Malaysian Journal of Soil Science 2025 Vol. 29: 219-232

Impact of Glyphosate Contamination on Shallots *(Allium ascolonicum* L.*)* Production in Inceptisols Ameliorated with Geo-Biomaterial

Herviyanti Herviyanti[1]*; Amsar Maulana[2]; Irwan Darfis[1]; Musliar Kasim[3]; Teguh Budi Prasetyo[1]; Darusman Darusman[4] & Syafrimen Yasin[1]

[1]Department of Soil Science and Land Resource, Agriculture Faculty, Andalas University, Limau Manis, Padang City, 25164, Indonesia
[2]Post-Doctoral Program, Agriculture Faculty, Andalas University, Limau Manis, Padang City, 25164, Indonesia
[3]Department of Agronomy, Agriculture Faculty, Andalas University, Limau Manis, Padang City, 25164, Indonesia
[4]Department of Soil Science, Agriculture Faculty, Syiah Kuala University, Banda Aceh 23111, Indonesia

**Corresponding author: herviyanti@agr.unand.ac.id*

ABSTRACT

The agronomic use of glyphosate as a weed killer has great potential as a form of contaminant in soil and crop systems. This study aims to assess the effect of glyphosate contamination on soil chemical properties and shallot production in Inceptisols ameliorated with geo-biomaterial. Geo-biomaterials based on sub-bituminous coal (SC) and three types of biochar (B) namely rice husk (RH), young coconut waste (YCW), and bamboo (Ba), where there are five formulations with a percentage of 100% SC; 75% SC+25% B; 50% SC+50% B; 25% SC+75% B, and 100% B ~ 40 t ha^{-1} and control (without geo-biomaterials). Then, there are three experiments, namely E1 (SC+B-RH); E2 (SC+B-YCW), and E3 (SC+B-Ba) using a completely randomized design (CRD) with three replications. The impact of glyphosate contamination significantly changes the chemical properties (pH, CEC, organic C, total N, available P) and shallots production (fresh and dry weights of bulbs and N, P, and K-plant) in Inceptisols ameliorated with geo-biomaterial. Geo-biomaterials from the formulation of 75% SC and 25% B, can increase OC, available P, and bulb dry weight (SC+B-RH); OC, bulb fresh weight, and P-plant (SC+B-YCW) and total N, available P, K, and P-plant (SC+B-Ba) and also proved effective in overcoming glyphosate residues (GR) in Inceptisols soil and reducing GR bioavailability in shallot plants, compared to the control. Application of 75% SC+25% B can provide a multifunctional solution to improve waste optimization, soil, and plant productivity, and at the same time reduce the negative impact of residual pesticides on agricultural land.

Keywords: Biochar, Glyphosate, Inceptisol, Shallots, Sub-bituminous coal

INTRODUCTION

Agricultural practices in Indonesia cannot be separated from the use of herbicides to suppress weed growth. Weeds can interfere with the growth of cultivated plants due to competition in nutrient absorption. In addition, weeds can also reduce the quality and quantity of crop yields and become nests for pests and plant diseases. The use of herbicides is based on efficiency considerations in terms of time and labor. Herbicides contain active ingredients, one of which is glyphosate. Glyphosate acts to inhibit the biosynthesis of amino acids tryptophane, phenylalanine, and tyrosine so that the amino acids needed in protein synthesis for growth are reduced (Zulet-González *et al*., 2020). Glyphosate is a systemic herbicide that is used directly on plant roots so that its contamination of the soil cannot be avoided (Fuchs *et al.* 2021). Herbicides that are sprayed, as much as 20% will hit the plants and 80% will fall and be absorbed into the soil (Kanssery *et al*., 2019).

Herbicides in the soil are determined by the adsorption process, namely the binding of herbicides by soil colloids, a transformation that includes absorption by plants and microorganisms, evaporation, leaching, and transfer through surface flow, and degradation (Bian *et al.*, 2022). Glyphosate-active herbicides are used continuously, so the ability of the soil to adsorb herbicides is also reduced, weeds become resistant, and the accumulation of glyphosate will also harm soil and crop quality. The accumulation of glyphosate in soil is due to the adsorption ability of soil exceeding the threshold. The adverse effects are reduced soil fertility and degradation of soil biota. Inceptisols, whose fertility is generally low due to constraints of acid pH, high clay content, and easily leached surface layers, will be further exacerbated by the accumulation of this herbicide. The application of 2 ml/L glyphosate can reduce the pH of Inceptisol from 6.06 to 5.75, decrease soil total %N by 0.07%, and decrease organic %C by 0.61% and correlation between glyphosate residue had no significant relationship with the chemical properties of an Inceptisol ameliorated (Herviyanti *et al*., 2024). In addition, the use of land for the cultivation of horticultural crops that focus on intensive care will affect the level of soil fertility that occurs in Inceptisol in the horticultural center of Nagari Sariak, Sungai Pua District, Agam West Sumatra, Indonesia which has a relatively acidic pH.

Nagari Sariak, Sungai Pua District is a horticultural production center that produces superior horticultural commodities and is competitive compared to other areas in West Sumatra. The amount of production of horticultural commodities per year in 2024 in Sungai Pua. The high quantity of production does not guarantee that the shallots produced are safe for consumption and do not contain herbicide residues. Herbicide residues made from the active ingredient glyphosate in plants are caused by plant absorption of glyphosate which is active in the soil solution. Intensive horticultural land management with herbicides so that the adsorption ability of the soil exceeds the threshold. The provision of soil ameliorants can be used to absorb herbicide residues on Inceptisol used as horticultural land. To increase the adsorption ability of Inceptisol, ameliorants can be applied to the soil. One of the potential ameliorant materials is sub-bituminous coal.

