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Agronomic Responses of Soybean (*Glycine max* L. Merrill) to Spent and Deoiled Bleaching Earth Filler-Based NPK Fertilization

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ABSTRACT

The objective of study was to study the effects of spent bleaching earth (SBE) and deoiled bleaching earth (DBE) filler-based NPK fertilizers on agronomical characters of soybean as a model crop. A field experiment was arranged in a single factor of randomized complete block design (RCBD) with four blocks as replications. The treatments were 1) NPK fertilizer with 10% of BC (control), 2) NPK fertilizer with 5% of BC + 5% of SBE, and 3) NPK fertilizer with 5% BC + 5% DBE. The variables observed were the levels of heavy metals in leaf tissue and the agronomic characteristics of soybean plants. The observations were made on several variables of and crop agronomical characters. The data were then analyzed with analysis of variance (ANOVA) at 5% levels, and continued with the Least Significant Difference (LSD) test if there were differences among treatments. The results confirmed that the SBE and DBE materials could partially replace the filler components in bentonite clay filler-based NPK fertilizers, which were shown to have the same effect on soybean agronomic characters in the form of leaf area, root volume, number of pods per plant, number of seeds per plant, and dry seed yield per hectare.

Keywords: *bentonite clay, heavy metals, NPK fertilizer, SBE, soybean*

1. INTRODUCTION

The quality of palm oil is determined by the level of purity of crude palm oil (CPO). CPO still contains several impurities, including coloring compounds (especially α and β-carotene) (Ribeiro et al., 2017) and heavy metals (Khan et al., 2020) which are also extracted during the pressing process of palm oil. These impurities are then removed during the refining process because they affect the quality of the palm oil (Ashaari et al., 2021).

Bleaching is one of the stages – in the CPO refinement process – which sufficiently determines the quality of the cooking oil produced which includes a pale yellow color and does not contain heavy metals (Hasibuan, 2016). Bleaching CPO is carried out using adsorbents (such as bleaching earth and activated clay/activated charcoal). In Indonesia, the cooking oil industry generally uses bleaching earth as an adsorbent because the price is cheaper and the absorption ability is the same when compared to activated charcoal (Haryono et al., 2012).

Used bleaching earth or SBE (Spent Bleaching Earth) is the largest waste in the cooking oil industry (Yusnimar et al., 2012). The more palm oil production that is used, the more bleaching waste in the form of SBE will also be produced. Even though based on PP No. 101 of 2014, SBE is categorized as a hazardous toxic waste (B3 waste), because SBE can cause pollution to soil, water, and air (Pasaribu & Sukandar, 2017). However, according to several studies, SBE and also the results of recovery in the form of deoiled bleaching earth (DBE) are potential materials that can be reused.

It is important to innovate the use of SBE as an effort to overcome the problems caused by B3 waste. Until now, the problem of B3 waste in the form of SBE has not been resolved, it is only dumped in land as landfills. In fact, SBE has the potential to be used as an economically valuable material. The economic potential of SBE is a potential substitute for pure clay components which are adhesives in the manufacture of compound NPK fertilizer. At this time the type of adhesive used is pure bentonite clay (brown/bentonite clay/BC). The bentonite clay has similar characteristics to bleaching earth (Sinaga et al., 2021).

Anugrah et al. (2020) and Purba et al. (2020) in a previous study on hybrid maize (*Zea mays* L.), reported that partial replacement of adhesive in NPK fertilizer using SBE and DBE waste material had the same effect as applying NPK fertilizer with bentonite clay adhesive on the biochemical and agronomic characters of hybrid corn. However, there was an increase in several biochemical observation variables which indicated the plants were experiencing oxidative stress which was thought to be due to the application of NPK fertilizer with adhesive waste material containing several types of heavy metals at the end of the observation.

