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Farmers' Bussiness as Usual Increase Lead (Pb) Level in the Soil: a Case Study Horticulture Land in Batu, Indonesia

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Abstract: Lead (Pb) is a toxic heavy metal for humans. Agrochemical applications contribute to Pb contamination and accumulation in plants which is harmful to humans. This study aims to investigate the habits of horticultural farmers in applying inorganic fertilizers and pesticides intensively on Pb concentration in the soil and cultivated plants, and its effect on plant growth. The measured parameters consisted of soil and plant Pb content, soil pH, organic C, total N, available P, and exchangeable K. This study used a randomized block design consisting of 4 treatments (Control (KT); (PR); (TN); and (TP)). The results showed that horticultural farmers' dosage of inorganic fertilizers exceeded Indonesia Ministry of Agriculture recommendation. The application of inorganic fertilizers and pesticides by farmers (business as usual) increased Pb content in plants up to 31.46 mg/kg. Besides the application of inorganic fertilizers increases fertilizer residues in the soil by up to 65%, which increases environmental pollution even though the application of inorganic fertilizers increases plant growth and production (shoot length, the number of leaves, and plant dry weight). Thus, wisely applying agrochemicals is required in order to support plant growth and production without further environmental problems.

Keywords: inorganic fertilizer, intensive farming, lead, fertilizer residue, bioremediation

Introduction

Lead (Pb) is a heavy metal that is toxic and harmful to human health (Maghfirah, 2020). Lead is mobile in the soil and carcinogenic. Lead can accumulate in the human body, which causes health problems such as kidney disease and hypertension, damaging reproductive health and inhibiting fetus growth and development (Jaishankar et al., 2014). Lead enters the human body through oral indigestion from foods containing lead, then accumulates in the human blood.

A survey by Litbang Kesehatan Indonesia (2014) reported that about 94.8% of Indonesian people consume vegetables. The vegetables may be contained Pb from agrochemicals used for agriculture, as Rahayu et al. (2019) reported that horticultural plants contain the highest Pb content, up to 31.72 mg/kg. The Pb content in horticultural crops, especially vegetables, exceeds the maximum concentration of Pb in vegetables according to Indonesian National Standard (SNI 7387:2009), which is 0.5 mg/kg.

In addition, irrigation water, organic fertilizers, inorganic fertilizers, and pesticides containing Pb, which are applied continuously, can increase Pb absorption by plants (Liu et al., 2023). Lead content in agricultural land with horticultural crop commodities is ranged from 11.35-11.62 mg/kg (Rahayu et al., 2019). According to the Cepa (2007), the maximum Pb content in the soil considered safe for agricultural activity is 140 mg/kg. Even though Pb content in many agricultural lands is below the maximum concentration, Pb can accumulate in plant tissue through Pb absorption from the soil, and humans may consume it, leading to health problems (Collin et al., 2022).

Therefore, it is important to study the effect of farmers' habits in applying excessive fertilizers and

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pesticides to determine the impact of intensive agriculture on environmental sustainability. The study result can be used as basic information for managing agrochemical application management so that it will not be harmful to human health and more environmentally friendly. This study aimed to analyze farmers' habit (business as usual) in applying agrochemical inputs on Pb content and fertilizer residues in soil and its effect on plant growth.

Method

This study consisted of an experimental greenhouse study, field observations, and interviews. The experimental study was conducted to analyze the effect of farmer's business as usual on soil fertility, Pb residue and plant growth. The field observation was conducted to analyze the existing condition of soil fertility and Pb residue before the soil was used for experiments in the greenhouse. Interviews with the key person were conducted to collect information on the soil history and farmers' habits to determine the treatment in the greenhouse experiment.

Sampling Location

This study was carried out in Soil Chemistry Laboratory and Green House, Faculty of Agriculture, University of Brawijaya, from June 2022 to December 2022. Pb-contaminated soil was collected from intensive agricultural lands in Sumber Brantas Village, Bumiaji District, Batu City, East Java, Indonesia (7°45'13" S and 112°31'04" E).