Sub-bituminous coal as a source of humic substance (HS) with a percentage of 21% is higher than the percentage of humic material contained in other organic materials, such as municipal waste compost (1.4%), manure (1.6%), rice straw compost (5%), and peat soil (9.2%) (Herviyanti *et al*. 2011). The HS is proven to improve degraded soil properties and facilitate nutrients to be absorbed by plants (Michalska *et al.* 2022). Optimizing the use of sub-bituminous coal, formulated with biochar is an innovation in geo-biomaterial technology. Biochar has been established as a soil amendment and carbon sequestration agent. Biochar also acts as an adsorbent for heavy metals in the soil. The use of biochar aims to suppress the mobility of herbicide residues in the soil so as not to pollute the surrounding environment. Biochar can be sourced from potential materials such as rice husks, young coconut waste, and bamboo (Herviyanti *et al.* 2023). This waste can be maximally utilized and economically valuable as a soil ameliorant for herbicide control through the adsorption process in the soil, so the possibility of potentially toxic residues on plants can also be minimized. One of the crops with high-intensity contamination by glyphosate-active herbicide pollution is shallot.

Shallot plants (*Allium ascolonicum* L.) as one of the horticultural commodities can be increased in quantity and quality of production by giving geo-biomaterials from coal and biochar as soil ameliorants. This commodity has considerable market potential due to increasing consumption needs and the development of the processed industry. The demand for shallots for consumption outside the needs of restaurants, hotels, and processed industries is estimated to continue to increase by approximately 5% each year (Dahara *et al.* 2022; Hindarti *et al.* 2023). The increasing public awareness of healthy vegetables and food safety encourages an increase in the need for quality shallots with herbicide residue content below the maximum threshold of 0.05 ppm by the Joint Decree of the Menteri Kesehatan dan Menteri Pertanian No.881/ Menkes/ SKBES/ SKBES: 881/ Menkes/ SKB/ VIII/ 1996;711/ KPTS/ TP.270/ 8/ 1996. The objective of this study was to assess the impact of glyphosate contamination on soil chemical properties and shallot production in Inceptisols ameliorated with geo-biomaterials based on sub-bituminous coal (SC) and three types of biochar (B) namely rice husk (RH), young coconut waste (YCW) and bamboo (Ba).

MATERIALS AND METHODS

The research was conducted from December 2022 to December 2023 in the Wire House of the Faculty of Agriculture, Andalas University for three experiments on shallot growth and soil and plant testing in the Laboratory of the Department of Soil Science and Land Resources, Faculty of Agriculture, and glyphosate residue testing in the Laboratory of technology and process engineering of agricultural products, Faculty of Agricultural Engineering, Andalas University.

Experimental design

This study used a completely randomized design (CRD) with three replications, where there were six treatments, namely control (without geo-biomaterial or 0 t ha^{-1}), and ameliorant formulations between sub-bituminous coal (SC) and biochar (B): (a) = 100% SC; (b) = 75% SC + 25% B; (c) = 50% SC + 50% B; (d) = 25% SC + 75% B, and (e) = 100% B equivalent to a dose of 40 t ha^{-1}. Thus, three research experiments have been conducted based on each of the different biochar types: (1) rice husk (RH); (2) young coconut waste (YCW), and (3) bamboo (Ba). The rate used for amelioration was 40 t ha^{-1}, while the recommended glyphosate addition was 100 mg l^{-1} glyphosate which is equivalent to 0.07 ml glyphosate plus 250 ml water for each polybag or equivalent to 17.5 L glyphosate ha^{-1} (Herviyanti *et al*., 2022).

Sub-bituminous coal

Sub-bituminous coal (SC) was taken from the Bonjol Pasaman, West Sumatra, Indonesia at a depth of 1-2 meters from the ground soil, then cleaned, smoothed with Disc Mill model FFC 23, and sieved with a sieve of 2,00 mm electromagnetic sieve shaker EMS-8 for 10 minutes, after SC is obtained.

Biochar production

Rice husk (RH) is a waste from the rice milling industry. Biochar from RH is produced using the Drum method through a pyrolysis process. Pyrolysis was performed in iron drums with a diameter of 58 cm, a height of 86 cm, and a capacity of 200 liters and combined with the Kon-Tiki method at temperatures up to 650^{0}C. The maximum pyrolysis temperature was kept constant for 45 min to ensure the completion of the final process.

Young coconut waste (YCW) from green coconut (*Cocos nucifera* L.) is cut to a length of about 10*5 cm and dried for one week in the Greenhouse of the Faculty of Agriculture, Andalas University until it achieves a moisture content of 18.20%. Furthermore, the manufacturing process is carried out using a method that has been tested three times. **Figure 1** shows the process of producing YCW biochar with a weight of up to 10 kg and the following technique specifications, The Kon-Tiki method is made of conical steel which has a top diameter of 100 cm, a height of 90 cm, a wall slope of 63.500, and a capacity of 827 liters.

