed phase; R7 = early maturity phase.

Table 7

Effects of Variety and Potassium Fertilizer on Nitrogen, Phosphorus, and Potassium Levels in Soybean Seeds

Treatment	Seed N (%)			Seed P (%)			Seed K (%)		
	R6	R7	R8	R6	R7	R8	R6	R7	R8
Variety									
'Dena 1'	5.77	6.18	5.93 b	0.48	0.51 a	0.41 b	1.28	1.57	1.64
'Denasa 1'	5.86	6.34	6.32 a	0.48	0.26 b	0.46 a	1.40	1.66	1.56
Potassium fertilizer (kg/ha)									
0	5.68	6.11	5.98	0.45	0.37	0.43	1.26	1.51	1.57
15	5.81	6.29	6.18	0.49	0.41	0.44	1.43	1.53	1.58
30	5.73	6.34	6.08	0.48	0.38	0.44	1.32	1.60	1.61
45	6.01	6.17	6.05	0.48	0.38	0.44	1.34	1.74	1.61
60	5.85	6.39	6.32	0.51	0.39	0.44	1.34	1.69	1.63

Note. Values followed by different letters in the same column differ significantly according to the DMRT at α = 5%. R6 = full seed phase; R7 = early maturity phase; R8 = full maturity phase.

Journal of Tropical Crop Science Vol. 13 No. 2, June 2026
www.j-tropical-crops.com
Received 1/28/2025; Revised 11/24/2025; Accepted 5/5/2026
https://doi.org/10.29244/jtcs.13.02.335-349

'Denasa 1' varieties tended to increase during the R6-R7 phase and decrease during the R8 phase (Table 8). Research by Kim et al. (2006) showed that protein accumulation increased rapidly during the reproductive stage and peaked at the R8 stage. A potassium fertilizer dose of 45 kg/ha tends to have a higher protein content than 0 kg/ha (36.09%). In addition, the 'Denasa 1' variety had the highest protein content (36.06%). According to Taha et al. (2020), stated that the application of potassium fertilizer increased the protein content by 63.19%. This is supported by the statement of Wang et al. (2013), potassium plays a role in carbohydrate metabolism, protein synthesis, and enzyme activation.

Soybean Seed Quality

Figure 2 shows the relationship between potassium fertilizer dose and seed potassium content at the R8 phase for two soybean varieties, 'Dena 1' and 'Denasa 1'. 'Dena 1' showed a negative response to increasing the potassium fertilizer dose. Meanwhile, the 'Denasa 1' variety responded positively to the increased potassium fertilizer dose. This indicates that the effectiveness of potassium fertilizer in increasing seed potassium content is influenced by each variety's potassium uptake efficiency, genetic factors, and environmental conditions. According to Brant et al. (2015), genetic variability and plant development affect nutrient absorption in plants. The dose of potassium fertilizer that can be given to produce low potassium levels in seeds for 'Dena 1' and 'Denasa 1' varieties is 60 kg/ha and 15 kg/ha, respectively. According to Bossolani et al. (2022), increasing potassium intake can affect the absorption of other nutrients, such as Ca and Mg, thereby altering overall nutrient balance.

Correlations between Variables

Based on the results of the correlation analysis, seed potassium content is positively correlated with the number of leaves (r = 0.93*), photosynthesis rate (r = 0.94*), transpiration rate (r = 0.92*), and plant potassium content (r = 0.94*) (Figure 3). Adequate potassium levels in soybean plants play an important role in various physiological processes, including leaf formation and growth. Potassium helps transport nutrients and water and activates enzymes required for protein synthesis and photosynthesis. Plants that receive sufficient potassium show improvements in various growth and yield parameters, including seed potassium levels (Sam et al., 2023).

Table 8

Effects of Soybean Variety and Potassium Fertilizer on Calcium, Magnesium, and Protein Content in Soybean Seeds

Treatment	Seed Ca (%)			Seed Mg (%)			Seed Protein (%)		
	R6	R7	R8	R6	R7	R8	R6	R7	R8
Variety									
'Dena 1'	0.29	0.24	0.23	0.15	0.17	0.16	32.95	35.25	33.85 b
'Denasa 1'	0.34	0.33	0.24	0.14	0.17	0.15	33.47	36.21	36.06 a
Potassium fertilizer (kg/ha)									
0	0.30	0.28	0.20	0.14	0.15c	0.15	32.71	34.87	34.16
15	0.32	0.30	0.22	0.15	0.17b	0.16	33.15	35.91	35.27
30	0.32	0.29	0.24	0.15	0.16c	0.17	33.41	36.18	34.71
45	0.33	0.30	0.31	0.15	0.20a	0.15	34.34	35.23	36.09
60	0.30	0.28	0.22	0.14	0.17bc	0.15	32.45	36.48	34.54

Note. Values followed by different letters in the same column differ significantly according to the DMRT at α = 5%. R6 = full seed phase; R7 = early maturity phase; R8 = full maturity phase.