In this study, the model plant used was soybean. Wahyudin et al. (2017) stated that in the food crop group, soybean is the third most important commodity after rice and corn which is rich in protein and is much needed in the food and feed industry. In addition to this, soybean plants (*Glycine max* L.) are also sensitive to soil acidity, salinity and toxic elements such as heavy metals, which are thought to be contained in SBE and DBE (Taufiq & Sundari, 2012; Wisnubroto et al., 2021).

Mao et al. (2018) in his research stated that soybean plants treated with heavy metals Cd, Cr, Cu, Pb, and Hg in a hydroponic system, at low concentrations showed an increase in growth variables in the form of root length and dry weight. However, as the concentration of heavy metals increased, soybean plants experienced growth disturbances in the form of low root length and dry weight.

Therefore, this research needs to be conducted to provide more detailed information regarding the agronomic response of soybean as a model crop – which has a high use value and is sensitive to heavy metals – to NPK fertilization in which some of the adhesive is substituted by SBE and DBE materials, so that it can be known whether the use of these two waste materials is safe to be implemented as an adhesive in the production of NPK fertilizer.

2. MATERIALS AND METHODS

This research was carried out at the Field of the Agro-Technology Innovation Center (PIAT), Universitas Gadjah Mada, Yogyakarta for soybean planting locations. Destructive observation activities were carried out at the Plant Science Sub-Laboratory, Plant Management and Production Sub-Laboratory, Plant Ecology Sub-Laboratory, Faculty of Agriculture, Universitas Gadjah Mada. Analysis of soil nutrient content was carried out at the Assessment Institute of Agricultural Technology (BPTP) Soil Laboratory, Maguwoharjo, Yogyakarta and the Analytical Chemistry Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Gadjah Mada. This research was conducted in October 2018–January 2019.

The field experiment was arranged in a single factor of randomized complete block design (RCBD) with four blocks as replications. The treatments tested consisted of 10% bentonite clay filler-based NPK fertilization (control), 5% bentonite clay + 5% SBE filler-based NPK fertilization and 5% bentonite clay + 5% DBE filler-based NPK fertilization. The SBE and DBE used were obtained from PT. Sentana Adidaya Pratama (SADP), which is a subsidiary of the Wilmar Group Indonesia. Fertilizer was applied using a deep placement system with a distance of ±5 cm from the roots of the plants so as not to disturb the roots.

The variables observed were 1) heavy metal levels in plant leaf tissue based on the method of Eviati & Sulaeman (2009); 2) agronomic characteristics which include a) crown part, namely leaf area and yield components (number of pods per plant, number of seeds per plant, and dry seed yield per hectare) and b) root part, namely root volume; and 3) analysis of plant growth, namely net assimilation rate (NAR) based on the method of (Watson, 1952). Observations related to the variable levels of heavy metals in leaf tissue and yield components were carried out at 70 days after planting (DAP), while leaf area and root volume were carried out at 30, 49, and 70 DAP. The data obtained were tested with analysis of variance (ANOVA). The variables showing significant differences between treatments were then tested with the Least Significant Difference

(LSD) test at 5%. The data analysis process was carried out using the SAS software version 9.4. The flowchart of the research implementation is presented in Figure 1 as follows.

