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The Patterns of N/P/K Stoichiometry of Indonesian Soybean Varieties in the Dryland Environment

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Abstract

Soybeans are among the best plant-based sources of protein. However, a high intake of rich potassium legumes such as soybean could have negative impacts on people who are sensitive to high potassium. A study on NPK stoichiometry of the most popular Indonesian soybean varieties was conducted as a preliminary evaluation to develop low-potassium soybeans. The experiment was conducted at Cikabayan Experimental Station, IPB University, from January to April 2024. The field experiment was arranged in randomized block design using 12 soybean varieties: "Anjasmoro", "Deja 2", "Dena 1", "Dering 1", "Denasa 1", "Denasa 2", "Dering 3", "Devon 1", "Devon 2", "Grobogan", "Mallika", and "Slamet". Results showed that "Slamet" produced the highest stover while "Anjasmoro" was the lowest. "Slamet", "Dering 1", and "Mallika" produced the highest bean production per hectare (3.75-4.73 t ha^{-1}). N uptake was higher than P, and K. Seed of "Dena 1" had the lowest K content, while the highest was "Denasa 1". The stoichiometric ratios of N/P, N/K, P/K showed different values according to varieties. Thus, decreasing the K level in seed could be done by selecting a low K variety.

Keywords: *Glycine max*, low potassium, nitrogen, nutrient balance, phosphorus

Introduction

Soybean (*Glycine max* L. Merr.) is a popular legume worldwide; of 350 megatons of global production in 2021, about 76% was used as feed, 20% as food, and 4% as biodiesel (Ritchie, 2021). Meanwhile, soybean productivity in Indonesia is 15.43 quintals per hectare. In Indonesia, soybean production ranks third after rice and corn (BPS, 2023). Soybeans in Indonesia are suitable for growth in open areas with a hot climate, especially at altitudes from lowlands up to 1200 meters above sea level (Subaedah, 2019). Soybean is rich in protein (Qin et al., 2022), and it has become a prominent protein diet for about a quarter of the global population. The seed contains 40-45% protein, 18-21% oil, and 26-30% carbohydrates (Sonah et al., 2015). It is also a good source of vitamins such as folate, and vitamin E (Padalkar et al., 2023). Soybean also rich in minerals, such as potassium, phosphorus, magnesium, sulfur, calcium, chloride, and sodium (Liu et al., 2022). K content in soybean seeds is higher than other minerals, ranging from 16.38 to 20.36 mg per kg (Özcan and Al Juhaimi, 2014). Soybean is a major protein source in Indonesia, with a consumption of 11-12 kg per capita (Harsono et al., 2022), and the consumption rate increases by 2.1% annually (Aldillah, 2015).

Soybeans have various health benefits due to certain compounds found in the seeds, including reducing the risk of osteoporosis (Rizzo and Baroni, 2018), acting as anti-cancer inhibitors (Jayachandran and Xu, 2019), and preventing obesity (Qin et al., 2022). However, limiting potassium intake is often recommended for people with certain health conditions, such as kidney disease due to the risk of hyperkalemia (Yamada and Inaba, 2021). Potassium issues are common in chronic kidney disease (CKD) patients and can negatively impact their health. Maintaining blood potassium levels within the normal range is crucial for CKD patients (Sumida et al., 2023). Francis et al. (2024) estimated that 850 million people globally who suffer from kidney disease are from low-income countries, including Indonesia. The number of patients with kidney disease in Indonesia in 2018 was more than one million, and the prevalence of people with kidney problems was 0.38% (Kemenkes RI, 2019). Controlling K intake with low-K foods is important in a person with kidney disease (Yamada and Inaba, 2021). As soybeans are an important source of protein and are widely

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consumed in Indonesia, the development of low-K soybeans is important to support a healthy diet for people with kidney disease.

Nutrient status in plants is determined by genetic and environmental factors (Pratama et al., 2017), which are the differences between varieties and gene expression. Environmental factors such as nutrient availability, temperature, and sunlight intensity can affect the results of NPK nutrient stoichiometry. In this study, based on soil analysis results and the classification by Balittanah (2005), the land condition falls into the dry category and the organic matter content status is classified as medium. Therefore, cow manure was added as a supplement to balance the organic matter content. Soybean needs N, P, and K as major nutrients to meet optimum growth, flower formation, and pod filling (Pratama et al., 2017). Based on the research conducted by Rabani et al. (2022), it was stated that NPK fertilization significantly increased cowpeas' productivity and seed weight at 8 weeks after planting (WAP). Therefore, nutrient stoichiometry is important to balance the biological needs of plants and nutrient supplementation (Zeng et al., 2016). Knowledge of nutrient balance is required to tailor nutrient management strategies to specific regions. Developing soybeans that are adaptive to low K soil is also important to enhance productivity (Liu et al., 2022).