Journal of Tropical Crop Science Vol. 13 No. 2, June 2026
www.j-tropical-crops.com
Received 1/28/2025; Revised 11/24/2025; Accepted 5/5/2026
https://doi.org/10.29244/jtcs.13.02.335-349

Figure 2

Correlation of Potassium Fertilizer Dose and Seed Potassium Content at the Full Maturity Phase (R8) in 'Dena 1' and 'Denasa 1'.

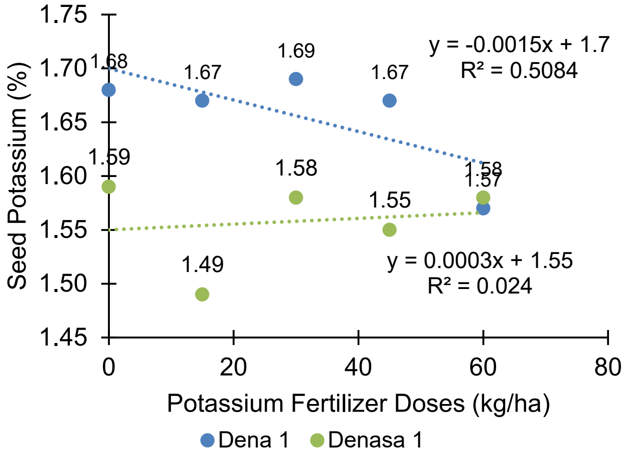
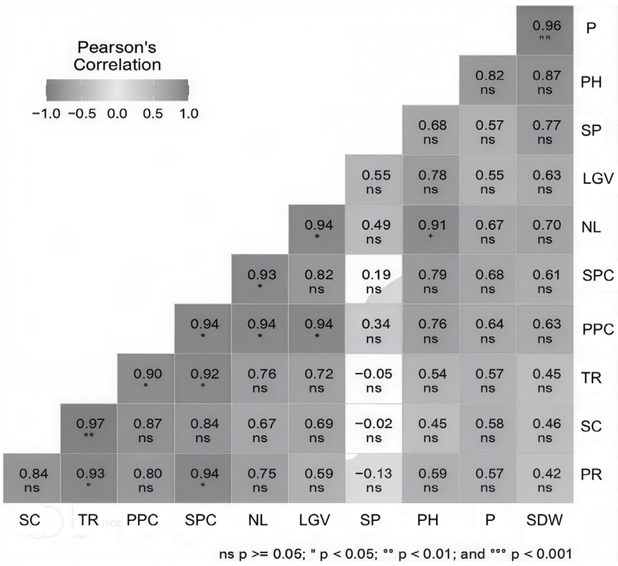


Figure 3

Correlation Analysis Between Characters



Notes. PH = plant height 8 weeks after planting; NL = number of leaves 8 weeks after planting; LG = leaf greenness value; SC = stomatal conductance; PR = photosynthetic rate; TR = transpiration rate; P = productivity; SDW = shoot dry weight; PPC = plant potassium content; SPC = seed potassium content; SP = seed protein.

Nutrient Stoichiometry

The N/P (Figure 4A), N/K (Figure 4B), and P/K (Figure 4C) ratios in plants did not differ significantly among treatments at R6 and R7. In general, plant N/P and N/K ratios across all treatments were higher in R7 than in R6, with values ranging from 9.63 to 15.70. Tamagno et al. (2017) reported an N/P ratio of 11.4 for soybean, based on experiments conducted in Argentina and the United States. There were no significant differences between treatments within the same variety, for example, between 'Dena 1' at 45 kg K_2O/ha and 'Dena 1' at 60 kg K_2O/ha, and between 'Denasa 1' at 45 kg K_2O/ha and 'Denasa 1' at 60 kg K_2O/ha, at either R6

