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OPTIMIZING SOYBEAN GROWTH AND YIELD THROUGH ENHANCEMENTS WITH DECANTER CAKE AND PLANT GROWTH-PROMOTING RHIZOBACTERIA

Made Deviani Duaja, Elis Kartika, Buhaira Buhaira, Ismi Barica Icha Wulandari
Agronomy Study Program, Faculty of Agriculture,, Jambi University, Indonesia
Jambi Street, Muara Bulian Km 5, Muaro Jambi, Jambi, Indonesia
email correspondence: made_deviani@unja.ac.id
madedevianiduaja@yahoo.com

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ABSTRACT

Soybean (Glycine max (L.) Merril) is a food and industrial crop and a base for agricultural production. Adding organic material can increase plant growth and produce high yields. One of the organic materials that can be used is palm oil mill solid waste, specifically solid decanter cake (DC). However, the results showed that DC could only substitute 50 per cent of chemical fertilizers. DC must be combined with other materials, specifically Plant Growth plant-promoting rhizobacteria (PGPR), to maximize its benefits. PGPR is a group of bacteria that live in the plant rhizosphere and actively function as biofertilizers, biostimulants, and bioprotectants. Combining DC and PGPR is necessary because they have a mutually beneficial relationship, as DC is an organic material that can provide the nutrients PGPR bacteria need. This research will evaluate whether the collaboration of DC and PGPR can increase soybean growth and yield in ultisols using a Randomized Block Design. Combining decanter cake (DC) with a PGPR concentration can enhance soybean growth and yield. Soybean plants treated with 15-ton ha-1 + 50% PGPR DC tend to have the highest number of leaves, plant height, and number of branches, but DC 10-ton, ha-1 + 30% PGPR, has an equivalent effect. The treatment of 10 tons per hectare of decanter cake with 30% PGPR concentration tended to have the highest number of pods and yield.

Keywords: Bacteria, bean, bioprotectant, palm oil mill, soil

INTRODUCTION

Soybeans are the third most important food crop commodity after rice and corn. It is a vital source of vegetable protein to improve human nutrition and is primary ingredient for making tempeh, tofu, and other foods. The demand for soybeans in Indonesia is estimated at 2.3 million tons of dry beans annually. Over the last five years, the average domestic production has been 982.47 thousand tons of dry beans, meeting 43 percent of the demand (Balitkabi, 2018). However, in 2021, domestic production could only fulfil 25-30 percent of the population's needs. This insufficiency led to reliance on imported soybeans, resulting in fluctuating prices in the market. In response to potential price variations, certain regions have reduced their production of soy-based foods. One potential solution to this issue involves encouraging farmers to cultivate soybeans, aiming to increase productivity from an average of approximately 1.5 tons per hectare to 3.0 tons per hectare (Suci, 2022). This goal can be achieved by improving cultivation techniquesand utilizing idle /abandoned land.

Indonesia possesses a vast area with the potential for soybean cultivation. However, the majority of land in Indonesia is characterized by acidic soil that has experienced extensive weathering, including ultisols and oxisols. According to data from the Central Logistics Agency (2005), ultisols in Jambi Province cover approximately 2.72 million hectares (53.46%) of the total land area of 5.1 million hectares in Jambi Province. Generally, soil fertility in this area is low, especially in acidic mineral soils such as ultisols. Research (Hakim, 2006) defines ultisols as having low pH and organic matter content, high aluminum and phosphorus deficiency levels, and low levels of other macronutrients. These characteristics contribute to the low productivity of ultisol soil, particularly for optimal soybean production. Incorporating organic matter can improve the productivity and soil fertility of ultisols. Adding organic material creates a favourable environment for the growth and development of soybeans (Tisdale et al.,1993).

The organic material that has the most potential and is easy to find, originating from factory waste, is palm oil mill solid waste. This waste is solid or decanter cake (DC) from a palm oil factory. DC comes from mesocarp or palm kernel fibre that has been processed at an oil palm mill, and it is the final product of fresh fruit bunches subjected to a decanter system. (Pahan, 2007). DC can be used as a source of organic matter for ultisols because it has a high pH and contains N nutrients. Analysis results of fermented DC content showed 4.22 percent total N and a pH of 7.32. (Duaja et al., 2019).