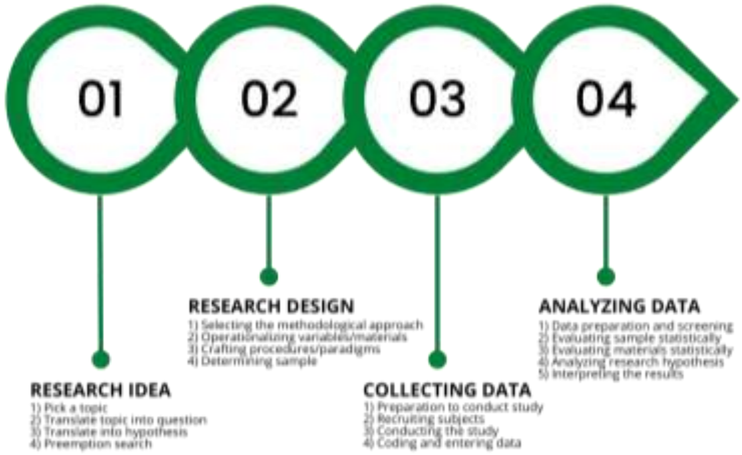

Figure 1. Flow chart of research implementation

3. RESULTS AND DISCUSSION

The results of fertilizer analysis showed that the levels of heavy metals in NPK fertilizer with SBE and DBE adhesives were higher than BC (Anugrah et al., 2020; Purba et al., 2020; Sinaga et al., 2021; Wisnubroto et al., 2021). This is most likely due to the fact that SBE and DBE are residual materials in the *bleaching* process which, in addition to removing dyes, can also reduce other unwanted components such as heavy metals.

According to Setiawan & Indrasti (2009), palm oil actually contains heavy metals. Heavy metals in palm oil can be assumed to originate from fertilization and control of plant-disturbing organisms (OPT) whose ingredients contain heavy metals and due to machine contamination during the extraction process. The content of heavy metals in palm oil cannot be completely removed but can be reduced during the refining process.

Heavy metal levels in leaf tissue

In general, heavy metals can be divided into two types, namely 1) essential heavy metals, namely heavy metals needed by organisms, but in excessive amounts can cause toxic effects, including Cu, Ni, and Zn and 2) non-essential heavy metals, whose benefits are unknown and even toxic, including Ag, Cr, and Pb. This shows that the presence of heavy metals in SBE and DBE materials (which are used to substitute some of the adhesive components in NPK fertilizers) as long as their levels are within optimal limits is actually beneficial for plants.

Nutrient levels (including essential and non-essential heavy metals) in plant tissue are an illustration of the nutrients contained in the soil. This is based on the principle that plant nutrient levels are the result of the interaction of all factors that influence the absorption of these nutrients from the soil.

In general, the plant tissue that is analyzed is the leaves based on the assumption that the nutrients taken from the soil will then be translocated to all parts of the plant, especially to the leaves. In addition, leaf organs are the main site of metabolism in plants (Hernita, 2016).

Based on this, measurement of variable levels of heavy metals in soybean plant leaf tissue is needed to identify heavy metals present in the soil. These measurements were made when the plants were 70 DAP which are presented in Table 1 as follows.

Table 1. Heavy metal levels in soybean plant leaf tissue on different types of NPK fertilizer adhesives at 70 DAP

Heavy Metal	Treatment	Heavy metal content in leaf tissue (ppm)	CV (%)	Critical limit of metals in soybean plant tissue (ppm)
Cr	BC	0.38 a	19.81	50–100 (Amin et al., 2014)
	SBE	0.38 a		
	DBE	1.28 a		
Ni	BC	0.25 a	25.78	50–100 (Fitriani et al., 2019)
	SBE	1.99 a		
	DBE	3.03 a		
Zn	BC	26.78 b	10.31	150–200 (Fageria et al., 1997)
	SBE	28.99 ab		
	DBE	32.24 a		

Remarks: Means followed by the same letters in the same column are not significantly different according to the LSD test at 5%; BC= NPK + 10% bentonite clay, SBE= NPK + 5% bentonite clay + 5% SBE, DBE= NPK + 5% bentonite clay + 5% DBE.

The results of the study in Table 1 show that the treatments given did not show significantly different results on the variable levels of heavy metals in soybean plant leaf tissue, except for Zn which is an essential heavy metal. In addition, all types of metals present in the observed leaf tissue were still below the critical limit that was safe for soybean plants.

Agronomic character

According to Zhang et al. (2021) Leaves are very important organs for plant growth. In the leaves there is a chlorophyll pigment that is used in the process of photosynthesis.

Meanwhile, the result of the photosynthesis process is carbohydrates that are used to produce energy for plants. The energy produced from the photosynthesis process is then used for plant growth and development.