The preparation process for biochar production uses bamboo (B) biomass from the type of bamboo Betung (*Dendrocalamus asper*) and is cut to a length of approximately 30*6 cm and dried for one week in the Greenhouse of the Faculty of Agriculture, Andalas University until it reaches moisture of 20.48%. Furthermore, the production process is carried out based on the method that has been carried out with three repetitions. In the production process of bamboo biomass biochar used as much as 10 kg with the specifications of The Kon-Tiki method is made of conical steel which has a top diameter of 100 cm, a height of 90 cm, a wall slope of 63.500, and a capacity of 827 liters. The results of the production of biochar from each method are watered to stop the combustion process. All biochar is dried in a 70^{0}C oven for 2*24 hours with the aim of homogeneous biochar water content and the next step is to analyze the characteristics of biochar in the laboratory (Maulana *et al.* 2022; Lita *et al.* 2022; Herviyanti *et al*. 2022)**.**

Soil sampling

Inceptisols were taken in Nagari Sariak, Sungai Pua, Agam, West Sumatera, Indonesia with coordinates of -0°21’56” S and 100°24’0” E. Soil samples were taken at a depth of 0-20 cm from 5 collection points which were then composited. Then, the soil was air-dried for 2 × 24 hours. After air-drying, the samples were pulverized and sieved with a 2 mm sieve. After that, soil samples were taken for preliminary soil analysis. The soil samples were weighed as much as 5 kg equivalent absolute dry weight into polybags. The soil in polybags was watered with glyphosate solution until it reached field capacity and the other polybags were added biochar based on recommendations, then mixed well and watered with glyphosate to field capacity. Furthermore, the soil was incubated for 2 weeks. After the incubation, soil samples were analyzed in the laboratory.

Glyphosate concentration from round-up herbicide

Glyphosate used in soil contamination is a type of herbicide with the trademark Roundup Biosorb 486 SL (GRB-486 SL). Glyphosate used in soil contamination is a type of herbicide with the trademark Roundup Biosorb 486 SL (GRB-486 SL). The concentration of glyphosate contaminated in the soil was 100 mg l^{-1} glyphosate from Round-up 486 SL herbicide or equivalent to 0.07 ml GRB-486 SL in 250 ml H_2O with $5kg^{-1}$ soil based on recommendations (Herviyanti, et al., 2022).

Analysis of soil, plant residual of glyphosate, and statistical analysis

Soil analysis conducted such as pH H_2O, CEC, organic C, total N, available P, exchangeable K, Ca, and Mg (Soil and Fertilizer Instrument Standard Testing Center, 2023). Meanwhile, tests on shallot plants have been carried out in the form of wet and dry weights of bulbs, plant nutrient levels (N, P, and K), and glyphosate residues in tubes. Analysis of glyphosate residues was conducted using the High-Performance Liquid Chromatography (HPLC) method (Glass, 1983; Bi *et al.* 2011; and Sun *et al.* 2017). The results of all analyses were statistically analyzed using SPSS 16.0, Statistic 8, and Excel 2016 software. The statistical analysis used was the analysis of variance (ANOVA) and Duncan’s multiple range test (DMRT). After detecting a significant effect with ANOVA, DMRT was used as a post hoc test to identify which specific group means differ from each other. Significance levels were determined as follows: if F count > F table at the 5% level, the results are significant and marked with [*], and if F count > F table at the 1% level the results are very significant and marked with [**]. The [*] and [**] annotations reflect the significance levels of these differences.

RESULTS AND DISCUSSION

The effect of glyphosate contamination was significant on pH, CEC, organic C, total N, and available P of inceptisols ameliorated with sub-bituminous coal and biochar from rice husk, young coconut waste, and bamboo (**Table 1**). The pH H_2O of Inceptisol increased after the amelioration process, whereas the pH H_2O of Inceptisol without ameliorants was classified as acidic (≤ 4.83). Geo-biomaterials from sub-bituminous coal (SC) with rice husk biochar (B-RH) at a percentage of 25% SC + 75% B-RH and 100% B-RH and SC showed a significant effect on increasing the pH H_2O of Inceptisol by 0.59; 0.52 and 0.45, respectively, compared to the control. Meanwhile, the formulation between SC with young coconut waste biochar (B-YCW) and bamboo biochar (B-Ba) showed a significant effect of 100% B-YCW and B-Ba on increasing the pH H_2O of Inceptisol by 0.97 and 0.86, respectively, compared to the control. The increase in pH of inceptisol ameliorated with geo-biomaterials can be classified as acidic.

Amelioration by giving biochar can increase the pH value of the soil because biochar is alkaline and can contribute a negative charge from functional groups, especially phenol. The alkaline nature of biochar is processed by the Kon-Tiki method and its modification has a pH of 7 – 10 (Maulana *et al*., 2022; Lita *et al*., 2022; Herviyanti *et al*., 2022). The amount of pH possessed by biochar can increase the pH of acidic soil. Meanwhile, the role of SC in the formulation is to increase carboxyl groups that can increase soil pH through the H^+ dissociation process. The increase in OH- ions causes the negative charge of the soil to increase so that the pH also increases.

Table 1: Effect of glyphosate contamination on soil chemical properties in Inceptisols ameliorated with the formulation of sub-bituminous coal and biochar from rice husk, young coconut waste, and bamboo.

