International Journal on Food, Agriculture, and Natural Resources

Volume 06, Issue 03, Page 55-59
ISSN: 2722-4066
http://www.fanres.org

Original Paper

Crop Development of Soybean Varieties: Mycorrizhal Application On Coastal Sandy Soils

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Received: 21 March 2025; Revised: 12 June 2025; Accepted: 22 September 2025
DOI: https://doi.org/10.46676/ij-fanres.v6i3.513

***Abstract*—This study evaluated the growth and yield of three soybean varieties in response to mycorrhizal dosage on coastal sandy soil in Purworejo Regency, Central Java, Indonesia. The experiment employed a Factorial Randomized Complete Block Design (RCBD) with Split-Plot analysis for growth variables. The first factor was soybean varieties–Grobogan (V1), Burangrang (V2) and Agro Mulyo (V3). The second factor was mycorrhizal dosages–0 g per plant (D1), 1 g per plant (D2) and 2 g per plant (D3). Each of the nine combinations was replicated three times. The observed variables ware Crop Growth Rate (CGR); Relative Growth Rate (RGR); Net Assimilation Rate (NAR); Chlorophyll a (Chl a); Chlorophyll b (Chl b); Harvest Index; Pods per Plant; Dry Weight of Seed per Plant (DSP); Dry Weight of Seed per Sample Area (DSS); Dry Weight of Seed per Hectare (DSH), and Protein Content (PC). Data were analyzed using Analysis of Variance (ANOVA), and significant differences were further examined using post hoc analysis by the Duncan Multiple Range Test (DMRT). The three soybean varieties showed differences in their CGR. The CGR at 59 days after planting showed variations among the three varieties. The most notable increase in CGR was observed in the Burangrang variety between 59 and 73 days after planting. Burangrang also produced the highest average number of pods per plant (67.71 pods), due to vigorous growth and optimal branching (1–2 branches per plant). However, the highest protein content at 42.88% was found in the Grobogan variety by 2 g per plant of mycorrhiza dosage.**

Keywords—Biofertilizer, Crop Growth Rate, *Glycine max* L. Merrill, Protein Content, Staple Crop.

I. INTRODUCTION (*HEADING 1*)

Soybean, a steple crop, is one of Indonesian's top three agricultural commodities [1]. It is a rich source of high-quality protein and one of the earliest plant-based proteins consumed by humans [2]. Despite rising demand, domestic production remains insufficient, leading to imports that threaten national food security. The main challenge is declining yields due to shrinking fertile land and competition with other crops. To address this, the government promotes land extensification on suboptimal area, such as coastal sandy soil and the used of superior varieties with high yield potential and resistance to biotic and abiotic stress [3].

Indonesia, an archipelagic country with approximately 81,000 km of coastline, has coastal zones with agricultural potential [4]. However, these area are largely classified as marginal lands, facing unique challenges [5], such as sandy soils, strong winds, low nutrients levels, high salinity, poor root anchorage due to loose soil structure, low water retention, and high daytime temperatures [4]. Soil texture impacts water retention by influencing field capacity and wilting points. Medium-textured soils have higher field capacity, affecting water availability for plants [6]. To enhance low nutrient levels, most farmers rely on inorganic fertilizers with minimum organic input. However, sandy soil requies organic matter to mitigate limiting factors. For example, adding organic fertilizer during soil tillage enhance root anchorage. Recently, biofertilizer have gained popularity as an environmental friendly approach to maintaining soil health [7]. Mycorrhizal fungi, used as biofertilizer, are known to enhance root architecture and nutrient absorption. They also improve plant tolerance to saline soils by strengthening roots and increasing nutrient uptake [8]. Arbuscular mycorrhizal (AM) fungi, in particular, serve as a direct link between soil and roots [7]. AM can originate in two ways by growing the hyphae longitudinally run through the cortex by the middle lamella to develop vesicles and intercellular arbuscules futhermore hyphae extend into rhizosphere and reach distant and deep in the soil to absorb nutrients and water efficiently even under nutrient and water-depleting soil zones [9].