Based on this, the measurement of canopy growth variables such as leaf area in which there is chlorophyll pigment is very necessary. The observations regarding the leaf area variable were carried out when the plants were 30, 49, and 70 DAP, which are presented in Table 2 as follows.

Table 2. Soybean leaf area on various NPK fertilizer treatments at 30, 49, and 70 DAP

Treatment	Leaf area (cm^2)		
	30 DAP	49 DAP	70 DAP
NPK + 10% bentonite clay	326.67 b	1447.32 b	2907.79 a
NPK + 5% bentonite clay + 5% SBE	462.12 b	1632.69 b	3225.55 a
NPK + 5% bentonite clay + 5% DBE	730.96 a	2952.85 a	3457.84 a
CV (%)	28.92	25.55	17.34

Remarks : Means followed by the same letters in the same column are not significantly different according to the LSD test at 5%.

Table 2 shows that the leaf area of soybean plants will increase with increasing age of the plants in all treatments given. At the age of 30 and 49 DAP, the replacement of pure clay mineral adhesive with 5% NPK fertilizer with DBE showed significantly different results compared to the control treatment. As for the treatment of pure clay mineral adhesive replacement in NPK fertilizer of 5% with SBE, although not significantly different from the control, it also tended to show higher yields at 30 DAP and 49 DAP. However, different results were seen when the plants were 70 DAP, because the treatments given did not show any significant differences.

These results showed that at 30 and 49 DAP, the replacement treatment of 5% pure clay mineral adhesive with DBE and SBE could stimulate the vegetative growth of soybean plants as seen from the increased variable leaf area. This is most likely caused by the higher levels of essential heavy metals in the form of Zn in the leaf tissue of soybean plants in the 5% DBE and SBE NPK adhesive treatment compared to the control.

According to Sitompul & Guritno (1995), the role of roots in plant growth is as important as the canopy. As an illustration, if the canopy functions to provide carbohydrates through photosynthesis, then the function of the roots is to provide water and nutrients needed in plant metabolism. The amount of water and nutrients that can be absorbed by plants can be influenced by root volume.

Manganesige et al. (2018) stated that root volume is related to the absorption capacity of water and nutrients by plants, so that the greater the root volume, the greater the water and nutrients absorbed by plants. The root volume was observed when the plants were 30 DAP, 49 DAP, and 70 DAP which are presented in Table 3 as follows.

Table 3. Soybean root volume in various NPK fertilizer treatments at 30, 49, and 70 DAP

Treatment	Root volume (ml)		
	30 DAP	49 DAP	70 DAP
NPK + 10% bentonite clay	2.70 b	3.15 b	13.02 a
NPK + 5% bentonite clay + 5% SBE	3.04 b	3.38 ab	13.35 a
NPK + 5% bentonite clay + 5% DBE	4.29 a	4.65 a	13.40 a
CV (%)	15.27	20.27	8.29

Remarks : Means followed by the same letters in the same column are not significantly different according to the LSD test at 5%.

Table 3 shows that the root volume of soybean plants will increase with increasing age of the plants in all treatments given. When the plants were 30 DAP, the 5% DBE NPK adhesive fertilizer treatment showed significantly different results, higher than the 5% SBE NPK adhesive treatment and the control. As for the NPK fertilizer treatment with 5% SBE adhesive, although not significantly different from the control, it also tended to show higher yields at 30 DAP. Meanwhile, when the plants were 49 DAP, the NPK treatment with 5% DBE adhesive showed significantly higher results compared to the control NPK treatment, but not significantly different when compared to the NPK treatment with 5% SBE adhesive.

These results showed that at 30 and 49 DAP, the replacement treatment of 5% pure clay mineral adhesive with DBE and SBE could stimulate the growth of soybean plant roots as seen from the increased root volume variable. This is most likely caused by the higher levels of essential heavy metals in the form of Zn in the leaf tissue of soybean plants in the 5% DBE and SBE NPK adhesive treatment compared to the control. Sourati et al. (2022) stated that Zn can induce root development due to increased synthesis of indole acetic acid (IAA).