Formulation of Ameliorant	Inceptisols				
	pH H_2O	**CEC**	**OC**	**Total N**	**Available P**
	unit	**cmol(+) kg^{-1}**	**%**		**ppm P_2O_5**
A. Sub-bituminous coal with biochar from rice husk					
Control	4.81 c	30.91 e	2.16 e	0.31 d	7.28 d
100% SC	**5.26 ab**	**48.33 a**	4.13 b	**0.51 a**	12.81 b
75% SC + 25% B-RH	5.16 b	42.33 c	**4.33 a**	0.44 b	**15.17 a**
50% SC + 50% B-RH	5.16 b	41.08 d	3.29 d	0.38 c	10.64 c
25% SC + 75% B-RH	**5.33 ab**	43.04 c	3.59 c	0.41 c	10.80 c
100% B-RH	**5.40 a**	46.04 b	4.09 b	0.45 b	12.35 b
CV (%) – Duncan's Test	*2.00***	*1.59***	*3.02***	*3.95***	*5.37***
B. Sub-bituminous coal with biochar from young coconut waste					
Control	4.83 e	29.98 e	2.17 c	0.32 c	7.40 e
100% SC	5.27 d	**51.03 a**	2.79 b	**0.52 a**	**14.83 a**
75% SC + 25% B-YCW	5.40 c	48.33 b	**3.35 a**	0.45 b	12.83 b
50% SC + 50% B-YCW	5.53 b	39.60 d	2.26 c	0.43 b	11.03 d
25% SC + 75% B-YCW	5.60 b	43.67 c	2.45 c	0.33 c	11.08 d
100% B-YCW	**5.80 a**	44.35 c	2.78 b	0.46 b	11.98 c
CV (%) – Duncan's Test	*1.26***	*3.14***	*6.22***	*3.97***	*1.18***
C. Sub-bituminous coal with biochar from bamboo					
Control	4.81 e	32.63 b	2.17 e	0.32 b	7.28 b
100% SC	5.27 d	**48.33 a**	**4.13 a**	**0.52 a**	**12.81 a**
75% SC + 25% B-Ba	5.37 c	33.93 b	3.13 c	**0.48 a**	**14.23 a**
50% SC + 50% B-Ba	5.53 b	**41.55 ab**	2.59 d	**0.43 a**	**12.01 a**
25% SC + 75% B-Ba	5.57 b	**42.56 ab**	2.72 d	**0.43 a**	**11.94 a**
100% B-B	**5.67 a**	**46.03 a**	3.83 b	**0.44 a**	**12.54 a**
CV (%) – Duncan's Test	*1.02***	*14.25***	*3.31***	*13.44***	*12.13***

Remarks: Numbers in the same column followed by the same lowercase letter are not significantly (ns) different according to Duncan's test at the 5% (*) and 1% (**) level; B-RH = rice husk biochar; B-YCW = young coconut waste biochar; B-Ba = bamboo biochar; CEC = cation exchange capacity; OC = organic carbon; exch = exchangeable; SC = sub-bituminous coal; CV = Coefficient of variation, and n = 18 samples/ experiments.

The impact of glyphosate contamination can reduce the pH of Inceptisol. Glyphosate as a form of organic compound can increase the concentration of hydrogen ions (H^+) in the soil solution, thus lowering the pH (Suwardji & Sudantha, 2021). Glyphosate can also mobilize aluminum bound to soil particles (Tévez & Afonso, 2015). This mobilized aluminum can increase soil acidity, as aluminum hydroxide is acidic. This interaction can also change the surface properties of minerals, thus affecting the pH buffering capacity of the soil. However, with amelioration, the impact of glyphosate contamination in the soil can be controlled. The highly polar nature of glyphosate which contains two types of hydrogen cations can contribute a positive charge to the soil (Azimzadeh & Martínez, 2024). The positive charge contribution by glyphosate causes a decrease in soil pH when glyphosate is in the soil solution *(*Pereira *et al.* 2019).

Increasing the pH value indirectly affects the availability of P in the soil (Jian *et al.*, 2022). Geo-biomaterials application is significant to increase available P of Inceptisols contaminated with glyphosate. The geo-biomaterial application of the formulation between SC and B-RH with a percentage of 75% + 25% was significant in increasing available P by 7.37 ppm, compared to the control. Meanwhile, formulation of SC with B-YCW showed 100% SC was significant to increase available P by 7.43 ppm, compared to the control. However, the SC formulation with B-Ba showed a difference, where the geo-biomaterial was significant towards increasing available P from 4.66 to 6.95 ppm, compared to the control.

The SC contains some minerals, including phosphorus, while biochar has a very high porous structure, so it can absorb and hold various nutrients, including phosphorus. Biochar can also increase soil pH and microbial activity which plays a role in mineralizing organic phosphorus (Pan *et al.*, 2021). Geo-biomaterials serve to enhance P uptake in the soil by the combination of both having the ability to exchange ions with the soil, thus helping to release phosphate ions bound to soil particles, making them more accessible to plant roots. Biochar tends to be alkaline, so it can increase the pH of soils that are too acidic. An increase in pH can increase the solubility of phosphorus in the soil and reduce phosphorus fixation by iron and aluminum (Johan *et al.*, 2021). A decrease in soil pH due to glyphosate can lead to the precipitation of phosphate into forms that are less available to plants, such as aluminum phosphate and iron phosphate. Changes in soil mineral surface properties due to glyphosate can increase phosphate adsorption by clay minerals, reducing their availability (Munira *et al.*, 2018). However, this can be controlled with amelioration.

The increase in organic C of Inceptisol can be attributed to the carbon contribution from SC and biochar which are stable. Geo-biomaterial application of 75% + 25% percentage in SC + B-RH and SC + B-YCW formulations gave a significant effect on increasing organic C by 2.17% and 1.18% C, respectively, compared to the control. However, it is different in the SC + B-Ba formulation showing that 100% SC is significant in increasing organic C by 1.96% C, compared to the control. Coal contains a very large amount of carbon (Spencer *et al.*, 2024). Carbon in biochar is more stable and resistant to decomposition, so it can increase the stock of organic carbon in the soil in the long term (Azzi *et al.*, 2024). The applied geo-biomaterial is expected to increase soil aggregation, which is the formation of larger and more stable soil particles. Good soil aggregation can improve soil aeration, drainage, and water-holding capacity, thus creating a more conducive environment for microorganism growth and organic C accumulation. Glyphosate can inhibit the activity of microorganisms that play a role in breaking down organic matter and disrupt the symbiosis between plant roots and microorganisms, which plays an important role in the carbon cycle and absorption of plant nutrients (Kanssery *et al.*, 2019). Amelioration with geo-biomaterial can be an alternative solution to increase microorganism activity.