Soybean K uptake can be four to seven times greater than the P uptake (Gaspar et al., 2017). The plant uptake of N, P, and K is influenced by soil nutrient availability (Gaspar et al., 2017). Each nutrient has a specific role in plants such as N is essential for plant growth (Meitasari and Wicaksono, 2017), P supports root nodulation and seed production (Perkasa et al., 2016), and K for growth and development (Zhang et al., 2018; Lu et al., 2022). K is essential for enzyme activation (Ragel et al., 2019), production and movement of carbohydrates from source to sink, protein synthesis, and improving nitrogen utilization (Pettigrew, 2008), and plant adaptation to environmental stresses (Hasanuzzaman et al., 2018). This study aimed to evaluate the NPK nutrient stoichiometry of several soybean varieties to develop low K seed content. Applying stoichiometry to several tested varieties involves collecting nutritional data regarding the nutrient content (nitrogen, phosphorus, potassium) and calculating the ratios of these three nutrients. This study uses existing soybean varieties such as "Deja 2", "Dena 1", "Denasa 1", "Denasa 2", "Dering 1", "Dering 3", "Devon 1", "Devon 2", "Grobogan", "Slamet", "Mallika," and "Anjasmoro", where several of these varieties are cultivated under uniform fertilization and soil conditions.

Materials and Methods

The research was conducted from January to April 2024 at Cikabayan Experimental Station, IPB University, Bogor, West Java, Indonesia. The implementation of the research began with a composite soil analysis, which involved combining several samples from areas that represent the entire experimental land. Soil was collected from five points at a depth of 20-30 cm diagonally. The distance between each point was approximately 125 cm. A total of 200 grams of soil was taken from each point. Then, the samples were mixed, and 1 kg was taken for analysis. The samples were subsequently analyzed at the Agronomy and Horticulture Testing Laboratory. Each soil parameter was tested using a different method, including soil pH with a pH meter; organic carbon (C-organic) and available phosphorus (potential P) with spectrophotometry; total nitrogen (N-total) with the Kjeldahl method; cation exchange capacity (CEC) and exchangeable aluminum (Al-dd) with titrimetric; and exchangeable magnesium (Mg-dd), calcium (Ca-dd), and sodium (Na-dd) with atomic absorption spectrophotometry (AAS). According to the criteria of Balittanah (2005), the soil was acidic, with moderate C-organic content, moderate N, very high P, and low K (Table 1). During the study, the average humidity was 87%, with an average daily minimum temperature of 23.4°C and an average daily maximum temperature of 32°C.

The research was arranged in a randomized block design single factor of 12 varieties, i.e., "Deja 2", "Dena 1", "Denasa 1", "Denasa 2", "Dering 1", "Dering 3", "Devon 1", "Devon 2", "Grobogan", "Slamet", "Mallika", and "Anjasmoro". The variety was selected from the most popular varieties in Indonesia. The varieties for various legumes and tubers were selected based on seed availability at the research center. These varieties have diverse phenotypes, including seed color, seed size, and morphological characteristics of the plants. Additionally, each variety has its advantages, such as "Slamet" being suitable for acidic soils, "Dering 1" and "Dering 3" being drought-tolerant, "Denasa 1" and "Denasa 2" being shade-tolerant, and "Deja 2" being tolerant to waterlogging stress. Each block (4 m x 3 m) was repeated three times.

After soil preparation, cow manure was applied at 20 $t.ha^{-1}$ (Kurniawati et al. 2017) and dolomite was applied at a dose of 2 $t.ha^{-1}$ (based on the pH value from soil fertility tests). Seeds were planted at a depth of 3-4 cm, with a planting distance of 40 cm x 25 cm and three seeds per planting hole. This planting distance is based on the study by Astuti et al. (2021), where a spacing of 40 cm x 25 cm showed the best

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effect on soybean production. This is because wider spacing reduces plant competition for nutrients, water, air, and sunlight, thus providing optimal yields. A carbofuran-containing pesticide was added 0.2 g around the planting hole.

NPK fertilizers were applied based on the local recommendation at a rate of 22.5 kg N (50 kg urea per ha), 45 kg K_2O (75 kg KCl per ha), and 18 kg P_2O_5 (50 kg SP-36 per ha) (Permentan, 2022). At planting, 50% urea, 50% KCl, and 100% SP-36 were applied. Depending on the variety, the rest of the urea and KCl were applied before flowering 25-30 days after planting. “Grobogan” variety was given at 25 days after planting (HST); “Dering 3”, “Denasa 1”, “Denasa 2”, and “Devon 2” varieties were given at 30 HST; “Dering 1”, “Dena 1”, “Anjasmoro”, “Devon 1”, “Deja 2”, “Mallika”, and “Slamet” varieties were given at 35 days after planting (DAP).

Crop maintenance consisted of replanting dead seeds, removing less vigorous plants, and leaving a single plant per planting hole. Additional water was applied in the absence of rain. Pest control uses different insecticides according to the plant’s growth phase: fipronil and chlorantraniliprole at 3 $mL.L^{-1}$ was applied at the vegetative phase, whereas deltamethrin at 2 $mL.L^{-1}$ was applied at the generative phase. Weed control uses herbicides with a.i. propaquizafop at $2g.L^{-1}$ (Sundari and Mutmaidah, 2018). Harvesting was done when 90% of the leaves senesced or 95% of the pods in one block reached maturity. Soybeans are considered ripened and ready to harvest when the plants have turned brown or dried. Harvesting was by cutting the whole plant from the stem base (Jauhari et al., 2016).