The genetic capacity and environmental conditions where its grown were determined for a crop performances [10]. Climate change as an environmental conditions was main factor affected plant resistant for abiotic stress. Among of climate change factors, drought stress condition become the most important and the key limiting factor that negatively affects crop productivity [11]. Lack of water and high temperatures in critical stages of soybean development is a growing global problem in soybean cultivation [12]. Water availability during flowering stage until pod filling on soybean development were critical period for soybean yield [13]. Approximately 40% of soybean seed loss is caused by drought [14], therefore, crop cultivars improves to withstand water deficit possess distinct physiological adaptive traits directed mainly to support yield under drought [15].

II. Material And Methods

A. Materials

Soybean varieties was obtained from Indonesian Legumes and Tuber Crops Research Institute. Arbuscular mycorrhiza was obtained from Chemistry and Soil Fertility Laboratory at Universitas Gadjah Mada.

B. Methods

Soybean cultivation on coastal sandy soils poses significant challenges due to harsh environmental conditions such as strong winds and low soil fertility. This study aimed to investigate the effects of different soybean varieties and mycorrhizal dosages on growth and yield, providing insights that could enhance agricultural practices in coastal regions. The study conducted in Munggang Sari Village, Purworejo Regency, Central Java, Indonesia. The land preparation was minimum tillage and constructed a fence around the area using coconut leaves, effectively reducing the impact of strong sea winds and preventing the soybean plants from toppling. A well was built and PVC pipes was installed to establish a shower irrigation system, watering the plants thrice daily.

This study employed a factorial Randomized Complete Block Design (RCBD). The first factor was soybean varieties (V1: Grobogan, V2: Burangrang and V3: Agro Mulyo), and the second factor was mycorrhizal dosages (D1: 0 g per plant, D2: 1 g per plant and D3: 2 g per plant). Each of the nine combinations was replicated three times. Soybean were planted at a spacing of 25 cm x 25 cm spacing on a 5 m^2 bed. Before planting, seeds were inoculated with *Rhizobium japonicum* to ensure the formation of effective root nodules, which is crucial for nitrogen fixation in newly cultivated sandy soils. Mycorrizal was applied one week after planting by creating 5 cm deep holes near the plants for respective dosage. The mycorrhizal fungi enhance nutrient and water uptake, benefiting plant growth in nutrient-poor sandy soils.

Measurement data were taken every two weeks using a Split-Plot Design for growth variables included Crop Growth Rate (CGR), Relative Growth Rate (RGR), Net Assimilation Rate (NAR). For Chlorophyll a (Chl a) and Chlorophyll b (Chl b) content was taken at maximum vegetative stage. Growth variables were analyzed by destructive sampling, where sample was harvested for analysis, providing detailed internal measurements. Subsequently, for yield variables were collected at harvest time, included pods per plant (PP), harvest index (HI), dry weight of seed per plant (DSP), dry weight of seed per sample area (DSS), dry weight of seed per hectare (DSH), and protein content (PC).

Data were analyzed using Analysis of Variance (ANOVA) to determine the significance of treatment effects. For variables showing significant differences, the post hoc analysis of Duncan's Multiple Range Test (DMRT) performed to identify specific differences between treatment means. This study findings offer valuable strategies for improving soybean production in challenging environments, contributing to food security in coastal regions.

III. Result And Discussion

Temperature and humidity were measured twice daily: morning (07:00–08:00) and afternoon (13:00–14:00). The average temperatures were 19.21°C in the morning and 31.19°C in the afternoon,with corresponding humidity levels of 55.26% and 48.01%, respectively. At 27 days after planting (DAP), the V1D3 plot in Block II experienced lodging and stunted growth due to strong, salt-laden sea winds. This adverse condition significantly reduced its productivity compared to the other research plots. To mitigate the impact, protective barriers were reinforced, and the affected plants were closely monitored, though some damage was unavoidable. Grobogan variety was harvested first, followed by Burangrang and Anjasmoro. Grobogan matured earlier than the other two, necessitating an earlier harvest. Harvest timing was determined by observing the change in pod color from greenish to brownish. Harvesting was carried out when 80% to 90% of the soybean pods reached morphological maturity, ensuring optimal seed quality and yield.

The variance analysis in Table 1 indicates that the growth and yield of the three soybean varieties were nearly identical, except for plant growth rate, number of pods per plant, and protein content. Notably, the impact of mycorrhizal dosage was independent of the soybean variety tested, suggesting that mycorrhizal application could be beneficial across different varieties without variety-specific adjustments.