Geo-biomaterials can increase the total N of Inceptisol contaminated with glyphosate, where SC + B-RH and SC + B-YCW formulations showed a significant effect of 100% SC on increasing total N by 0.20% N, respectively, compared to the control. However, it was different in the SC + B-Ba formulation which showed a significant effect of geo-biomaterials on increasing total N by 0.11-0.20% N, compared to the control. The role of coal is that it can bind $N\text{-}NH_4^+$ due to the presence of its functional and carboxyl groups and also contains N by 0.5%-2% of its weight (Thomas *et al.*, 2024). The N composition of SC can contribute N to the soil and cause N to be retained in the soil. In addition, with its many pores and large surface, biochar can absorb and retain N added from fertilizers so that the potential loss of N can be minimized and N in the soil increased. The impact of glyphosate in the soil can inhibit the activity of nitrifying bacteria that convert ammonia into nitrate, as well as denitrifying bacteria that reduce nitrate to nitrogen gas (Brochado *et al.*, 2023). This impact of glyphosate can change the form of organic nitrogen into a form that is more stable and difficult to access by plants. However, applied geo-biomaterials can increase total soil N by reducing the level of glyphosate pollution through the sorption process, thus indirectly contributing to increased nitrogen fixation.

An increase in pH and organic C directly causes an increase in the CEC of Inceptisol. An increase in the negative charge of the soil will affect the ability of the soil to absorb and exchange cations. Geo-biomaterials from the formulation between SC + B-RH and SC + B-YCW showed that 100% SC gave a significant effect on increasing the CEC which was classified as very high at 17.42 and 21.05 cmol(+) kg^{-1}, respectively, compared to the control. However, geo-biomaterials in the SC + B-Ba formulation showed that at 100% SC and B-B as well as at a percentage of 50% + 50% and 25% + 75% had a significant effect on increasing the CEC by 15.70; 13.40; 9.93 and 8.92 cmol(+) kg^{-1}, respectively, compared to the control. The negative charge resulting from the presence of carboxyl and phenolic groups that undergo H^+ dissociation due to the decomposition of organic matter causes the negative charge to bind base cations in the soil solution (Adusei-Gyamfi *et al.*, 2019). Biochar has many pores and a large enough surface area, allowing biochar to expand its absorption and exchange cations (Gul *et al.*, 2024). The high functional groups on the surface of geo-biomaterial can interact with cations in the soil, thus making an increase in the cation exchange capacity of the soil. Functional groups on the surface of coal and biochar can become complex compounds with cations that can later increase the CEC in the soil (Nicholas *et al.*, 2022). The SC contains humic acid and fulvic acid that form complex organic compounds with cations in the soil, such as calcium, magnesium, and potassium. These complex organic compounds can help the soil by increasing the amount of available cations in the soil. The impact of glyphosate can interact with clay minerals and change their surface charge (Pereira *et al.*, 2020; Galicia-andrés *et al.*, 2021). This change in charge can affect the ability of clay minerals to absorb cations. However, applying geo-biomaterials to the soil can increase CEC and improve soil structure.

The best increase in K-exch Inceptisol occurs in geo-biomaterials with SC + B-YCW formulation, where 100% B-YCW has a K-exch of 1.30 cmol(+) kg^{-1}. The highest increase in Ca-exch occurred in SC + B-RH and SC + B-Ba formulations, where 100% B-RH and B-Ba had Ca-exch of 2.75 and 2.77 cmol(+) kg^{-1}. However, the increase in Mg-exch fluctuated in each geo-biomaterial application with SC and biochar formulations. The application of geo-biomaterials can increase the potential as a binding agent for organic matter and minerals in the soil. The porosity of biochar mostly consists of micropores so the addition of biochar into the soil can increase the availability of cations for plants and increase the soil CEC value (Li & Tasnady, 2023). Meanwhile, SC can increase the base value because, sub-bituminous added to the soil contains humic acid and fulvic acid which can form complex organic compounds with metal cations in the soil to increase the K, Ca, and Mg-exch in the soil. The impact of glyphosate tends to reduce soil pH, whereas, in acidic conditions, basic cations are more easily leached or fixed by clay minerals, thus reducing their availability to plants (Duke *et al.*, 2013). Inhibited decomposition of organic matter and reduced humus formation due to the impact of glyphosate contamination will reduce the soil's ability to retain base cations. Thus, an alternative solution to control glyphosate contamination of soils requires the application of geo-biomaterial-based ameliorants from formulations between SC and biochar.