Growth measurements included plant height, measured from the soil surface to the growing point, number of trifoliate, and number of productive branches (branches with flowers or pods). Morphological observations were conducted at two-week intervals. NPK level on stover was evaluated at the maximum growth stage, while NPK + protein on seeds was evaluated at harvest. Nutrient uptake was calculated at the R7 stage for the plant and the R8 stage for the seed using the following formula: nutrient uptake = (nutrient content) / (100%) x dry weight (g). N seed to stover ratio (NSSR), P seed to stover ratio (PSSR), and K seed to stover ratio (KSSR) were calculated using the formula: total content in seed / total content in stover.

Growth measurements include plant height, number of trifoliate leaves, number of productive branches, flowering time, time for pods to start filling, harvest time, seed production, biomass production, harvest index, number of filled pods, number of empty pods, weight of filled pods, weight of seeds per plant, weight of 100 seeds, dry weight of the plant, and dry weight of the roots. For each parameter, 12 sample plants were measured. Data was analyzed for variance (ANOVA) using the SAS application at a significant level of 5%. If ANOVA showed significant differences, the analysis was continued using Duncan’s Multiple Range Test (DMRT) at a significance level of α = 5%.

Table 1. Soil chemical properties of the study areas before planting

Soil parameters	Extraction method	Value	Status^z
pH	H_2O	4.67	Acid
pH	KCl	4.49	Very acid
C-Organic (%)	Spectrophotometry	2.05	Medium
Total N (%)	Kjeldahl	0.36	Medium
Available P (Bray I, ppm P_2O_5)	Spectrophotometry	<0.08	Very low
CEC (cmol/kg)	Titrimetric	15.49	Low
Exchangeable Mg (cmol Mg/kg)	AAS	0.75	Low
Exchangeable Ca (cmol Ca/kg)	AAS	3.68	Low
Exchangeable K (cmol K/kg)	AAS	0.19	Low
Exchangeable Na (cmol Na/kg)	AAS	0.12	Low
Exchangeable Al (cmol Al/kg)	Titrimetric	1.03	Low
Potential K (mg K_2O/100 g)	AAS	17.27	Low

Notes: ^{z}Based on Balitanah soil classification (2005).

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Results and Discussion

Plant Growth and Development

Plant height, leaf number, and productive branch number varied among varieties (Table 2). At 8 weeks after planting (WAP), three soybean varieties, i.e., “Dena 1”, “Dering 1”, and “Mallika,” had the tallest canopy of other varieties. In contrast, Denisa 1, “Grobogan”, and “Anjasmoro” had the lowest canopy among varieties, accounting for about half of the tallest ones. The variety with the highest trifoliate number at 8 WAP was “Dering 1” and “Mallika”, while the smallest number belonged to “Denasa 2” and “Grobogan” (Table 2). The “Anjasmoro” (20.82) and “Grobogan” (15.19) varieties have fewer leaves than the others. Research conducted by Handriawan et al. (2016) on the coastal sandy land of Bugel, Kulon Progo, showed that the plant height of the “Anjasmoro” and “Grobogan” varieties at 8 weeks after planting (WAP) reached 55.41 cm and 43.00 cm, with a total of trifoliate leaves amounting to 16.18 leaves and 30.96 leaves. This is due to the use of shading in that study, where the plant canopy parts that do not receive light grow rapidly because auxin activity is not inhibited. Therefore, it can be concluded that these two varieties are shade-tolerant. Morphogenesis and plant development are controlled by genetic factors and environmental factors such as light quality, intensity, and orientation (Aldesuquy et al. 2000; Wahidin et al., 2013).

“Denisa 2” had the highest number of productive branches, while “Anjasmoro” had the lowest branching variety (Table 2). However, the number of branches in the “Anjasmoro” variety in this study tended to be higher than the results of Dwiputra et al. (2015), which recorded a branch count of 4.12. “Slamet” failed to produce any branch up to 6 WAP, similar to “Mallika” with limited branching. However, both “Slamet” and “Mallika” varieties expanded extensive branching at 8 WAP similar to “Devon 1”. Soybean branches develop from axillary buds. In soybean varieties with few branches, the activity of genes regulating the development of these axillary buds is low, resulting in fewer branches. Conversely, the genes regulating axillary bud development in varieties with many branches are more active, forming more branches (Bao et al., 2019). Liang et al. (2022) stated that branching is an important component in soybean yield, and the presence of the Dt2 gene determines its variation. Xu et al. (2021) noted that pod number is determined by branch number, and the branch number is affected by plant spacing.

Soybean varieties varied in the time of flowering, pod filling, and harvesting (Table 3). “Grobogan” flowered earlier and had a shorter pod filling and harvesting time, showing better adaptation to start the reproductive phase. “Slamet” and “Mallika” varieties exhibited the longest flowering time, i.e., 47 days after planting (DAP), which shows a longer vegetative development before entering the reproductive phase.