TABLE I. F-Test Matrix Of Observational Data On The Growth And Yield Of Three Soybean Barieties (V) Under Mycorrhizal Dosages (D) Treatments

No	Variables (T)	T						
		V	**D**	**VxD**	**T**	**VxT**	**DxT**	**VxDxT**
1	CGR	s	s	-	s	s	-	-
2	RGR	-	-	-	s	-	-	-
3	NAR	-	-	-	s	-	-	-
4	Chl a	-	-	-				
5	Chl b	-	-	-				
6	HI	-	-	-				
7	PP	s	-	-				
8	DSP	-	-	-				
9	DSS	-	-	-				
10	DSH	-	-	-				
11	PC	s	s	s				

s : significantly different; V: varieties; D: dosages; T : Variables

1) Crop Growth Rate of Soybean Varieties on Coastal Sandy Soil

a) Growh Component

The three soybean varieties exhibited differences in their plant growth rates, indicating that genetic factors influence growth dynamics. All three varieties are considered superior, possessing high yield potential and robust growth, and are suspected to be drought-tolerant. CGR was evaluated at reproductive stage, once every two week started from 31 DAP until 73 DAP. Table 2 showed variations in CGR were observed among varieties. CGR is calculated as the increase in the community biomass per unit area over a specific time period. However, in this study, CGR was measured per individual plant in each planting hole, with four plants sampled during each observation. This approach was chosen due to the sampling method used during the destructive process.

TABLE II. CROP GROWTH RATE OF SOYBEAN VARIETIES ON COASTAL SANDY SOIL

Treatment	CGR		
	1	2	3
V1	0.418	0.530	0.597 s
V2	1.359	1.399	4.014 s
V3	0.513	0.644	1.131 s
$F_{cal\text{-}interaction}$	3.080		
$F_{0.05}$	2.642		

s : significantly different; CGR 1: 31-45 DAP; CGR 2: 45-59 DAP; CGR 3: 59-73 DAP; V1: Grobogan, V2: Burangrang, V3: Agro Mulyo

The most notable increase in the average plant growth rate was observed in the Burangrang variety between 59 to 73 DAP. This is believed to be due to the Burangrang variety having a larger number of leaves, attributed to possessing 1-2 branches per plant. Additionally, the Burangrang variety has broader leaves compared to the other two varieties, resulting in greater assimilation from the photosynthesis process, which is utilized for plant growth. Relative growth rate represents the increase in dry weight over a time interval, in relation to the original weight [16]. The relative growth rate did not show differences among the three plant varieties. This is suspected because the increment of dry weight during the relative growth phase in all three varieties exhibited a nearly identical average pattern. It is presumed that the addition of dry weight per age interval occurred consistently relative to the original dry weight within each plant age interval. There was a decrease in each dry weight increment as the plants aged; however, the Burangrang variety exhibited an increasing pattern in relative growth rate at 59-73 DAP. This is thought to be a characteristic across all three soybean varieties.

The three varieties did not show differences in the average NAR. This is suspected because the increase in source activity or photosynthate production was accompanied by the addition of leaf area at each observation interval in all three varieties. Nevertheless, the Burangrang variety showed a tendency for increased net assimilation rate at 59-73 DAP. This is believed to be because the photosynthate in the Burangrang variety was more extensively used for the thickening of stems and leaves as a response to environmental conditions. Net assimilation rate is the net result of assimilation, mostly derived from photosynthesis per unit leaf area and time. Additionally, leaf thickness also affects the plant's net assimilation rate. The net assimilation rate is not constant over time but shows an ontogenetic decline with plant age [16]. This age-related tendency is accelerated by unfavorable environmental conditions [17], and the gain of dry weight per unit leaf area decreases with the addition of new leaves due to mutual shading [18]. Drought stress at reproductive stage was affected yield, consequently as critical period which the water requirements double compared to the vegetative stage of soybean [19]. The CGR 3 at 59 until 73 DAP, all soybean varieties was at pod filling stage (R5), which was a sensitive stages of drought stress (R1–R6) that significantly reduces yield by affecting pollen fertility, sink size and yield components (seed number per pod and branch) [20;21;22;23].

b) Yield Components

The research results indicated that the three varieties did not show differences in yield components—including dry seed weight per plant, dry seed weight per production plot, and dry seed weight per hectare—except for the number of pods per plant and protein content. Based on variance analysis results, it was shown that the number of pods among the three soybean varieties differed. This is suspected because the tested soybean varieties exhibited highly variable pod counts, but the highest average number of pods was produced by the Burangrang variety, totaling 67.711 pods. This is due to the vigorous growth of the Burangrang variety and its ideal branching pattern of 1-2 branches per plant, leading to an increased number of leaves and more photosynthetic products being translocated for pod formation. Under the drought stress, protein accumulation was higher compared with wild-type soybean, as a result of C1 cysteine protease activity [24].