Research of Gustianty & Hasibuan (2017) showed that the 15 tons/ha DC application produced the highest plant height, number of leaves, and Pak Choy (*Brassica rapa*) yield. In addition, Damanik et al. (2017) explained that the combination of DC and NPK gave a DC dose of 26 tons/ha, and 50 per cent of the recommended NPK dose gave the highest peanut weight. Furthermore (Duaja, 2019a) found that for celery (*Apium graveolens*), a DC dose of 15 tons ha-1 combined with 50 percent NPK resulted in the highest fresh weight of celery. Furthermore, Duaja et al. (2019a) reported that using DC combined with chemical fertilizers on soybean plants in tidal land resulted in the highest yield of soybean grain at a rate of 20 tons/ha of DC without chemical fertilizers or with DC combined with 50 percent chemical fertilizers. Additionally, the use of DC combined with chemical fertilizers on kailan plants (*Brassica oleracea)* grown in ex-coal mining soil showed the highest wet weight of Kailan achieved at a DC dose of 20 tons/ha combined with 50 percent NPK (Duaja et al., 2020a). Finally, for edamame plants, Duaja (2021) found that combining DC at a rate of 15 tons/ ha and liquid fertilizer with a concentration of 60 percent was the best combination for achieving the highest edamame yield.

To further enhance the effect of decanter cake in increasing soybean yield, liquid fertilizer is required to accelerate the availability of nutrients around the roots, namely, plant growth- promoting rhizobacteria (PGPR). PGPR is a group of bacteria that lives around plant roots, such as *Bacillus*, *Rhizobium*, *Azospirillum* sp., phosphate solubilisers, and Pseudomonas. This group of bacteria is beneficial and aggressive in colonising the root rhizosphere. The activity of PGPR is helpful for plants directly or indirectly. The direct effect is based on its ability to provide, mobilize, and facilitate the absorption of various soil nutrients and synthesize and change the concentration of growth-promoting phytohormones. The indirect effect is related to its ability to suppress pathogen activity by producing different metabolite compounds, such as antibiotics. According to (Utami et al., 2018), soil + compost containing a bacterial formula has a more influential effect on soybean plants than soil + lime.

Research conducted by Madun et al. (2017) on kailan plants (*Brassica et al.* cv. Kailan) revealed that a decanter cake dose of 10 tons ha-1 resulted in the highest fresh weight of Kailan. In addition, (Siringoringo & Duaja, 2016) found that for long bean plants, a decanter cake application of 20 tons per hectare had the same effect as the recommended dose of inorganic fertilizer on all growth parameters, including length and the number of long bean pods. Similarly, decanter cake applications of 15 tons per hectare in Liberica coffee nurseries showed the same effect as inorganic fertilizers on coffee's stem diameter and leaf area (Yacob et al., 2017). Further research Buhaira et al. (2017) demonstrated that applying a decanter cake dose of 15 tons per hectare in combination with liquid fertilizer had the same effect as a decanter cake dose of 20 tons ha-1 on the diameter of Liberika coffee stems. Moreover, Duaja (2019b)) discovered that a DC dose of 15 tons ha-1 gave the highest growth and celery yields and had a significant effect on the number of leaves, number of clumping stems, fresh weight, and dry weight of celery plant roots, with the same effect as the NPK 100 percent dose. Additionally, (Duaja et al., 2020) reported that a DC dose of 15 tons/ha resulted in the highest weight of 100 soybean seeds compared to the inorganic fertilizer treatment.

Moreover, research conducted by (Duaja et al., 2020b) on Kailan plants grown on ex-mining lands showed that decanter cake fertilizer had a significant effect on growth, with the highest wet weight of Kailan achieved at a DC dose of 20 tons ha-1 combined with 75 percent chemical fertilizer.