Table 2. Plant height, number of trifoliate leaves, and number of productive branches of various soybean varieties

Soybean variety	Plant height (cm)		Number of trifoliate leaves		Productive branches number	
	6 WAP	8 WAP	6 WAP	8 WAP	6 WAP	8 WAP
“Deja 2”	34.17 cd	54.76 ab	14.8 bcd	35.6 bc	1.1 de	4.9 cd
“Dena 1”	38.82 bc	61.25 a	14.4 bcd	35.8 bc	3.4 a	6.3 ab
“Denasa 1”	32.48 cd	37.89 d	13.3 bcd	21.9 de	3.1 ab	6.3 ab
“Denasa 2”	37.09 bc	43.24 cd	17.5 ab	25.3 e	3.7 a	6.9 a
“Dering 1”	42.97 ab	60.66 a	16.7 abc	47.2 a	3.3 a	6.5 ab
“Dering 3”	47.66 a	56.98 ab	19.1 a	29.6 cde	3.6 a	6.5 ab
“Devon 1”	33.12 cd	42.25 cd	13.6 bcd	28.4 cde	0.9 e	5.3 cd
“Devon 2”	38.37 bc	47.03 bcd	12.5 cd	28.1 de	2.4 bc	5.7 bcd
“Grobogan”	32.31 cd	36.18 d	12.3 d	15.2 e	2.9 ab	5.9 abc
“Slamet”	27.63 de	49.20 bc	10.8 de	34.3 bcd	0.0 f	5.2 cd
“Mallika”	38.11 bc	60.96 a	15.06 bcd	40.8 ab	0.5 ef	6.8 ab
“Anjasmoro”	25.42 e	37.23 d	8.08 e	20.8 de	1.8 cd	4.8 d
P-value	0.0001	0.0001	0.0006	0.0001	0.0001	0.0009
Sig.	**	**	**	**	**	**

Notes: values in a column followed by similar letters are non-significant different in the DMRT test; ns= non-significant; *= significant at α=0.05; ** = significant at α=0.01; WAP: week after planting.

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However, compared to the flowering time and maturity age described for each variety used, this study's flowering time and maturity age were relatively longer than the normal duration. Santana (2021) stated that this variation in development time reflects genetic differences and the adaptive potential of each variety to different growing environments.

"Slamet", "Mallika", and "Anjasmoro" had the longest pod-filling time. However, the longest time to harvest was "Anjasmoro" at 99.0 DAP, followed by "Slamet" and "Mallika" at 94.0-94.7 DAP. Thus, the study classified "Slamet", "Mallika", and "Anjasmoro" as late-harvesting varieties. During the seed filling stage, the key stage determining seed size, weight, composition, and final soybean yield, soybean plants are more sensitive to water deficits. Seed filling involves carbohydrate mobilization and biochemical synthesis of proteins and lipids in developing seeds (Farooq et al., 2016).

Stover and Yield

"Slamet" produced the highest seed yield, followed by "Mallika" and "Dering 1" (Table 3). The seed yield in the present research is higher than that of Toleikiene et al. (2021), 0.7-3.2 $t.ha^{-1}$. The high seed yield for "Slamet," "Mallika," and "Dering 1" was supported by the high number and weight of filled pods (Table 4). The longer pod likely filling time favored pod filling, leading to higher yields, especially in "Slamet" and "Mallika". This is due to the more significant accumulation of nutrients in the pods, resulting in higher yields. This aligns with the statement by Basuchaudhuri (2016) that in soybeans, pod formation, development, and filling—both the number and growth of pods—are influenced by the supply of assimilates and the balance of endogenous plant growth regulators. "Slamet" not only had the highest number of filled pods but also had the largest stover weight, indicating the high capacity of the source. More extended growth periods may yield higher (Li et al., 2020).

Soybean "Grobogan" and "Anjasmoro" produced the lowest number and weight of filled pods (Table 4). The low yield in "Grobogan" (Table 3) was likely due to low biomass production as compared to the other varieties, although it had the highest weight of 100-seed index (Table 4). This is consistent with the findings of Mahardika and Simanjuntak (2020), where the low number of pods and seed weight was accompanied by low plant dry weight. Perkasa et al. (2016) revealed that the 100-seed weight of "Grobogan" was 15.5 g, which is smaller than in the present study, 16.9 g. Agroecology seems to affect 100-seed weight (Perkasa et al., 2016). Conversely, Zuyasna et al. (2022) conducted research in Aceh Besar District and noted that "Deja 2" has a 100-seed index of 12.1 g, higher than in the present study at 11.07 g (Table 4).

Table 3. Flowering age, pod set, and harvesting time of various soybean varieties

Soybean varieties	Flowering time (DAP)	Pod filling time (DAP)	Harvest time (DAP)	Production ($t.ha^{-1}$)^z		Harvest index ($kg.kg^{-1}$)^x
				Seed	Stover DW ^{y}	
"Deja 2"	43.0 bc	63.7 cd	88.0 e	3.27 bc	11.47bc	0.34
"Dena 1"	40.0 d	61.0 ef	87.0 ef	2.93 bc	8.21cde	0.36
"Denasa 1"	37.0 e	61.7 ef	91.0 d	2.31 cd	6.18ef	0.40
"Denasa 2"	37.0 e	62.0 de	86.0 f	2.86 bcd	8.89cde	0.32
"Dering 1"	41.0 cd	60.0 fg	93.0 c	3.75 ab	13.01ab	0.29
"Dering 3"	34.3 f	58.3 g	86.0 f	2.51 bcd	7.80de	0.33
"Devon 1"	41.3 cd	65.0 bc	93.0 c	3.08 bc	10.67bcd	0.29
"Devon 2"	38.0 e	65.0 bc	91.0 d	3.08 bc	10.69bcd	0.29
"Grobogan"	29.0 g	54.0 h	79.0 g	2.02 e	4.45f	0.45
"Slamet"	47.0 a	67.7 a	94.7 b	4.73 a	15.74a	0.30
"Mallika"	47.0 a	66.0 ab	94.0 bc	3.78 ab	13.77ab	0.27
"Anjasmoro"	44.0 b	67.0 a	99.0 a	1.53 e	4.22f	0.25
P-value	0.0001	0.0001	0.0001	0.0003	0.0001	0.1059
Sig.	**	**	**	**	**	ns