The mycorrhizal dosage treatments did not affect all growth variables, which include plant growth rate, relative growth rate, net assimilation rate, and chlorophyll a and b content. Based on supporting data regarding existing mycorrhizal infection, it was shown that higher percentages of mycorrhizal infection in plant roots were followed by increased phosphorus uptake in seeds. However, the increase in phosphorus uptake was not significantly different across the mycorrhizal dosage treatments tested. Mycorrhizal infection in roots was relatively low, ranging between 20-40%, with phosphorus uptake in seeds only ranging between 0.83-1.41 g P_2O_5 per plant. Root colonization by arbuscular mycorrhizal fungi (AMF) averaged 68%, showing aggressive colonization of various tropical plant roots growing in acidic mineral soils (Dodd et al., 1990; Sieverding, 1991). This is suspected because not all phosphate can be absorbed by plants; some remains in the soil and cannot be utilized by the plants for their growth.

The application of different doses of mycorrhiza did not significantly affect most yield variables, including harvest index, number of pods per plant, dry seed weight per plant, dry seed weight per production plot, and dry seed weight per hectare.

Variance analysis showed no interaction effects between varieties and mycorrhiza doses on all observed variables. This indicates that differences in all variables were independently influenced by each treatment factor. The variety factor and the mycorrhiza dose factor did not jointly affect the growth and yield of soybean plants; in other words, these two factors acted separately and independently. Dominant environmental factors caused the addition of mycorrhiza doses in each soybean variety to have no significant effect on all growth and yield variables.

2) Interaction Effects between Varieties and Mycorrhiza Doses on Protein Content of Three Soybean Varieties in Coastal Sandy Soils

The interaction between soybean varieties and mycorrhiza application significantly influenced protein content, with the highest values observed across all varieties treated with 2 g mycorrhiza per planting hole. Specifically, Grobogan demonstrated the greatest response (42.88%), followed by Burangrang (40.18%) and Agro Mulyo (37.67%), while untreated plants exhibited the lowest protein levels. These findings align with recent studies highlighting mycorrhiza-mediated phosphorus (P) uptake as a critical driver of protein synthesis in legumes grown in nutrient-poor soils [25]. Coastal sandy soils, characterized by low organic matter and nutrient retention [26], likely amplified soybean dependency on mycorrhizal networks to access immobilized P, thereby enhancing nitrogen fixation and amino acid production [27].

Varietal differences in protein response may reflect genetic variations in root exudate profiles and mycorrhizal colonization efficiency [28]. For instance, Grobogan's superior performance could stem from its enhanced compatibility with mycorrhizal symbionts, facilitating efficient nutrient translocation to seeds. In contrast, Agro Mulyo's lower protein gain might indicate trade-offs in carbon allocation or reduced symbiont compatibility [29]. Nonetheless, the universal protein improvement in mycorrhiza-treated plants underscores its role in mitigating abiotic stress in marginal agroecosystems [30].

The markedly reduced protein content in untreated controls emphasizes the insufficiency of native soil nutrients to sustain optimal biosynthesis. This corroborates findings that mycorrhizal deprivation limits P bioavailability, directly impairing metabolic pathways linked to protein formation [25]. Thus, applying 2 g mycorrhiza per planting hole emerges as a practical strategy to boost soybean protein yields in coastal sandy soils.

IV. Conclusions

The combination of variety and mycorrhiza dosage did not show differences in all observations. However, the Agro Mulyo variety's seed weight could reach 1.29 tons per hectare with a mycorrhiza dose of 2 g per plant. The treatment of the three soybean varieties did not show differences in almost all observed variables, except for the plant growth rate, and the number of pods per plant. However, in the variable of dry seed weight per plant, the Argo Mulyo variety yielded the highest result of 16.378 g per plant compared to the other two varieties.

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