Furthermore, the study by Jainah et al. (2019) demonstrated an increase in soybean yield by applying 20 ml of PGPR per liter of water and 20 tons/ha of chicken manure. Still, an optimal dose has yet to be determined. (Siadi et al., 2017) PGPR in compost formulations significantly enhances plant resistance to dwarf disease, as evidenced by decreased disease attack percentage and increased plant peroxidase activity. The peroxidase activity was increased by 80.25 percent - 97.33 percent compared to the control due to the PGPR treatment of the compost formulation. Moreover, Rosyida & Nugroho (2017) reported that the highest wet weight of pakchoy plants was achieved with 25 percent NPK + 75 percent PGPR treatment, while the plants treated with 75 percent NPK + 25 percent PGPR exhibited the highest chlorophyll content among other plant leaves. This research will evaluate whether the collaboration of DC and PGPR can increase soybean growth and yield in ultisols.

MATERIALAND METHODS

Materials

The materials utilized in this study included soybean seeds of the Anjasmoro variety. The primary fertilizer was cow manure collected from the Faculty of Animal Husbandry at Jambi University (located in coordinates -1.6145864, 103.5184665). Fresh decanter cake was obtained from PT. Batanghari Sawit Sejahtera in Lubuk Raman village (location in maps 1.34630,103.55167) in Tanjung Jabung Barat Regency. Before use, the decanter cake was fermented for four weeks with biodecomposer commercial (EM4). The PGPR used is a commercial one; it contains the bacteria *Azotobacter* sp., *Azospirillum* sp., *Aspergillus* sp., *Bacillus* sp., *Rhizobium* sp., and *Pseudomonas* sp., with a density of 108 CFU ml-1. Additionally, the fertilization dose followed each treatment.

Experimental design

The study used a randomized complete block design with six treatments. Each treatment is repeated four times. The treatments consisted of a combination of decanter cake (DC) and plant growth-promoting rhizobacteria (PGPR): P0 = DC 10 tons/ha + without PGPR, P1 = DC 15 tons/ha + without PGPR, P2 = DC 10 tons/ha + 30 ml PGPR L-1 of water, P3 = DC 15 tons/ha + 30 ml PGPR L-1, P4 = DC 10 tons/ha + 60 ml PGPR L-1, and P5 = DC 15 tons/ha + 60 ml PGPR L-1. The variables observed were plant height, number of leaves, number of branches, seed weight per plant, number of pods containing grains, and weight of 100 grains. The data were analyzed using one-way analysis of variance (ANOVA), and the means were compared for significance by the Least Significant Difference Test at $P < 0.05$. The statistical analysis is performed using SPSS 22.0 software.

Management

This research was conducted at the Teaching and Research Farm, Faculty of Agriculture, Jambi University, Mendalo Darat Village, Jambi (coordinates -1.60584, 103.52016) from June to December 2022. The palm oil mill solid waste decanter cake was obtained from the factory in a wet form and fermented using EM4 as a decomposer. It was mixed with sawdust, limestone, rock phosphate, humic acid, mycorrhizal propagules, and *Trichoderma* sp.

All the ingredients were thoroughly mixed and left for 90 days to mature into organic fertilizer. The experiment followed a randomized complete block design with six treatments and four replications. Each treatment consisted of 36 plants, with one plant per hole. Based on the evaluated parameters, the plant's response to the treatments was observed at 14, 21,28, and 35, 42 days after planting (DAP) for number of leaves and plant height. The parameters of soybean branches were observed 28, 35, and 42 days after planting. Parameters: Several soybean pods were observed at various plant ages, 49,56,63 and 70 DAP. Number of pods, weight, number of pods Containing grains and hollow pods at each decanter cake dosage, and each PGPR concentration counted at harvest.

Soil and Material Analysis

Soil analysis was conducted before and after the research, and plant tissue analysis was conducted in the V4 phase. Before planting began, soil samples were taken from the research area. All the samples were placed into paper bags, and the chemical and physical properties of the soil were analyzed.