Notes: values followed by the different letters in the same column are significantly different according to the Duncan test; ns= non-significant; *= significant at α=0.05; ** = significant at α=0.01; DAP: days after planting; ^{z} Estimated from 100.000 population per ha. ^{y}DW-dry weight shoot + root; x seed/stover ratio.

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Soybean “Slamet,” “Mallika,” and “Anjasmoro” are classified as having small seed sizes based on a 100-seed index of 8.50-9.15 g (Table 4). Interestingly, “Slamet” had the most extensive shoot and root dry weight (Table 4), in contrast to low branch production (Table 2). High biomass production in “Slamet” is likely due to the tall canopy with more trifoliate.

Nutrient Stoichiometry

Soybean stover (Table 5) and seeds (Table 6) exhibited different NPK levels and uptake. This research can provide new insights into the NPK nutrient stoichiometry of several soybean varieties. Additionally, the results of this study can assist in developing more efficient nutrient management strategies, increase soybean productivity, and support agricultural sustainability amid the growing food demand. In this study, the sample size may not be sufficient to reflect the variation in the broader population of soybean varieties. This limitation can affect the reliability and generalizability of the research results. By using a limited number of sample sizes of varieties, there is a possibility that the obtained results do not fully represent the nutritional responses. Both stover and seeds had higher N levels, followed by K and P levels. In stover, N level was 1.66-2.71%, P level was 0.12-0.27%, and K level was 0.36^{-1}.61% (Table 5). In seeds, N level was 5.55-6.75%, P level was 0.14-0.45%, and K level was 1.23-1.63%. Tiwari et al. (2019) stated that NPK levels in stover are 2.10-2.97%, 0.17-0.21%, and 2.14-2.49%, and in seeds are 4.98-6.31%, 0.27-0.37%, and 1.31-1.61%, for N, P, and K, respectively.

The variety and their production level determined NPK uptake by stover and seeds (Table 5 and Table 6). The NPK uptake by seed was higher than by stover. It seems that significant variation in NPK uptake by seed was due to different seed weights per plant because uptake was calculated from the total weight of the seed by the level of its nutrients. N becomes a prominent nutrient uptake and level compared to P and K. Tiwari et al. (2019) reported that N is important in legume leaf production and protein biosynthesis.

The seed protein content ranged from 31.72 to 38.45% (Table 6), which is lower than those reported by Sonah et al. (2015), which reported a protein content of up to 49.2%. This is due to differences in the varieties used and the research location. The highest protein content was found in the “Mallika” variety, while the lowest was in the “Dering 1” variety.

Seeds of all varieties had higher NPK levels than those of stover, except “Dena 1” which had lower K. From calculation, the average N seed to stover ratio (NSSR) was 3.02 ± 0.42% (mean ± SD), P seed to stover ratio (PSSR) was 2.22 ± 0.62%. K seed to stover ratio (KSSR) was 1.72 ± 0.78% (data not shown). Seed is a strong NPK sink (Da Silva et al., 2018). Since stover and seeds were evaluated at harvest,

Table 3. Flowering age, pod set, and harvesting time of various soybean varieties

Soybean varieties	Flowering time (DAP)	Pod filling time (DAP)	Harvest time (DAP)	Production ($t.ha^{-1}$)^{z}		Harvest index ($kg.kg^{-1}$)^{x}
				Seed	Stover DW^{y}	
“Deja 2”	43.0 bc	63.7 cd	88.0 e	3.27 bc	11.47bc	0.34
“Dena 1”	40.0 d	61.0 ef	87.0 ef	2.93 bc	8.21cde	0.36
“Denasa 1”	37.0 e	61.7 ef	91.0 d	2.31 cd	6.18ef	0.40
“Denasa 2”	37.0 e	62.0 de	86.0 f	2.86 bcd	8.89cde	0.32
“Dering 1”	41.0 cd	60.0 fg	93.0 c	3.75 ab	13.01ab	0.29
“Dering 3”	34.3 f	58.3 g	86.0 f	2.51 bcd	7.80de	0.33
“Devon 1”	41.3 cd	65.0 bc	93.0 c	3.08 bc	10.67bcd	0.29
“Devon 2”	38.0 e	65.0 bc	91.0 d	3.08 bc	10.69bcd	0.29
“Grobogan”	29.0 g	54.0 h	79.0 g	2.02 e	4.45f	0.45
“Slamet”	47.0 a	67.7 a	94.7 b	4.73 a	15.74a	0.30
“Mallika”	47.0 a	66.0 ab	94.0 bc	3.78 ab	13.77ab	0.27
“Anjasmoro”	44.0 b	67.0 a	99.0 a	1.53 e	4.22f	0.25
P-value	0.0001	0.0001	0.0001	0.0003	0.0001	0.1059
Sig.	**	**	**	**	**	ns

Notes: values followed by the different letters in the same column are significantly different according to the Duncan test; ns= non-significant; *= significant at α=0.05; ** = significant at α=0.01; DAP: days after planting; ^{z} Estimated from 100.000 population per ha. ^{y}DW-dry weight shoot + root; x seed/stover ratio.