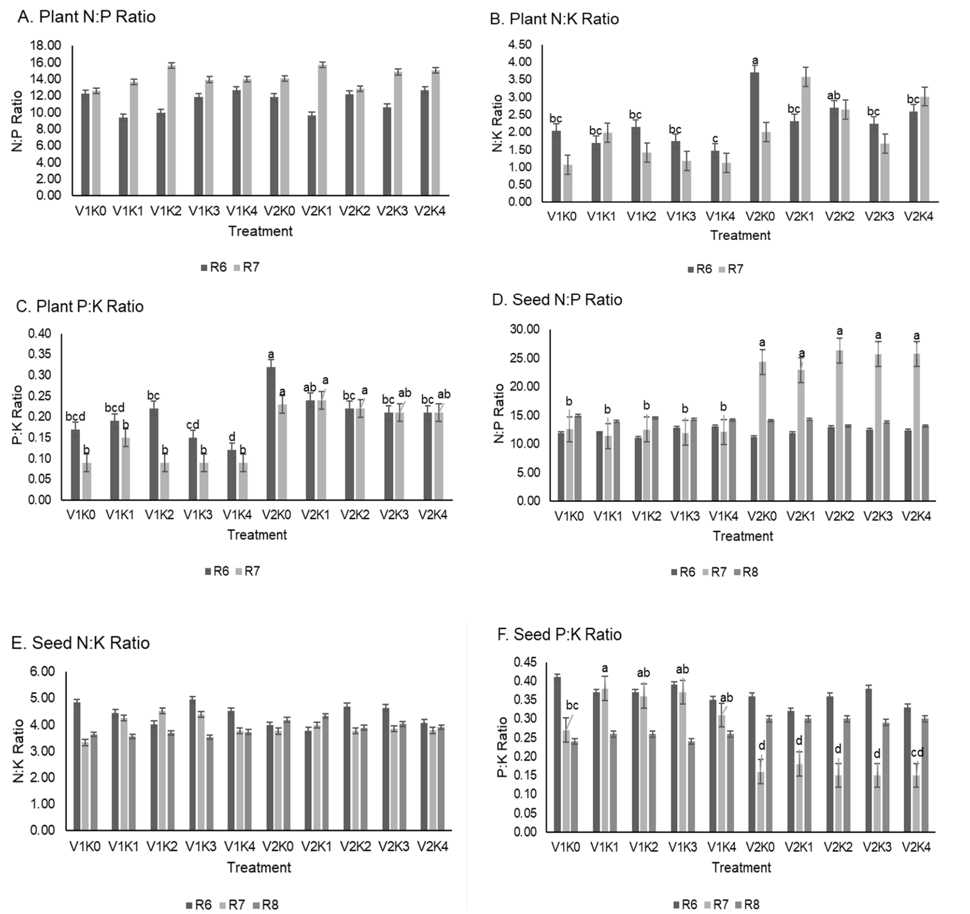
Received 1/28/2025; Revised 11/24/2025; Accepted 5/5/2026
https://doi.org/10.29244/jtcs.13.02.335-349

or R7 for N/P ratio. However, the N/P ratio was significantly lower in the no-potassium treatment (0 kg K_2O/ha) than in the other treatments for both varieties. The N/P (Figure 4D), N/K (Figure 4E), and P/K (Figure 4F) ratios in the seeds did not differ significantly. In the ‘Dena 1’ treatment group, the N/P ratio remained relatively stable within a narrow range. In contrast, the N/P ratio increased significantly in the ‘Denasa 1’ treatment group compared with the ‘Dena 1’ group. Overall, this graph shows that the ‘Denasa 1’ treatment group consistently produced higher N/P ratios than the ‘Dena 1’ group, with treatments at 15-60 kg K_2O/h showing significant increases. In the ‘Dena 1’ treatment group, the N/K ratio ranged from 3.5 to 5.0. In contrast, in ‘Denasa 1’, the N/K ratio slightly decreased and ranged from 3.0 to 4.0. In general, the N/K ratio values in ‘Denasa 1’ were lower than those in ‘Dena 1’, but the differences among the treatments in this group were not significant. The P/K ratio in seeds showed greater variation among treatments than the N/K ratio.

In ‘Dena 1’, the P/K ratio varied from 0.20 to 0.45, while in ‘Denasa 1’ it ranged from 0.15 to 0.25. Overall, ‘Denasa 1’ consistently showed a lower P/K ratio than ‘Dena 1’. According to Salvagiotti et al. (2012), variations in N/P and N/K ratios are closely linked to changes in stover nutrient concentrations. The main factor behind the change in P and K stoichiometry is the differential partitioning between seed and stover.