RESULTS AND DISCUSSION

The availability of nutrients in soil and plants affects the growth and production of soybeans, and soil nutrient content generally shows criteria ranging from low to very high. The soil analysis results conducted before the experiment showed that the soil was acidic, with a shallow total N content (0.09%) and moderate soil fertility with a very high P2O5 content (26 mg 100 g-1) and medium K2O content. The organic C content in the soil was found to be 0.35 percent, which falls under the low category.

Oil palm processing activities generate liquid, solid, and gaseous waste, with solid waste including empty fruit bunches, shells, fibers, sludge, decanter cake, and oil palm cake (Pahan, 2006). Decanter cake (DC) is a solid waste produced during crude palm oil processing. It is called palm sludge in Indonesia, and it is typically separated from liquid waste. A single palm oil mill processes approximately 4.5 tons of fresh fruit bunches per hour, generating 4 percent solid waste, or 180 kg of solid waste (decanter cake), for every ton of fresh fruit bunches processed (Tim et al., 2000). Although the capacity of each palm oil mill varies, the average processing capacity is 4.5 tons per hour. However, the decanter cake is typically not utilized by palm oil factories and is discarded around the plantation, causing potential environmental pollution.

The decanter cake analysis revealed that the fermented solid nutrient content contains N 3.52 percent, total P205 1.97 percent, K2O 0.33 percent, CaO 2.53 percent, MgO 0.49 percent, C-Organic 15.73 percent, C/N 4.47 percent, and pH 7.4. With a relatively low C/N ratio, the decanter cake is easily decomposable and provides plant nutrients quickly. The availability of adequate nutrients at the start of plant growth and throughout its life cycle significantly affects plant growth and yield. Applying decanter cake to plants can improve soil's physical, chemical, and biological properties and reduce the need for inorganic fertilizers (Pahan, 2006). Plant growth-promoting rhizobacteria (PGPR) play a vital role in the biocontrol of plant pathogens and can enhance seed germination, root development, and water utilization (Gashash et al., 2022). The microbial population in the soil near plant roots (rhizosphere) is generally higher than in other soil areas because plant roots secrete secondary metabolites such as sugars and amino acids that serve as the energy source for microorganisms. Combining PGPR with organic matter, such as decanter cake, has an interconnected effect. PGPR requires an energy source, which can be obtained from a decanter cake. The organic matter triggers various mechanisms of PGPR, including biological nitrogen fixation, ethylene level reduction, siderophore production, phytohormone production, induction of pathogen resistance, nutrient solubilization, mycorrhizal functioning, and decreased pollutant toxicity.

Decanter cake and PGPR content analysis

Organic C content is a significant factor in determining mineral soil quality. The higher the total organic C content, the better the quality of the mineral soil. Soil organic matter is vital in improving soil physical properties, increasing soil biological activity, and increasing plant nutrient availability. The analysis showed that the decanter cake had a high range of C-Organic content (23.89%), with a C/N ratio of 14.22 and macro elements (N 2.68; P2O5 0.46; K2O 0.13). The pH was 6.5, and The plant growth rhizobacteria (PGPR) used are commercial, with content included *Trichoderma harzianum* at 5.00 x 108 CFU/ml, *Azospirilum* sp. at 2.90 x 10' CFU /ml, *Rhizobium* sp. At 2.80 x 10' CFU /ml, *Aspergillus niger* at 5.00 x 100 CFU/ml, and *Pseudomonas fluorescent* at 2.65 x 109 CFU /ml.

Number of Leaves

The development of soybean plant leaves showed slow progress at the beginning of growth until 42 DAP. The pattern of the number of leaves development is affected by the combination of decanter cake and PGPR concentration.

At the early growth stage, no significant difference was observed between treatments. However, as the soybean plants grew older, at 28 DAP, the combination of 10 tons ha-1 of decanter cake with a PGPR concentration of 30 ml L-1 showed a similar effect on the number of leaves to the treatment of DC 15 tons ha-1 + 50 ml L-1 PGPR, and this trend continued until 35 DAP.