However, at 70 DAP, the results in Table 3 show an interesting trend that the soybean plants given the control treatment experienced a higher increase in root volume compared to the other two treatments, so that there was no significant difference between the treatments that was given at 70 DAP. This was most likely due to the higher and significantly different accumulation of the essential heavy metal Zn in plant leaf tissue in the 5% DBE and SBE adhesive NPK treatment compared to the control (Table 1), which caused the plants to experience Zn poisoning.

As previously explained, observation of agronomic characters in the crown and roots is necessary because they contribute to the economic yield of soybean plants. The variables related to economic yields observed in this study included the number of pods per plant, the number of seeds per plant, and the dry seed yield per hectare. The observation variable related to yield is the most important variable in agronomy because it is the ultimate goal of the cultivation process. Plant yield is the accumulation of all the processes carried out by plants to finally form the final product.

According to Salimi & Moradi (2012), an important character for soybean seed yield is the number of seeds per plant. Several other studies state that the number of pods per plant is an important character in determining yield (Suhartina et al., 2016). Ngalamu et al. (2012) stated that the number of pods per plant, number of seeds per pod, leaf area, and number of branches are agronomic characters that contribute to yield.

The observations on the outcome variables and the outcome components in this study are presented in Table 4 as follows.

Table 4. The number of pods per plant, the number of seeds per plant, and the dry seed yield per hectare of soybean plants in various different NPK fertilizer treatments

Treatment	Number of pods per plant	Number of seeds per plant	Dry seed yield per hectare (ton ha^{-1})
NPK + 10% bentonite clay	90.58 a	172.33 a	1.93 a
NPK + 5% bentonite clay + 5% SBE	100.17 a	196.58 a	2.36 a
NPK + 5% bentonite clay + 5% DBE	102.92 a	187.67 a	2.12 a
CV (%)	22.86	18.23	14.26

Remarks : Means followed by the same letters in the same column are not significantly different according to the LSD test at 5%.

The results in Table 4 show that the three treatments of NPK fertilizer with different adhesives did not give significantly different results for all observed yield variables and yield components. This shows that the replacement treatment of 5% pure clay mineral adhesive with DBE or SBE had no effect on all observed variables. In addition, the research results in Table 4 also provide information that the soybean productivity produced does not reach the average yield per hectare according to the variety description, which is 2.77 tonnes per hectare (Srihartanto, 2019). This indicates that the number of seeds formed is less, which is most likely due to the large number of fallen flowers.

The results of the study also provided information that during the generative phase there was a tendency for the 5% DBE adhesive NPK treatment to yield lower results than the 5% SBE adhesive NPK treatment, but higher than the control, although not statistically significant. This was due to the excess accumulation of the heavy metal Zn in the 5% DBE adhesive NPK treatment at 49-70 DAP so that it had a negative effect on the formation of flowers and pods. The number of flowers and pods formed decreased as a result of Zn accumulation towards the end of the soybean plant life cycle. According to Rout & Das (2003), excess Zn levels in plant leaf tissue can inhibit flower formation.

Plant growth analysis

The processes that occur in plant growth and development have a very large role in determining the final result in the form of economic results. Based on this, plant growth analysis is also important to know as an approach to be able to analyze the factors that can affect plant growth and yield which is a process of accumulating photosynthetic products.

In this study, the plant growth analysis parameter analyzed was the net assimilation rate (NAR), which is presented in Figure 2 as follows.