Figure 4

Ratios of N/P, N/K, and P/K in Plants and Seeds of Different Soybean Varieties under Different Potassium Doses



Notes. Values followed by different letters differ significantly at the α = 5% level based on the DMRT. V1: ‘Dena 1’, V2: ‘Denasa 1’, K0: 0 kg/ha KCl, K1: 15 kg/ha K_2O, K2: 30 kg/ha K_2O, K3: 45 kg/ha K_2O, K4: 60 kg/ha K_2O.

Received 1/28/2025; Revised 11/24/2025; Accepted 5/5/2026
https://doi.org/10.29244/jtcs.13.02.335-349

Conclusions

The morphological and physiological traits of the soybean varieties 'Dena 1' and 'Denasa 1' did not exhibit significant responses to varying levels of potassium (K) fertilization. Nevertheless, both varieties achieved peak reproductive performance, characterized by maximum pod number and seed weight, at a potassium dose of 45 kg K_2O/ha. Significant interaction effects between potassium dose and variety were observed for the number of trifoliate leaves, filled pods, seed weight per plant, and crown dry weight. Statistical analysis revealed that seed potassium content was positively correlated with leaf number, photosynthetic rate, transpiration rate, and total plant K content. Furthermore, K fertilization modulated the nutritional stoichiometry of the seeds, specifically influencing N/P, N/K, and P/K ratios. While differences between K treatments were not statistically significant, Denasa 1 consistently maintained higher N/P ratios and lower N/K and P/K ratios than Dena 1, suggesting distinct, specific nutrient-partitioning strategies. Overall, seeds from plants receiving 15 to 60 kg K_2O/ha exhibited more stable nutrient ratios than those from the control (0 kg K_2O/ha), indicating that sufficient K availability is essential for balanced nutrient allocation to reproductive tissues.

Acknowledgement

The authors thank Directorate General of Higher Education, Research, and Technology, Indonesian Ministry of Education, Culture, Research and Technology, for funding the research through Grant No: 027/E5/PG.02.00.PL/2024.

References

Ahmed, A., Aftab, S., Hussain, S., Cheema, H. N., Liu, W., Yang, F., & Yang, W. (2020). Nutrient accumulation and distribution assessment in response to potassium application under. *Agronomy, 10*, 725. https://doi.org/10.3390/agronomy10050725.

Batista, M. S., da Silva, A. V., de Oliveira, L. L., da Silva, R. M., da Silva, C. M., & Meilezrski, F. (2020). Productive potential and economic viability of soybeans in response to potassium application. *Journal of Agricultural Studies, 8*, 221-236. https://doi.org/10.5296/jas.v8i3.16558.

Bender, R.R., Haegele, J. W., Ruffo, M. L., & Below, F. E. (2013). Nutrient uptake, partitioning, and remobilization in modern, transgenic insect-protected maize hybrids. *Agronomy Journal, 105*, 161–170. https://doi.org/10.2134/agronj2012.0352.

Bossolani, J. W., Meneghette, H. H. A., Sanches, I. R., Dos Santos, F. L., Parra, L. F., & Lazarini, E. (2022). 5-year effects of potassium fertilization levels on nutrition balance and yield in the maize/soybean succession. *Communications in Soil Science and Plant Analysis, 53,* 2017–2028. https://doi.org/10.1080/00103624.2022.2070192.

Brant, A., & Chen, H. (2015). Patterns and mechanisms of nutrient resorption in plants. *Critical Reviews in Plant Sciences, 34*, 471-486. https://doi.org/10.1080/07352689.2015.1078611.

Cui, J., & Tcherkez, G. (2021). Potassium dependency of enzymes in plant primary metabolism. *Plant Physiology Biochemistry, 166*, 522–530. https://doi.org/10.1016/j.plaphy.2021.06.017.

Du, Y., Zhao, Q., Chen, L., Yao, X., Zhang, H., Wu, J., & Xie, F. (2020). Effect of drought stress during soybean R2–R6 growth stages on sucrose metabolism in leaf and seed. *International Journal of Molecular Science, 21*, 1–19. https://doi.org/10.3390/ijms21020618.

Gaymard, F., Pilot, G., Lacombe, B., Bouchez, D., Bruneau, D., Boucherez, J., Michaux-Ferrière, N., Thibaud, J. B., & Sentenac, H. (1998). Identification and disruption of a plant shaker-like outward channel involved in K^+ release into the xylem sap. *Cell, 94*, 647–655. https://doi.org/10.1016/S0092-8674(00)81606-2.