Table 1 The Development of the number of leaves of soybean

Various DC Dose and PGPR Concentration	Days after planting (DAP)				
	14	21	28	35	42
DC 10 ton ha^{-1} +0% PGPR	$3.93±0.07^a$	$7.00±0.50^a$	$9.67±0.71^a$	$12.6±1.25^a$	$15.50±1.66^b$
DC 15 ton ha^{-1} +0 % PGPR	$4.00±0.23^a$	$7.23±0.29^a$	$10.67±0.98^a$	$13.73±0.81^a$	$14.65±0.64^b$
DC 10 ton ha^{-1} + 30 % PGPR	$3.93±0.07^a$	$7.33±0.53^a$	$11.33±1.12^b$	$13.93±0.47^{ab}$	$15.80±2.85^b$
DC 15 ton ha^{-1} + 30 % PGPR	$3.87±0.07^a$	$6.93±0.52^a$	$10.67±0.73^a$	$13.80±1.06^a$	$12.20±0.44^a$
DC 10 ton ha^{-1} +50% PGPR	$4.07±0.07^a$	$7.33±0.33^a$	$9.80±0.80^a$	$13.60±1.00^a$	$15.90±0.53^b$
DC 15 ton ha^{-1} +50 % PGPR	$3.87±0.24^a$	$7.20±0.31^a$	$12.0±0.42^b$	$15.20±1.11^c$	$16.85±0.68^c$

Note: Figures columns followed by different letters show a significant difference at 5% of DMRT

Table 1 shows that increasing the dose of decanter cake and PGPR concentration increased the number of leaves. The development pattern depends on various combinations of decanter cake doses and PGPR concentrations. Decanter cake is a fertilizer that utilizes microbial-based ingredients during fermentation, which can promote plant growth. Providing organic materials such as decanter cake can increase phosphorus availability by suppressing the activity of aluminum and iron in Ultisol. According to (Jindo et al., 2020), the presence of phosphorus (P) is affected by the level of organic matter in the soil, its pH value, and the presence of exchangeable and soluble forms of aluminum (Al), iron (Fe), and calcium (Ca).Top of Form Furthermore (Ch'Ng et al., 2014), this is due to compost from agro-industry waste being able to increase soil pH and reduce soil acidity, thereby increasing available phosphorus and reducing exchangeable acidity, aluminum, and iron.

Moreover, PGPR utilizes nitrogen fixation as a primary mechanism to stimulate plant growth. Pseudomonas sp. has the potential to be a fertilizer since it can fix free nitrogen and dissolve phosphate as a source of nutrients for soybeanplants (Singh et al., 2011).

Plant Height

The rapid increase in soybean plant height was observed in the initial growth stage until 28 days after planting (DAP), followed by rapid growth and a slight increase during the reproductive stage at 35- 42 DAP. The diverse combinations of decanter cake doses and PGPR influenced the growth pattern of plant height. Notably, the treatment involving 15 tons ha-1 of decanter cake and 50 ml L-1 of PGPR tend demonstrated a significant disparity in plant height compared to other treatments. This indicates that the tallest plants were achieved with the highest dose of decanter cake with or without PGPR. The combination of decanter cake and plant growth-promoting rhizobacteria (PGPR) significantly impact the growth height of soybean plants, although early growth shows the same effect.

Number of Branches

At the beginning of the observation, the 14- 22 DAP indicates no branch growth. In these early phases, the plant is more focused on primary stem growth and elongation, where the growth tends to be at the root tip and stem tip (primary meristematic) and soybean root nodules growth (Streeter, 1981)). Branch growth begins to appear at the age of 22 -28 DAP.