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NPK from stover are probably remobilized to seed. It is important to note some varieties had NSSR < 3.00, i.e., "Dena 1" (2.30), "Grobogan" (2.30), "Slamet" (2.69), and Denasa (2.96). Variety with PSSR < 2.00 were "Anjasmoro" (1.00), "Grobogan" (1.59), "Slamet" (1.62), and "Devon 2" (1.79), and variety with KSSR < 1.50 were "Dena 1" (0.76), "Grobogan" (1.18), "Dering 1" (1.23), "Anjasmoro" (1.29), and "Devon 2" (1.49).

N/P, N/K, and P/K ratio of the soybean stover and seeds are in Figure 1. N dominated P and K in the stover (Figures 1A and 1C) and the seeds (Figures 1B and 1D). K level was higher than the P level in both stover (Figure 1E) and seed (Figure 1F), as indicated by the P/K ratio < 0.5. The high N/P ratio in stover was discernible for "Dena 1" and "Denasa 2", while the low N/P ratio was for "Devon 2" and "Grobogan" (Figure 1A). "Devon 1" had the highest N:P ratio in seed compared to other varieties (Figure 1D). Güsewell (2004) stated that the N:P

Table 4. Pods number, pod and seed weights, and dry weight of shoot and root per plant of various soybean varieties at harvest

Soybean varieties	Number of filled pods	Number of empty pods	Number of filled pods	Seed weight per plant (g)	100-seed weight	Shoot dry weight (g)	Root dry weight (g)
"Deja 2"	100.6 bc	4.1 b	65.26 bc	32.68 bc	11.07 bc	11.68 ab	3.72 b
"Dena 1"	81.5 bc	4.4 b	39.04 de	29.28 bc	13.13 abc	8.70 bcd	2.55 bc
"Denasa 1"	54.9 bc	2.5 b	28.84 de	23.12 cd	13.63 abc	6.31 def	2.52 bc
"Denasa 2"	83.2 bc	5.1 b	45.91 cd	28.59 bcd	14.73 ab	8.45 bcde	3.03 bc
"Dering 1"	130.9 b	1.8 b	78.54 ab	37,48 ab	9.84 bc	11.14 abc	2.80 bc
"Dering 3"	73.2 bc	9.4 a	38.76 de	25.05 bcd	12.20 abc	7.06 cdef	2.45 bc
"Devon 1"	90.9 bc	2.2 b	64.30 bc	30.78 bc	13.46 abc	7.41 cdef	4.07 b
"Devon 2"	89.7 bc	2.8 b	66.30 bc	30.83 bc	12.00 abc	7.23 cdef	2.16 bc
"Grobogan"	34.1 c	4.8 b	16.08 e	20.15 cd	16.90 a	4.26 ef	1.46 c
"Slamet"	234.2 a	3.3 b	90.33 a	47.29 a	8.50 c	13.27 a	6.32 a
"Mallika"	135.7 b	2.9 b	85.91 ab	37.79 ab	9.14 c	9.87 bcd	3.90 b
"Anjasmoro"	47.3 c	1.0 b	21.88 e	15.33 d	8.86 c	3.67 f	1.24 c
P-value	0.0024	0.1059	0.0001	0.0032	0.0501	0.0012	0.0017
Sig.	**	ns	**	**	ns	**	**

Notes: Values in a column followed by similar letters are non-significant different in the Duncan test; ns= non-significant; *= significant at α=0.05; ** = significant at α=0.01.

Table 5. Stover NPK levels and nutrient uptake of various soybean varieties

Soybean varieties	Nutrient levels (%)^z			Nutrient uptake ($kg.ha^{-1}$)^y		
	N	P	K	N	P	K
"Deja 2"	1.91	0.15	0.86	25.50	2.00	11.50
"Dena 1"	2.67	0.16	1.61	41.20	2.46	24.80
"Denasa 1"	1.76	0.14	0.77	17.20	1.37	7.55
"Denasa 2"	2.00	0.12	0.80	29.18	1.75	11.67
"Dering 1"	1.73	0.15	1.07	20.00	1.70	12.40
"Dering 3"	2.10	0.15	0.36	19.70	1.41	3.38
"Devon 1"	1.66	0.12	0.81	20.30	1.47	9.90
"Devon 2"	1.99	0.19	0.91	17.40	1.66	7.95
"Grobogan"	2.71	0.27	1.07	18.70	1.86	7.40
"Slamet"	2.36	0.21	0.88	36.00	3.20	13.40
"Mallika"	2.04	0.14	0.75	23.20	1.60	8.50
"Anjasmoro"	2.03	0.14	1.11	12.60	0.87	6.90

Notes: ^{z} Based on dry weight; population of 100,000 plants per hectare.