Research Method

This research consisted of experimental research in a greenhouse, field observation, and interviews. The collected data consisted of plant commodities, types and doses of fertilizers and pesticides, frequency of pesticide application, and age and the wide area of agricultural land. The measured parameters consisted of soil and plant Pb content using the atomic absorption spectrophotometer (AAS), soil pH (glass electrode), organic C (Walkley and Black), total N (Kjeldahl), available P (Olsen), and exchangeable K (NH_4OAc pH 7).

Experimental Design

This study used a randomized block design consisted of 4 treatments (Control (KT); Fertilizer according to Indonesia Ministry of Agriculture recommendation (PR); Fertilizer Application Without Nitrogen (TN); Fertilizer Application Without Phosphate (TP)), with 6 replications. The applied fertilizer consisted of Urea 150 kg/ha (0.225 g/polybag), TSP 100 kg/ha (0.15 g/polybag) and KCl 75 kg/ha (0.1125 g/polybag). The applied pesticide consisted of abamectin (0.05 mL/polybag), cypermethrin (0.05 mL/polybag), and mancozeb (0.125 g/polybag).

Research Procedure

The growth medium was 3 kg mixture of Pb-contaminated soil, manure, and 100 mg/kg $Pb(NO_3)_2$. Fertilizers were applied at 7 and 20 days after planting (DAP). Pesticides were applied every two days. Pots were watered every day with 500 mL/polybag.

Respondents criteria

Farmers who cultivated horticulture plants and owned a wide area of agricultural lands (minimum 6,800 m^2). The farmers usually applied excessive fertilizers and pesticides (business as usual) for over 10 years.

Data Analysis

The obtained data were analyzed using Analysis of Variance (ANOVA) followed by Tukey test at 5% significant level. Data analysis was carried out using Genstat 12.

Result and Discussion

Habits of Horticultural Farmers Using Fertilizers and Pesticides

The study showed that farmers' habit (business as usual) of applying inorganic fertilizers was considered intensive farming. Intensive farming is cultivating plants using inputs of fertilizers and pesticides in excessive doses and frequency to increase production (Kumar et al., 2022). The dose of inorganic fertilizer farmers apply was high, exceeding the recommended dose by Indonesia Ministry of Agriculture (Table 1). Intensive application of inorganic fertilizers reduces soil organic matter content, increases soil bulk density, and causes environmental pollution due to heavy metal accumulation (Soekamto & Fahrizal, 2019).

Applying inorganic fertilizers and pesticides containing Pb in agricultural land increases Pb content in agricultural products (Liu et al., 2023). Several studies reported that fertilizers contained Pb, such as urea 4.45 mg/kg, nitro-ponska 2.16 mg/kg (Rasman, 2018), superphosphate 21 mg/kg, foliar fertilizers 16 mg/kg (Rahayu et al., 2019), and TSP 7-225 mg/kg (Alloway, 1995), Propinep 70 WP 12.48 mg/kg, Beta Siflutrin 25 EC 2.04 mg/kg (Hartini, 2015), Mancozeb M 45 80 WP 19.37 mg/kg (Rasman, 2018). Rahayu et al. (2019) stated that Pb content in the fungicide is 8 mg/kg, insecticide 99 mg/kg, acaricide 3.77 mg/kg, herbicide 2 mg/kg, and adhesive pesticide 0.71 mg/kg.