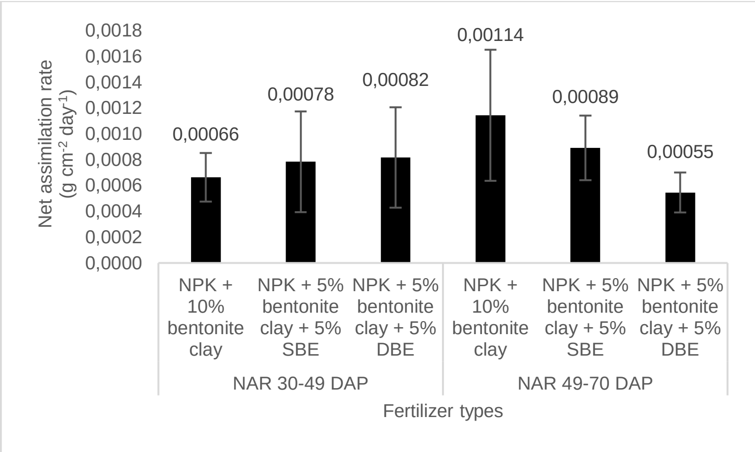

Figure 2. Net assimilation rate (NAR) is on various types of NPK fertilizer with different adhesives at 30-49 DAP and 49-70 DAP. Note: the data showed are means ± standard deviation.

The net assimilation rate (NAR) is the rate of accumulation of dry matter per unit leaf area per unit time. NAR is a measure of the average efficiency of leaf photosynthesis in a cultivated plant community (Gardner et al., 1991). The results of the study in Figure 2 show that at 30-49 DAP, the NPK treatment with 5% DBE adhesive showed a higher NAR than the NPK treatment with 5% SBE adhesive and controls. However, at 49-70 DAP, the 5% DBE adhesive NPK treatment actually showed the opposite, namely a lower NAR compared to the 5% SBE adhesive NPK treatment and controls. This is most likely caused by excess accumulation of essential heavy metals in the form of Zn in plant leaf tissue (5% DBE adhesive NPK > SBE > control) so that these metals are potentially toxic (Table 1).

Figure 3. Morphological performance of soybean plants on various types of NPK fertilizer treatment with different adhesives at 70 DAP.

Wisnubroto et al. (2020) added that excess levels of essential heavy metals in the form of Zn in plant leaf tissue in the 5% NPK DBE and SBE adhesive treatment could increase the vegetative growth of soybean plants quickly which could then increase LAI to exceed its optimum limit at 30-49 DAP, so that it can cause a decrease in NAR. Tagliapietra et al. (2018) stated that the optimum leaf area index (LAI) value could increase the net assimilation rate (NAR), so that dry weight and crop growth rate (CGR) increased and vice versa.

The results of the study from the agronomical aspect as a whole showed that the treatment of replacing the adhesive components in NPK fertilizer with SBE and DBE materials as much as 5% had no effect on the agronomic characters of soybean plants at 70 DAP which was shown to have the same effect as the control treatment based on the variable leaf area, volume roots, number of pods per plant, number of seeds per plant, and dry seed yield per hectare.

The SBE and DBE treatments were able to accelerate the growth of soybean plants at the age of 0-49 DAP because of the ability of these two materials to optimally provide essential nutrients in the planting medium. However, in line with the development of plant age, the good ability of SBE and DBE in providing metal elements becomes counter-productive to the growth behavior of soybean plants due to toxicity.

This toxicity causes inhibition of plant metabolic activity which results in disruption of soybean plant growth in the final phase, age 49-70 DAP. The opposite was true for soybean plants that received control treatment. The impact of this situation was the homogeneous growth capacity and yield of soybean plants in the three treatments tested when the plants were in the final phase, 49-70 DAP (Figure 3).

These results as a whole can confirm that the two waste materials studied, namely SBE and DBE can be used as substitute materials for some of the BC components in NPK fertilizers because they show negative effects that are equivalent to BC adhesive NPK fertilizers on model plants in the form of soybeans. In the future, the innovation intended to utilize SBE and DBE waste will be very important because it can overcome the problem of B3 SBE (and DBE) waste, which so far has only been stored in landfills, as well as turning it into material with economic value.

4. CONCLUSION

The results confirmed that the SBE and DBE materials could partially replace the filler components in bentonite clay filler-based NPK fertilizers, which were shown to have the same effect on soybean agronomic characters in the form of leaf area, root volume, number of pods per plant, number of seeds per plant, and dry seed yield per hectare.

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