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Table 6. Seed NPK levels, uptake, and protein content of various soybean varieties

Soybean varieties	Nutrient levels (%)[z]			Nutrient uptake (kg.ha^{-1})[y]			Protein (%)[x]
	N	P	K	N	P	K	
"Deja 2"	6.00	0.37	1.38	196.00	12.10	45.10	34.27
"Dena 1"	6.13	0.39	1.23	180.00	11.40	36.00	35.03
"Denasa 1"	6.03	0.37	1.63	139.00	8.60	37.60	34.45
"Denasa 2"	5.91	0.35	1.49	169.00	10.00	42.60	33.72
"Dering 1"	5.55	0.36	1.32	208.00	13.50	49.40	31.72
"Dering 3"	6.55	0.38	1.40	164.00	9.50	35.10	37.42
"Devon 1"	6.12	0.24	1.62	188.00	7.40	49.80	34.93
"Devon 2"	6.14	0.34	1.36	189.00	10.50	41.90	35.03
"Grobogan"	6.23	0.43	1.26	126.00	8.60	25.40	35.57
"Slamet"	6.35	0.34	1.34	300.00	16.10	63.30	36.25
"Mallika"	6.75	0.45	1.25	255.00	17.00	47.20	38.45
"Anjasmoro"	6.08	0.14	1.43	93.20	6.00	21.90	34.73

Notes: [z] Based on dry weight; population of 100,000 plants per hectare.

ratio in stover may vary within a species in different environments, soil fertility, growth stages, and plant organs. Moreover, the authors pointed out that plants with a high N/P ratio allocate less biomass to roots, have high leaf dry matter content, accelerate leaf senescence, and have shorter leaf life spans. Magyar et al. (2024) noted that algae with a high N:P ratio produce marked chlorophyll and higher biomass. In the present study, seed N:P ratio was higher than stover, i.e., 18.9 vs. 14.6, which was also reported by Güsewell (2004). Vergeer et al. (2003) reported that a high N:P ratio increases stover biomass and seed number per plant.

The marked N/K ratio was recorded in "Dering 3" stover than in other varieties (Figure 1B), while in seed, the N: K ratio was slightly different among varieties, unlike in stover (Figure 1E). According to Cardoso et al. (2017), N:K ratio is important to evaluate the balance between vegetative and reproductive stages; high K availability facilitates K's ability to regulate plant growth. In the present study, most varieties had an N/K ratio of stover below 3, except "Dering 3", with a value of about 6.0 (Figure 1B). The N/K ratio in seed fell between 3.0 to 5.0 (Figure 1E), indicating lower variation among soybean varieties. The finding is in line with soybean seeds, as found in research by Tiwari et al. (2019), growing in different fertilizer applications in vertisol to have an N: K ratio of 3.5 to 4.5. Figures 1C and 1F show that seeds had more P: K ratio diversity than stover. Most stover had a P:K ratio < 0.2 except "Dering 3" (0.43), "Devon 2" (0.21), "Grobogan" (0.25), and "Slamet" (0.24). On the other hand, all varieties had P/K ratio higher than 0.2 except "Devon 1" (Figure 1F). Figure 1F shows that "Mallika" had the highest P/K ratio. The P/K ratio reflects the plant's ability to adapt to dry environments (Sardans et al., 2012). Taufiq and Adie (2013) classified "Mallika" as a moderate tolerant variety to drought stress.

The actual K status and low N and K ratio were used to select soybeans with low K levels. Seeds with low N: K meaning had lower protein content, which can be an option for patients with chronic kidney disease, as the implementation of a low-protein diet (LPD) is recommended to slow the decline of glomerular filtration rate (GFR) and reduce the accumulation of protein waste in patients with chronic kidney disease (Ko et al., 2017). Six soybean varieties exhibited lower K than the others, i.e., "Dena 1", "Dering 1", "Devon 2", "Grobogan", "Mallika", and "Slamet". Varieties with low N:K ratio were "Denasa 1", "Denasa 2", "Devon 1", "Grobogan", and "Anjasmoro". "Dena 1", "Devon 2", "Denasa 2", "Grobogan", "Slamet", and "Anjasmoro" are potential varieties for further evaluation of low K status. Additional studies are needed to explore a broader genetic variation among soybean varieties, which can enhance understanding of their differing nutrient content and growth. Assefa et al. (2019) reported that soybean nutritional content might vary by environment (70%), management (2%), and genetics (28%), whereas Liu et al. (2022) recorded that soybeans with high K uptake efficiency have higher protein content without K application.