Table 1. Fertilizer and Pesticides Applied in Horticulture Land by Farmers in Sumberbrantas Village

Plant	Form	Dose	Type	Active Ingredients	Frequency
Brassica pekinensia	ZA	200 kg/ha	Fungicide	Mankozeb	Every two days
	NPK	300 kg/ha			
			Insecticide	Abamectin	
				α-cypermethrin	
Brassica oleracea	ZA	200 kg/ha	Fungicide	Mankozeb	Every two days
	NPK	300 kg/ha			
	Dolomite	2.500 kg/ha	Insecticide	Abamectin	
	Manure	30 ton/ha		α-cypermethrin	
	Compost	30 ton/ha			
Solanum tuberosum	NPK	600 kg/ha	Fungicide	Fertila	Every two days
				Mankozeb	
			Insecticide	Abamectim	Every four days
				Supermectim	
Daucus carota	NPK	200 kg/ha	Fungicide	Mankozeb	Every two days
			Insecticide	Abamectin	
				α-cypermethrin	
				Carbofuran	Before planting

Source: Interview of key person (respondents)

Soil Chemical Properties

Preliminary soil chemical analysis showed that the main problem in the study site is the soil pH which is very acidic. The low soil pH was mainly caused by farmers' habits in applying fertilizers that exceed the recommended dose by Indonesia Ministry of Agriculture, which consists of 150 kg/ha urea, 150 kg/ha SP-36, and 100 kg/ha KCl. The application of ZA in high doses by farmers potentially decreases soil pH due to the acid released by ZA (Triharto et al., 2014). ZA dissolves in water $(NH_4)_2SO_4 + H_2O \rightarrow NH_4OH + H_2SO_4$, where H_2SO_4 is a strong acid that can decrease soil pH (Atmadja et al., 2021). In addition, low soil pH will also increase the solubility of heavy metals so that they are more easily absorbed and accumulated in plant biomass (Binh et al., 2021).

Organic C in the studied area is classified as high (Table 2) due to farmers applying cow manure before planting in high doses, around 30 tons/ha. Cow manure contains nutrients that can improve the soil's physical, chemical, and biological properties (Yusnaeni et al., 2021). It mainly contains organic C, which increases organic matter in the soil. Soil containing high organic matter can increase crop yield and production, such as corn, soybeans, cucumbers, and vegetables (Simarmata & Setyowati, 2016).

Table 2. Soil Chemical Properties in the Studied Area

Location	Parameter	Result
Sumberbrantas village	pH	4.21(VA)
	Organic C (%)	3.99(H)
	Total N (%)	0.49(M)
	Available P (mg/kg)	108.12(VH)
	Exchangeable K (me/100 g)	0.48(M)

Note: VA = Very Acidic; H= High; M = Moderate; VH = Very High (Soil Research Institute 2009).

Nitrogen (N) and exchangeable potassium (K) were moderate, and phosphorus (P) was very high (Table 2). The high availability of soil nutrients in the studied area is related to the farmers' habits of applying inorganic fertilizers frequently in high doses. Moreover, applying inorganic fertilizers in high doses exceeding the recommended dosage will increase fertilizer residues as the impacts of low nutrient uptake by plants (Roba, 2018), which leads to increased leaching, volatilization, and environmental pollution (Chandini et al., 2019).

Pb Concentrations in Horticultural Land

This study showed that Pb concentration in the horticulture product, specifically chinese cabbage, was 31.46 mg/kg (Table 3), and it exceeded the maximum Pb concentration in leafy vegetables according to

Indonesian National Standard (SNI), which is only 0.5 mg/kg. A previous study reported that *Brassica* sp. is a hyperaccumulator plant that can absorb high concentrations of heavy metals without exhibiting toxicity symptoms (Bortoloti & Baron, 2022).

Pb uptake by plants is closely related to soil pH. Acidic soil pH can increase Pb solubility, which may increase Pb uptake by plants (Collin et al., 2022). Plant roots uptake available Pb in the soil, then Pb will be bound to the carboxyl group of uronic acid or directly to polysaccharides on the surface of rhizodermis cells. After penetrating the rhizodermis cells, Pb passively enters the plant roots and spreads throughout the plant body by water flow translocation (Pourrut et al., 2011). The intensive pesticide application also impacts the high Pb concentration in plants. Rahayu et al. (2019) reported that Pb content in fungicide is 8 ppm, insecticides is 99 ppm, acaricides is 3.77 ppm, herbicides is 2 ppm and pesticide adhesives is 0.71 ppm. Applying these agrochemicals frequently for a long time will increase the product residues and Pb accumulation in the soil. Thus after a long time, the soil in the studied area will harm human health and the environment if no remediation measures are applied.