Haworth, M., Marino, G., Loreto, F., and Centritto,

Received 1/28/2025; Revised 11/24/2025; Accepted 5/5/2026
https://doi.org/10.29244/jtcs.13.02.335-349

M. (2021). Integrating stomatal physiology and morphology: Evolution of stomatal control and development of future crops. *Oecologia, 197*, 867-883. https://doi.org/10.1007/s00442-021-04857-3.

Hu, W., Ren, T., Meng, F., Cong, R., Li, X., White, P., & Lu, J. (2019). Leaf photosynthetic capacity is regulated by the interaction of nitrogen and potassium through the coordination of CO_2 diffusion and carboxylation. *Physiologia Plantarum, 167*, 418-432. https://doi.org/10.1111/ppl.12919.

Islam, M. M., Ishibashi, Y., Nakagawa, A. C. S., Tomita, Y., Iwaya-Inoue, M., Arima, S., & Zheng, S. H. (2016). Nitrogen redistribution and its relationship with the expression of GmATG8c during seed filling in soybean. *Journal of Plant Physiology, 192*, 71–74. https://doi.org/10.1016/j.jplph.2016.01.007.

Khan, T., Sanchary, I., & Rahman, T. (2023). Effects of fertilization on soybean productivity. *International Journal for Multidisciplinary Research, 5*, 1-9. https://doi.org/10.36948/ijfmr.2023.v05i06.11349.

Kim, S. L., Berhow, M. A., Kim, J. T., Chi, H. Y., Lee, S. J., & Chung, I. M. (2006). Evaluation of soyasaponin, isoflavone, protein, lipid, and free sugar accumulation in developing soybean seeds. *Journal of Agriculture and Food Chemistry, 54*, 10003–10010. https://doi.org/10.1021/jf062275p.

Maathuis, F.J. (2009). Physiological functions of mineral macronutrients. *Current Opinion in Plant Biology*, *12*, 250–258. https://doi.org/10.1016/j.pbi.2009.04.003.

Meenakshi, M., Punia, S., Batra, D., Sinky, S., Rani, P., & Singh, N. (2023). Potassium fertilization for improving water relations, photosynthetic pigments, and antioxidant defense system in the intercropping system of *Gossypium hirsutum* L. and *Cajanus cajan* (L.) Mills. under different irrigation regimes. *Research Journal of Biotechnology, 16*, 23-32. https://doi.org/10.25303/1807rjbt023032.

Minister of Agriculture Regulation Number 13 of 2022. (2022). *Penggunaan dosis pupuk N, P, K untuk padi, jagung, dan kedelai pada lahan sawah*. https://peraturan.bpk.go.id/Details/224926/permentan-no-13-tahun-2022

Parveen, Anwar-ul-Haq, M., Akhtar, J., & Basra, S. M. A. (2016). Interactive effect of salinity and potassium on growth, biochemical parameters, protein, and oil quality of soybean genotypes. *Pakistan Journal of Agriculture Sciences, 53*, 69–78. https://doi.org/10.21162/PAKJAS/16.4755.

Pratiwi, H., & Artari, R. (2018). Respon morfo-fisiologi genotipe kedelai terhadap naungan jagung dan ubikayu. *Jurnal Agronomi Indonesia, 46*, 48-56. https://doi.org/10.24831/jai.v46i1.15441.

Proklamasiningsih, E., Prijambada, I. D., Rachmawati, D., & Sancayaningsih, R. P. (2012). Laju fotosintesis dan kandungan klorofil kedelai pada media tanam masam dengan pemberian garam aluminium. *AGROTROP: Journal of Agriculture Science, 2*, 17-24.

Salvagiotti, F., Ferraris, G., Quiroga, A., Barraco, M., Vivas, H., Prystupa, P., Echeverria, H., & Gutierrez Boem, F. H. (2012). Identifying sulfur deficient fields by using sulfur content; N:S ratio and nutrient stoichiometric relationships in soybean seeds. *Field Crop Research, 135*. http://dx.doi.org/10.1016/j.fcr.2012.07.011.

Sam, K., Geofrey, G., & Moses, M. (2023). Effects of potassium application on yield, protein and oil content of selected soybean varieties in Trans Nzoia County, Kenya. *Journal of Agriculture and Ecology Research International*, *24*, 37–50. http://dx.doi.org/10.9734/JAERI/2023/v24i5540.

Sharma, T., Dreyer, I., & Riedelsberger, J. (2013). The role of K^+ channels in uptake and redistribution of potassium in the model plant *Arabidopsis thaliana*. *Frontiers in Plant Science, 4*, 224. https://doi.org/10.3389/fpls.2013.00224.