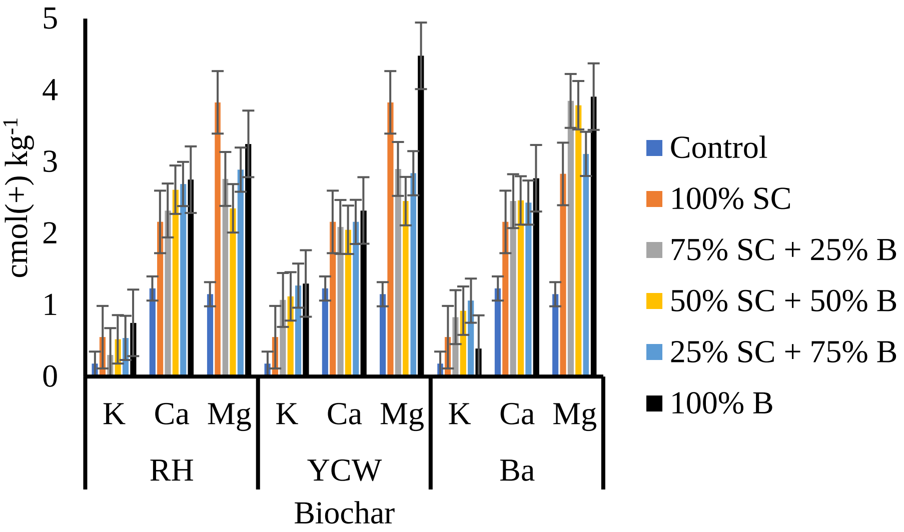

Figure 1. Effect of glyphosate contamination on K, Ca, and Mg-exch in Inceptisols ameliorated with the formulation of sub-bituminous coal (SC) and biochar from rice husk (RH), young coconut waste (YCW), and bamboo (Ba).

The effect of glyphosate contamination was significant on bulb weight and shallot nutrient levels in Inceptisols ameliorated with formulation SC with B-RH, B-YCW, and B-Ba (**Table 2**). The SC + B-RH and SC + B-YCW formulations showed that geo-biomaterials had a significant effect on the fresh and dry weight of onion plant bulbs with an increase of 24.24-42.88 g plant^{-1}; 13.72-27.25 g plant^{-1} and 23.65-47.15 g plant^{-1}; 16.93-31.94 g plant^{-1}, respectively, compared to the control. However, it is different in geo-biomaterial with SC + B-B formulation, where the application of 50% SC + 50% B-Ba; 100% SC, B-Ba is significant to increase the fresh and dry weight of shallot plant bulbs by 51.08; 50.42; 47.22 g plant^{-1} and 30.22; 28.49; 27.25 g plant^{-1}, respectively, compared to the control. The significant increase in shallot plant weight is due to the improvement of soil chemical properties and the increase in soil organic matter content by geo-biomaterials. This affects increasing the availability of nutrients for the needs of plant growth and development. The increase in pH, organic C, and soil CEC by the application of geo-biomaterial causes the availability of soil nutrients such as N, P, K, Ca, and Mg to increase (**Table 1**). The high content of organic C can increase the absorption and storage of water in the soil also increases, so that the availability of nutrients is sufficient in the process of growth and development of shallot bulbs (Kumalasari *et al.*, 2022; Rahmawati & Ladewa, 2023). Increased absorption of water and CO_2 with the help of sunlight will increase the process of photosynthesis in the leaves so that the formation of bulbs also increases. Thus, more shallot bulbs are produced and the weight is also greater. On the other hand, the high shrinkage of fresh weight and dry weight of plants affects the quality of plant production. Low shrinkage of plant weight indicates that the plant has good water storage capacity. Therefore, during the storage process, the plants are not easily rotten and germinate, it is necessary to store shallots at a temperature of 5°C with 80% moisture content to produce the best quality shallots (Anwar *et al.,* 2024).

The nutrient levels of shallot bulbs in the control showed lower values compared to the application of geo-bio materials, both nutrient levels of N, P, and K. Geo-biomaterial with SC + B-RH formulation shows that the application of 100% SC and the percentage of 25% SC + 75% B-RH is significant to increase the N of shallot plants by 0.073 and 0.07%, respectively, compared to the control. Meanwhile, the SC + B-YCW formulation shows that the application of 100% B-YCW is significant in increasing the N of shallot plants by 0.073%, compared to the control. However, it is different in the SC + B-B formulation showing the percentage of 75% + 25%; 100% SC, and 50% + 50% significant to increase the N of shallot plants by 0.074; 0.073 and 0.064%, respectively, compared to the control. This increase is in line with the increase in total N in the soil, which is classified as medium to high. Soil must contain a total N with moderate criteria to obtain optimal plant growth. N nutrients are needed by plants in leaf development, chlorophyll formation, and tiller formation (Verdenal *et al.* 2021). Available P that can be absorbed directly by shallots comes from an increase in soil available P levels that are classified as medium to high after the amelioration process with geo-biomaterials.

Table 2. Effect of glyphosate contamination on shallot production in Inceptisols ameliorated with the formulation of sub-bituminous coal and biochar from rice husk, young coconut waste, and bamboo