Table 2 The Development of soybean plant height

Various DC Dose and PGPR Concentration	Days after planting (DAP)				
	14	21	28	35	42
DC 10 ton ha^{-1} +0 % PGPR	12.2±0.11^{a}	28,67±0,74^{a}	49,2±4,35^{a}	76,0±1,10^{b}	92,67±0,53^{a}
DC 15 ton ha^{-1} +0 % PGPR	11.8±0.001^{a}	29,2±0,41^{a}	51,33±1,69^{ab}	75,53±0,24^{a}	96,93±1,39^{b}
DC 10 ton ha^{-1} + 30 % PGPR	11.54±0.17^{a}	28,8±2,07^{a}	48,0±3,27^{a}	73,3±2,78^{a}	92,4±0,72^{a}
DC 15 ton ha^{-1} + 30 % PGPR	11.6±0.40 ^{a}	31,00±1,73^{a}	51,87±3,63^{ab}	75,13±0,18^{a}	93,53±1,09^{a}
DC 10 ton ha^{-1} +50 % PGPR	11.6±0.50^{a}	28.33±2.97^{a}	48,2±4,41^{a}	68,53±2,78^{a}	95,80±2,30^{b}
DC 15 ton ha^{-1} +50 % PGPR	12.4±0.35^{a}	30.67±1.27^{a}	53,27±3,06 ^{b}	76,45±1,96^{b}	98,8±0,95^{c}

Note: The columns of the figures followed by different letters show a significant difference at 5% of DMRT; DC: Decanter Cake, PGPR: Plant growth-promoting rhizobacteria; ±: Standard error.

Regarding branch count, the combination of decanter cake treatment and plant growth-promoting rhizobacteria influenced the number of branches at 35 and 42 days after planting (DAP). However, the impact on branch count differed from that on plant height. An increase in the decanter cake dose and PGPR concentration led to a rise in branches. Nevertheless, in the early phase, they exhibited a similar effect to all treatments. At the early stages of soybean growth, the effect of combining decanter cake and plant growth-promoting rhizobacteria (PGPR) on the number of soybean branches may not be significant due to the energy and resources are primarily directed towards establishing a solid root system. According to (Adnan et al., 2021) 2021, in the early phase, the number of branches dependson genetic factors.

The combination of decanter cake treatment and plant growth-promoting rhizobacteria affected the number of branches at 35 and 42 DAP. However, the effects varied. The number of branches increased with the dose of decanter cake and PGPR concentration. However, in the early phase, all treatments showed the same effect on the number of branches. At 42 days after planting, all treatments had a similar effect except for DC 15 tons per hectare + 30% PGPR.Decanter cake, a by-product of the oil extraction process, is rich in organic matter and nutrients, improving soil fertility and structure and providing a better environment for soybean root development (Ashaembrandiri, 2016). On the other hand, PGPR are beneficial bacteria that colonize plant roots and enhance plant growth by various mechanisms, including nitrogen fixation, phosphate solubilisation, and the production of growth-promoting hormones such as auxins and cytokinins.

Sugeng (2005) states that an imbalance of nutrients can lead to reduced production. The concentration of nutrients significantly impacts plant growth and yield, and the limiting factors strongly influence plant production. (Lingga/ & Marsono, 1986) also agree that plants require sufficient elements to grow and produce, available around the root. Plants acquire P as phosphate, which is present in deficient concentrations in the soil solution, making it necessary for roots to search for this element (Hammond et al., 2009). PGPR promotes plant growth by producing a siderophore to sequester the limited supply of iron in the rhizosphere, reducing its availability to develop microbial

Table 3 The development of soybean Branches

Various DC Dose and PGPR Concentration	Days after planting (DAP)		
	28	35	42
DC 10 ton ha^{-1} + 0% PGPR	1.53±0,24 ^{a}	2.73±0,43^{a}	3.60±0.50 ^{b}
DC 15 ton ha^{-1} + 0% PGPR	2.00±0,50^{a}	3.13±0,53^{ab}	3.89±0.64 ^{b}
DC 10 ton ha^{-1} + 30% PGPR	1.33±0,24^{a}	2.73±0.29^{a}	3.77±0.38 ^{b}
DC 15 ton ha^{-1} + 30% PGPR	1.60±0,64^{a}	2.80±0.75^{a}	3.27±0.48 ^{a}
DC 10 ton ha^{-1} + 50% PGPR	1.67±0,69^{a}	3.45±0,55^{b}	3.87±0.44 ^{b}
DC 15 ton ha^{-1} + 50% PGPR	1.73±2.49^{a}	2.67±2.45 ^{a}	3.80±0.53 ^{b}

Note: Figures columns followed by different letters show a significant difference at 5% of DMRT, ±: Standard error, DC: Decanter Cake, PGPR: Plant growth promoting rhizobacteria pathogens. A siderophore is a Fe3+ complexing compound or a specific iron-chelating compound produced by microbes to hide elements of micro-iron in the rhizosphere environment. (de Andrade et al., 2023).