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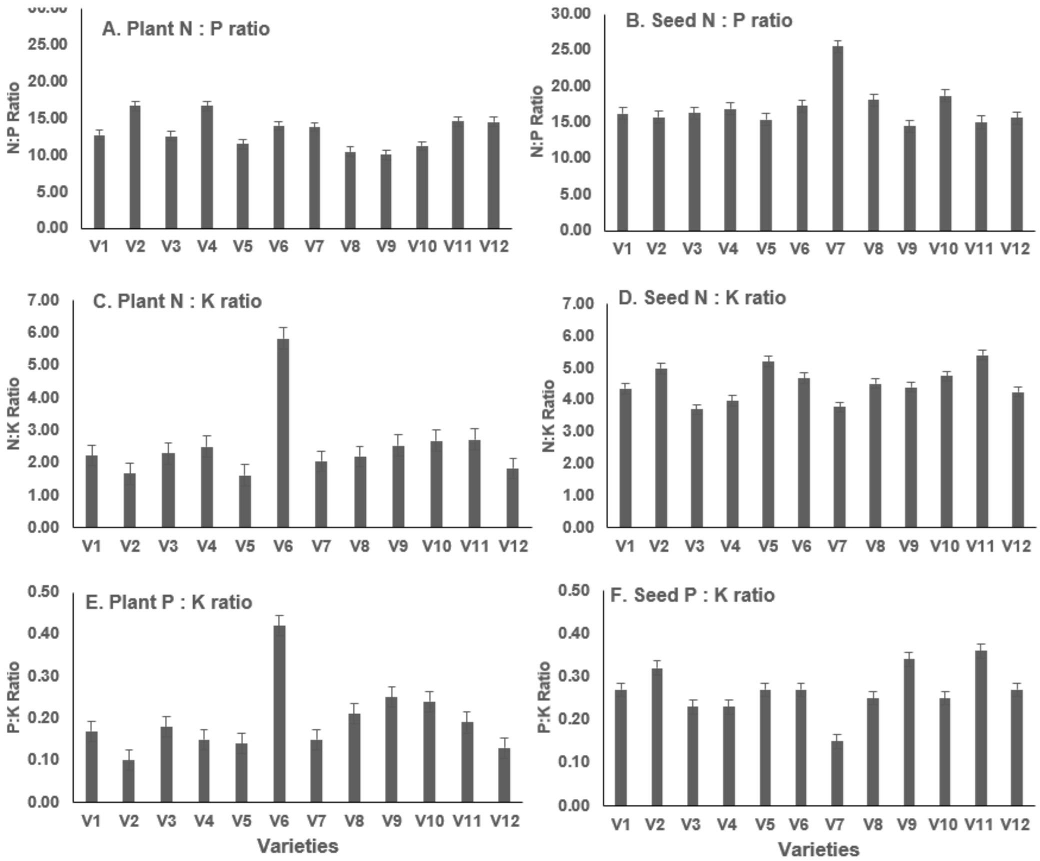

Figure 1. Ratios of N:P, N:K, P:K in plants and seeds of different soybean varieties. V1: “Deja 2”, V2: “Dena 1”, V3: “Denasa 1”, V4: “Denasa 2”, V5: “Dering 1”, V6: “Dering 3”, V7: “Devon 1”, V8: “Devon 2”, V9: “Grobogan”, V10: “Slamet”, V11: “Mallika”, V12: “Anjasmoro”.

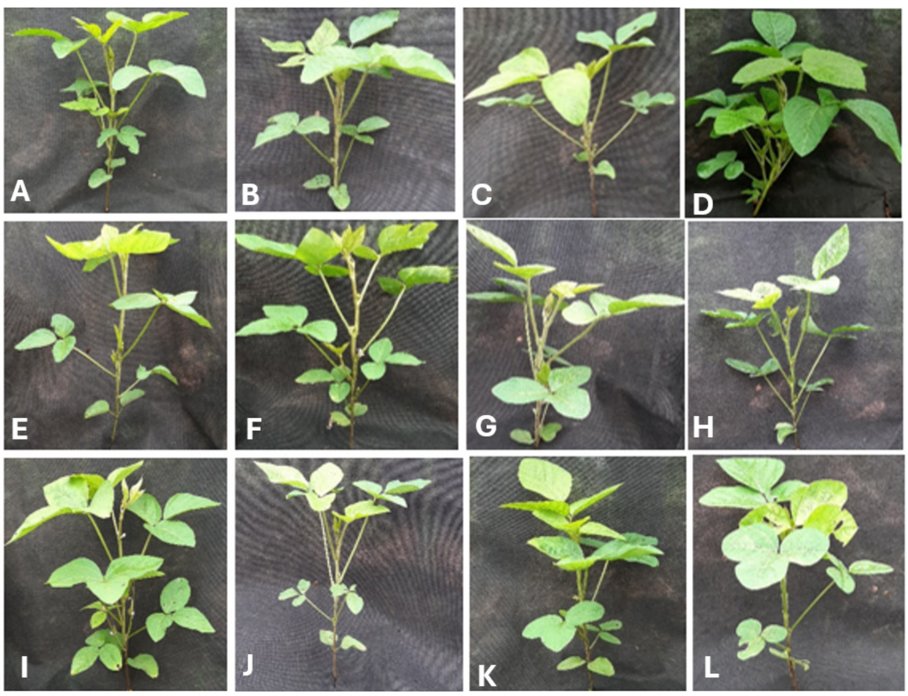

Figure 2. Soybean varieties at 30 days after planting. A: “Deja 2”, B: “Dena 1”, C: “Denasa 1”, D: “Denasa 2”, E: “Dering 1”, F: “Dering 3”, G: “Devon 1”, H: “Devon 2”, I: “Grobogan”, J: “Slamet”, K: “Mallika”, L: “Anjasmoro”.

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Conclusion

Soybean varieties exhibited differences in growth, yield, seed NPK levels, and the stoichiometric of N/P, N/K, and P/K ratios. The NPK levels in seeds were higher than those in stover. "Dena 1, "Devon 2, "Denasa 2, "Grobogan, "Slamet," and "Anjasmoro" are potential soybean varieties with low seed K status. Further studies should evaluate how different levels of K application affect nutrient stoichiometry in soybeans.

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