Silva, J., & Uchida, R. (2000). *Essential nutrients for plant growth : Nutrient management in Hawaii's soils, approaches for tropical and*

Received 1/28/2025; Revised 11/24/2025; Accepted 5/5/2026
https://doi.org/10.29244/jtcs.13.02.335-349

subtropical agriculture. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa.

Stover, P. J., & King, J. C. (2020). More nutrition precision, better decisions for the health of our nation. *The Journal of Nutrition, 150*, 3058-3060. https://doi.org/10.1093/jn/nxaa280.

Sultana, S., Al Ansary, M. S., Jahan, M. A., & Paul, A. K. (2023). Seed yield and nutrient contents of soybean as influenced by the application of potassium and molybdenum fertilizers. *International Journal of Scientific and Research Publications, 13*, 220–226. https://doi.org/10.29322/IJSRP.13.06.2023.p13830.

Sumida, K., Biruete, A., Kistler, B. M., Khor, B. H., Ebrahim, Z., Giannini, R., Sussman-Dabach, E. J., Avesani, C. M., Chan, M., Lambert, K., Moon-Wang, A. Y., Clegg, D. J., Burrowes, J. D., Palmer, B. F., Carrero, J. J., & Kovesdy, C. P. (2023). New insights into dietary approaches to potassium management in chronic kidney disease. *Journal of Renal Nutrition, 33*, S6-S12. https://doi.org/10.1053/j.jrn.2022.12.003.

Taha, R., Seleiman, M., Alotaibi, M., Alhammad, B., Rady, M., & Mahdi, A. (2020). Exogenous potassium treatments elevate salt tolerance and performance of *Glycine max* L. by boosting the antioxidant defense system under actual saline field conditions. *Agronomy, 10,* 1741. https://doi.org/10.3390/agronomy10111741.

Tamagno, S., Balboa, G. R., Assefa, Y., Kovacs, P., Casteel, S. N., Salvagiotti, F., Garcia, F. O., Stewart, W. M., & Ciampitti, I. A. (2017). Nutrient partitioning and stoichiometry in soybean: A synthesis-analysis. *Field Crops Research, 200*. https://doi.org/10.1016/j.fcr.2016.09.019.

Toro-Martin, J. D., Arsenault, B. J., & Depres, J. P. (2017). Precision nutrition: A review of personalized nutritional approaches for the prevention and management of metabolic syndrome. *Nutrients, 22*, 913. https://doi.org/10.3390/nu9080913.

Volf, M. R., Guimarães, T. M., Scudeletti, D., Cruz, I. V., & Rosolem, C. A. (2018). Potassium dynamics in ruzigrass rhizosphere. *Revista Brasileira de Ciência do Solo, 42*, 1–12. https://doi.org/10.1590/18069657rbcs20170370.

Volf, M. R., Batista-Silva, W., Silverio, A. D., dos Santos, L. G., & Tiritan, C. S. (2022). Effect of potassium fertilization in sandy soil on the content of essential nutrients in soybean leaves. *Annals of Agriculture Sciences*, *67*, 99-106. https://doi.org/10.1016/j.aoas.2022.06.001.

Wang, M., Zheng, Q., Shen, Q., & Guo, S. (2013). The critical role of potassium in plant stress response. *International Journal of Molecular Sciences, 14*, 7370–90. https://doi.org/10.3390/ijms14047370.

Wasaya, A., Yasir, T., Sarwar, N., Farooq, O., Rehman, A., Mubeen, K., Ali, M., Affan, M., & Aziz, A. (2021). Foliar-applied potassium improves stay-green, photosynthesis, and yields in maize (*Zea mays* L.) under rainfed conditions. *Plant Physiology Reports, 26*, 38–48. https://doi.org/10.1007/s40502-021-00572-6.

Xu, X., Du, X., Wang, F., Sha, J., Chen, Q., Tian, G., Zhu, Z., Ge, S., & Jiang, Y. (2020). Effects of potassium levels on plant growth, accumulation and distribution of carbon, and nitrate metabolism in apple dwarf rootstock seedlings. *Frontiers in Plant Science, 11*, 1–13. https://doi.org/10.3389/fpls.2020.00904.

Yang, Q., Lin, G., Lv, H., Wang, C., Yang, Y., & Liao, H. (2020). Environmental and genetic regulation of plant height in soybean. *BMC Plant Biology, 21*. https://doi.org/10.1186/s12870-021-02836-7.