Yield Components and Yield of Soybean

Number of Pods at Various Days After Planting

Applying different concentrations of plant growth-promoting rhizobacteria (PGPR) with decanter cake affected the number of pods at 56 and 70 days after planting (DAP). Increasing the dose of decanter cake and PGPR concentration increased the number of pods. However, in the early stages, all treatments had the same effect. At 63-70 DAP, rapid pod development and 15 tons per hectare of decanter cake with 30 percent PGPR concentration tended to have the lowest number of pods at various plant ages.

The application of decanter cake with different concentrations of PGPR influenced the number of pods at harvest. At a dose of 10 tons ha-1, all PGPR concentrations showed similar effects on the number of pods. The number of pods showed a similar effect for all treatments. However, it showed a different result based on the content of grains in the pods. Even though the number of pods was similar for all treatments, the number of pods with grains showed a significant effect. Even without PGPR, increasing the decanter dose to 15 tons per hectare had a significantly different effect-the number of pods containing grains per plant. DC does 15 tons/ha +30 %, which showed the highest number of pods with grain and had the same effect as DC 15 tons ha^{-1} +0% PGPR. DC contains a high N level, according to that the highest total N content could also affect seed formation because nitrogen is a chlorophyll- forming component which is the primary source in the photosynthesis process, which produces carbohydrates and energy for building the structure of the plants, including flowers and fruit (Ferayanti et al., 2020)

However, at a DC dose of 15 tons ha-1, both 0 percent and 50 percent PGPR concentrations resulted in the highest number of filled pods. All PGPR concentration levels had a similar effect at each DC dose, except for a concentration of 30 percent.

The number of empty pods showed that the decanter cake dose + PGPR concentration had a different effect on it. The lowest number of empty pods was observed at a decanter cake dose of 10 tons/ha + 30% PGPR, while the

Table 4 The Development of Several Pods at Various Plant Ages

Various DC Dose + PGPR Concentration	Days after planting (DAP)			
	49	56	63	70
DC 10 ton ha^{-1} +0% PGPR	7.07±0.18[a]	13.05±0.95[b]	43.25±2.92[a]	72.65±0.13[ab]
DC 15 ton ha^{-1} +0% PGPR	7.60±1.40[b]	11.85±1.91[a]	46.00±3.14[b]	74.65±0.74[b]
DC 10 ton ha^{-1} + 30% PGPR	6.40±0.40[a]	12.65±1.35[a]	45.15±5.31[ab]	72.45±2.02[b]
DC 15 ton ha^{-1} + 30% PGPR	6.73±0.41[a]	12.45±1.00[a]	41.30±4.09[a]	67.25±2.26[a]
DC 10 ton ha^{-1} +50% PGPR	6.60±0.72[a]	12.90±1.00[a]	45.80±3.13[ab]	73.45±1.40[b]
DC 15 ton ha^{-1} +50% PGPR	6.53±0.73[a]	13.70±1.50[b]	46.05±2.63[b]	76.35±2.05[b]

Note: Figures columns followed by different letters show a significant difference at 5% of DMRT; ±: Standard error, DC: Decanter Cake, PGPR: Plant Growth Promoting Rhizobacteria

Table 5 Number of pods, pods weight, number of pods Containing grains and number of hollow pods at each decanter cake dosage and each PGPR Concentration at harvest