Formulation of Ameliorant	Shallot (*Allium ascolonicum* L.)				
	Fresh bulbs Weight	Dry bulbs Weight	N-plant	P-plant	K-plant
	g plant^{-1}		%		
A. Sub-bituminous coal with biochar from rice husk					
Control	7.20 b	7.18 b	0.017 e	0.005 c	0.31 f
100% SC	**44.39 a**	**34.43 a**	**0.090 a**	**0.008 a**	0.86 b
75% SC + 25% B-RH	**54.44 a**	**25.39 a**	0.075 c	**0.008 ab**	0.65 d
50% SC + 50% B-RH	**31.44 ab**	**21.70 ab**	0.082 b	**0.008 a**	0.77 c
25% SC + 75% B-RH	**50.08 a**	**24.79 a**	**0.087 ab**	0.007 b	0.38 e
100% B-RH	**39.47 ab**	**20.35 ab**	0.068 d	0.005 c	**0.92 a**
CV (%) – Duncan's Test	*46.97**	*39.18**	*4.84***	*7.40***	*1.98***
B. Sub-bituminous coal with biochar from young coconut waste					
Control	7.29 b	7.32 b	0.017 d	0.005 b	0.37 f
100% SC	**50.50 a**	**39.26 a**	0.066 b	**0.008 a**	**0.87 a**
75% SC + 25% B-YCW	**37.92 a**	**29.11 ab**	0.070 b	**0.008 a**	0.83 b
50% SC + 50% B-YCW	**42.05 a**	**31.75 ab**	0.049 c	**0.008 a**	0.61 c
25% SC + 75% B-YCW	**30.94 ab**	**24.25 ab**	0.042 c	**0.008 a**	0.49 d
100% B-YCW	**54.44 a**	**41.16 a**	**0.090 a**	**0.008 a**	0.45 e
CV (%) – Duncan's Test	*44.50***	*47.86***	*11.95***	*3.49***	*1.19***
C. Sub-bituminous coal with biochar from bamboo					
Control	7.21 c	7.18 c	0.017 c	0.005 c	0.31 d
100% SC	**54.43 a**	**34.43 a**	**0.090 a**	**0.008 a**	**0.87 a**
75% SC + 25% B-Ba	39.19 b	23.68 b	**0.091 a**	**0.008 a**	0.46 c
50% SC + 50% B-Ba	**58.29 a**	**35.67 a**	**0.081 ab**	**0.008 a**	0.63 b
25% SC + 75% B-Ba	35.30 b	23.39 b	0.071 b	**0.008 a**	0.34 c
100% B-B	**57.63 a**	**37.40 a**	0.073 b	0.006 b	0.48 c
CV (%) – Duncan's Test	*17.27***	*16.50***	*12.95***	*5.01 ***	*16.47***

Remarks: Numbers in the same column followed by the same lowercase letter are not significantly (ns) different according to Duncan's test at the 5% (*) and 1% (**) level; SC = sub-bituminous coal; B-RH = rice husk biochar; B-YCW = young coconut waste biochar; B-Ba = bamboo biochar; CV = Coefficient of variation, and n = 18 samples/ experiments.

Application of geo-biomaterials with SC + B-RH formulation showed that the percentage of 25% + 75%: 50% + 50% and 100% SC significantly increased the P of shallot plants by 0.003% each, compared to the control. Meanwhile, the formulation of SC + B-YCW and SC + B-Ba shows that the application of geo-biomaterials is significant in increasing the P of shallot plants by 0.003% each, compared to the control. Potassium acts as an enzyme activator to maintain cell turgor and water content in plants and increases plant resistance to disease (Hasanuzzaman *et al.* 2018). Soil conditions such as texture, moisture, temperature, aeration, and soil pH can affect K absorption by plants. This is shown in the application of 100% B-RH in the SC + B-RH formulation, which has a significant effect on increasing the K of shallot plants by 0.61%, compared to the control. Meanwhile, the SC + B-YCW and SC + B-Ba formulations showed a significant application of 100% SC to increase the K of shallot plants by 0.50% and 0.56%, respectively, compared to the control. The N, P, and K are essential nutrients for plant growth and optimum yield. The element N plays a role in increasing overall growth, especially in the vegetative phase, and plays a role in forming leaf-green substances (chlorophyll), fats and proteins, and other compounds. The element of phosphorus (P) plays a role in stimulating the growth and development of roots, as a basic ingredient of protein helps assimilation and respiration, K plays a role in helping the formation of proteins and carbohydrates, enriching plant tissue, playing a role in plant anti-bodies for disease and drought (Ahmad *et al.* 2014).

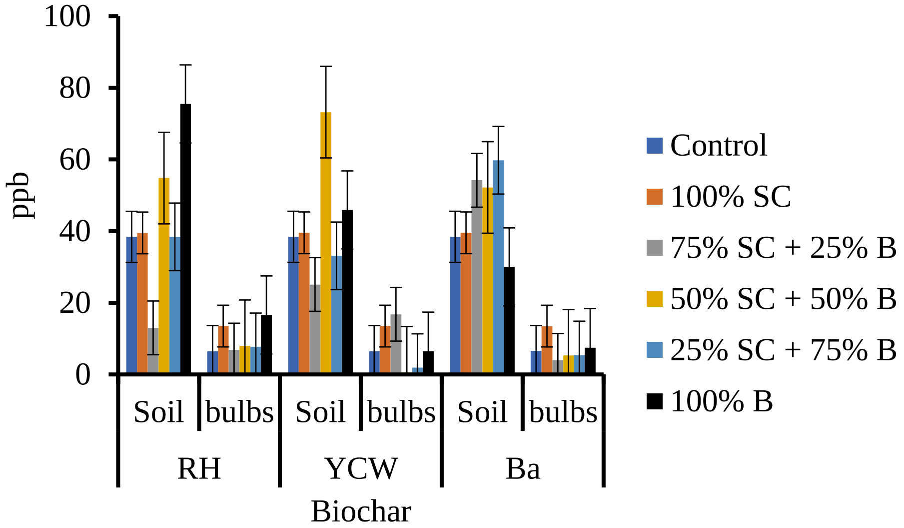

Figure 2. Residual glyphosate on shallot plants in Inceptisols ameliorated with the formulation of sub-bituminous coal and biochar from rice husk (RH), young coconut waste (YCW), and bamboo (Ba).