Various DC Dose + PGPR Concentration	Number of pods per plant	Pods weight per plant (g)	The number of pods containing grains per plant	Number of hollow pods
DC 10 ton ha^{-1} +0% PGPR	96.8 ±0.13[a]	78.40 ±0.55[a]	81.7±0.81 [a]	15.13±0.81[e]
DC 15 ton ha^{-1} +0% PGPR	96.6±2.02[a]	82.43±4.02[a]	89.9±1.91 [bc]	6.93 ±0.93[a]
DC 10 ton ha^{-1} + 30% PGPR	97.9± 1.40[a]	86.10±3.76[b]	87.4 ±0.76 [b]	9.33±1.04[bc]
DC 15 ton ha^{-1} +30% PGPR	99.5 ±0.74[a]	90.28±5.23[b]	90.5±2.82[c]	9.00±2.51[b]
DC 10 ton ha^{-1} + 50% PGPR	89.6± 2.26[a]	82.01±3.65[a]	81.7±1.80[a]	10.47±1.01[c]
DC 15 ton ha^{-1} +50 % PGPR	97.8± 2.05[a]	83.19±2.52[a]	83.8±0.77[a]	13.93±1.34[d]

Note: Figures columns followed by different letters show a significant difference at 5% of DMRT; ±: Standard error, DC: Decanter Cake, PGPR: Plant Growth Promoting Rhizobacteria

highest number of empty pods was found at a decanter cake dose of 10 tons/ha without PGPR. Providing PGPR with the decanter can reduce the number of empty pods and ultimatelyincrease the number of filled pods.

Pod weight per plant

The table above shows that the decanter cake treatment of 10-ton ha-1 + 50 per cent PGPR has a similar effect to that of 15-ton ha-1 + 0% PGPR. If the decanter cake dose is 10 tons ha-1, it should receive a 50 per cent PGPR. Increasing the dose of decanter cake to 15 tons per hectare showed a significantly different effect without applying PGPR.

Weight of 100 seeds

The weight of 100 seeds showed it is evident that all treatments have a similar effect, except for the DC 15 tons/ha + 50 per cent PGPR concentration. To obtain large soybean seeds, organic matter from decanter cake should be provided along with plant growth-promoting rhizobacteria (PGPR) at the highest concentration of 50 per cent. Hundred seed weight, in this study, was higher than the soybean description. Larger seeds may come from plants with better growth characteristics.

Similarly, grain weight per plant showed that the lowest seed weight per plant was observed at a decanter cake dose of 10 tons/ha without PGPR. However, if the decanter cake dose is increased to 15 tons/ha, without PGPR, it will give the same effect as that given by PGPR.

Table 6 Weight of 100 grains per plant at each decanter cake dosage and each plant growth Promoting Rhizobacteria (PGPR) Concentration

Various DC Dose + PGPR Concentration	Weight of 100 grains (g)	Grains weight per plant (g)
DC 10 ton ha^{-1}+ 0% PGPR	19,9 ±0,03 [a]	55,1 ± 2,50[a]
DC 15 ton ha^{-1} +0% PGPR	20,54 ±0,02[a]	64,1 ± 4,02 [b]
DC 10 ton ha^{-1} + 30% PGPR	20,62±0,19 [a]	66,2 ± 3,76 [b]
DC 15 ton ha^{-1} +30% PGPR	21,2±0,63 [a]	69,9 ± 5,23 [b]
DC 10 ton ha^{-1} + 50% PGPR	20,52±0,59[a]	64,1 ± 3,65 [b]
DC 15 ton ha^{-1} +50 % PGPR	29,8±0,26 [b]	64,1 ± 3,65 [b]

Note: Figures columns followed by different letters show a significant difference at 5% of DMRT Uppercase for horizontal reading while lowercase for vertical reading; ±: Standard error, DC: Decanter Cake, PGPR: Plant Growth Promoting Rhizobacteria

CONCLUSION

The optimum yield was observed when soybean plants were treated with 10 tons/ha of decanter cake (DC) and a 30% concentration of Plant Growth-Promoting Rhizobacteria (PGPR), resulting in the highest pod weight. This combination equalled the performance of a 15 tons/ha DC application with the same PGPR concentration. Such integration of DC and PGPR effectively promotes soybean growth and productivity, impacting seed weight per 100 seeds, pod weight per plant, and seed-bearing pod count. The most effective mix for soybean enhancement involves using DC at 10 tons/ha alongside a 30% PGPR concentration.

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