Pesticide residues in the soil are influenced by the type of herbicide, the dose used, the application method, and the weather and climate. Measurable residues indicate how much herbicide remains in the soil after application. The more glyphosate that is absorbed by the soil, the less potential for glyphosate to pollute the environment and groundwater and the less absorption of glyphosate by plants. Measured glyphosate residues in soil and shallot bulbs (**Figure 2**). The application of geo-biomaterials showed that glyphosate residues in the soil were higher than in the bulbs of shallot plants. The application of 100% B-RH has a glyphosate residue level in inceptisol of 75.50 ppb, compared to the SC + B-YCW and SC + B-Ba formulations which have glyphosate residue levels in inceptisol of 73.21 ppb (50% SC + 50% B-YCW) and 59.78 ppb (25% SC + 75% B-Ba), respectively.

Inceptisol can absorb glyphosate contamination in the soil without the addition of ameliorants. However, the application of ameliorants to inceptisol showed an increase in soil absorption of glyphosate contamination, where the level of glyphosate residue tended to increase after the application of geo-biomaterials. In addition, shallot plants can also absorb glyphosate from the soil. However, the application of geo-biomaterials can inhibit absorption by plants. This is evidenced by the fact that glyphosate residues in the bulbs of shallot plants are lower than glyphosate residues in the soil. The level of glyphosate residues in the bulbs of shallot plants after the application of geo-biomaterials decreased from 0.60 ppb in the SC + B-YCW formulation to 16.60 ppb in the application of 100% B-RH. The application of geo-biomaterials can absorb and bind glyphosate in the soil so that it is not available to plants. The limited sorption capacity of soil to glyphosate causes the detection of glyphosate in plants (Gandhi *et al.*, 2021).

The use of glyphosate to control pre-plant weeds causes glyphosate to be available mainly in the soil and plants with the highest concentration that will be retained in the soil. Herbicides retained in the soil may undergo degradation due to catalysis provided by soil composition or under the influence of sunlight (Ćwieląg-Piasecka *et al.*, 2023). Glyphosate molecules can seep into the subsoil and reach underground water reserves (Reynoso *et al.*, 2020). The amount of glyphosate residue in the soil can be influenced by the organic C content of the soil. An increase in organic C will affect the soil's ability to absorb and exchange cations (CEC), causing more glyphosate to be absorbed. The higher the organic C and the lower the leaching of glyphosate by groundwater, the higher the glyphosate residue. The presence of a large surface with many pores owned by biochar can increase the ability of soil to absorb glyphosate. Bamboo biochar processed by the Kon-Tiki method has a surface area of 158.452 m^2/g and rice husk biochar of 17.47 m^2/g (Herviyanti *et al.*, 2022). This allows glyphosate to occupy the pores of biochar. The physical and chemical attraction of glyphosate ions by biochar causes glyphosate to adhere and be trapped in the pores.

Glyphosate that has been adsorbed also has the potential to desorb or release back into the soil solution. Weak adsorption encourages glyphosate to desorb and be absorbed by plants. Weakly adsorbed compounds are more easily leached and lost through runoff water than strongly adsorbed compounds (Garba *et al.*, 2024). The water-soluble nature of glyphosate also leads to faster degradation rates. The faster glyphosate is desorbed, the greater the possibility of groundwater pollution, and glyphosate can be absorbed by shallots. The detection of glyphosate residues in shallot bulbs is due to the limited sorption capacity of glyphosate by clay and ameliorants, causing an increase in active glyphosate in the soil solution.

The contact of glyphosate in the soil solution with plant roots for a long time causes glyphosate to be absorbed by shallots. Thus, the more residue measured in the soil, the less glyphosate can be absorbed by plants. Increased soil sorption capacity by geo-biomaterials increases the degradation of glyphosate in the soil and the immobility of glyphosate in the soil becomes greater and glyphosate becomes inactive so that the glyphosate content in shallot bulbs becomes low. The analysis of glyphosate residues in shallots aims at the safety of consuming shallots that do not contain glyphosate after glyphosate is absorbed by soil ameliorated with geo-biomaterials. Although there were glyphosate residues in the bulbs, the value did not exceed its maximum limit in plants. The maximum residue limit of pesticides in plants is 0.05 ppm according to the Joint Decree of the Minister of Health and the Minister of Agriculture 881/ MENKES/ SKB/ VIII/ 1996; 711/ KPTS/ TP.270/ 8/ 1996. Thus, the formulation of 75% SC + 25% B for the three types of biochar used is the best ameliorant formulation in controlling glyphosate residues in shallot bulbs and can also support plant productivity on Inceptisols.

CONCLUSION

The impact of glyphosate contamination significantly changes the chemical properties (pH, CEC, organic C, total N, available P,) and shallots production (fresh and dry weights of bulbs and N, P, and K-plant) in Inceptisols ameliorated with geo-biomaterial. Geo-biomaterial from the formulation of 75% sub-bituminous coal and 25% biochar, especially B-RH can increase 2.17% C, 7.89 ppm P_2O_5, and 18.21 g $plant^{-1}$ from the dry weight of bulbs, while B-YCW can increase 1.18% C, 30.63 g $plant^{-1}$ from fresh weight of bulbs and 0.003% P-plant and B-Ba can increase 0.16% N, 6.95 ppm P_2O_5, 0.074% K-plant and 0.005% P-plant, and also proved effective in overcoming glyphosate residues (GR) in Inceptisols soil and reducing GR bioavailability in shallot plants (GR soil > plant), compared to the control. Application of 75% SC+25% B can provide a multifunctional solution to improve waste optimization, soil, and plant productivity, and at the same time reduce the negative impact of residual pesticides on agricultural land.

ACKNOWLEDGEMENTS

The authors would like to thank Andalas University under the research contract for Penelitian Unggulan Jalur Kepakaran (PUJK) Batch I No. 348/UN16.19/PT.01.03/PUJK/2024.

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