Table 3. Pb Concentrations in the Studied Area

Location	Parameter	Result (mg/kg)
Sumberbrantas village	Pb in Soil	17.86
	Pb in Biomass of *B. chinensis*	31.46*

Note: *The Pb concentration in plants exceeds the maximum limit of SNI 7387:2009.

Soil pH

This study showed that inorganic fertilizer application as a single fertilizer significantly reduced soil pH ($p<0.05$). However, there were no significant differences in the reduction of pH between inorganic fertilizers, whether applied as single or compound fertilizers, compared to control fertilizers ($p>0.05$) (Figure 1). However, the application of inorganic fertilizers according to the recommendation of Indonesia Ministry of Agriculture had a higher soil pH than the application of single inorganic fertilizers and control. This occurs due to chemical reactions from the application of inorganic fertilizers, as Singh (2018) previously reported that a single application of N fertilizers decreases soil pH and organic matter content. More intensive application of N fertilizer leads to rapid soil acidification. The N fertilizer that farmers generally apply is urea. Urea hydrolysis in the soil forms ammonium and bicarbonate, then ammonium undergoes nitrification and produces nitrate, which releases protons (H^+) into the soil, causing soil acidification and a decrease in pH (Goulding, 2016).

Besides N-containing mono-fertilizers, P-containing mono-fertilizers can also decrease soil pH due to P fertilizers reacting with water and producing phosphoric acid. This acidification process can lower soil pH (Labbilta et al., 2021). The level of soil acidification depends on the type and amount of fertilizer applied, as well as the soil's buffering capacity. Soils with low buffering capacities are more susceptible to changes in pH than soils with high buffering capacities (Zhao et al., 2021).

Soil pH affects the availability of nutrients for plants because some nutrients are more available at a certain pH level. For example, P is more available at a pH of 6.0-7.5, while iron (Fe) and manganese (Mn) are more available at a pH of 5.0-6.5 (Labbilta et al., 2021). Therefore, monitoring and adjusting soil pH is necessary to ensure optimal plant growth.

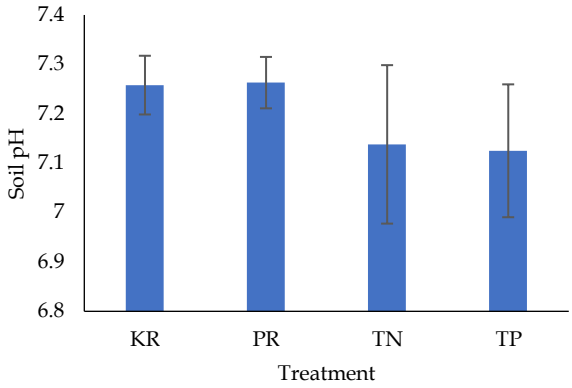

Figure 1. Soil pH; KT = Control; PR = Fertilizer according to Indonesia Ministry of Agriculture recommendation; TN = Fertilizer Application Without Nitrogen; TP = Fertilizer Application Without Phosphate

Soil Total N

This study proved a significant increase in soil total N due to the application of inorganic fertilizers ($p<0.05$). However, there was no significantly different between applying N and P fertilizers as single or compound fertilizers on soil total N (Figure 2). The application of inorganic fertilizers according to the recommendation of Indonesia Ministry of Agriculture as a compound fertilizer containing N and P, had a higher soil total N than the other treatments. This study aligns with a study by Jiaying et al. (2022) who reported that N, P and K are essential nutrients needed for plant metabolism. However, N is uptook by plants only around 20% to 40% of the total N fertilizer applied during one growing season. It is estimated that between 10% and 65% of the applied N fertilizer will be lost through various processes, such as runoff, leaching, and evaporation, as N in the soil has high mobility (Yao et al., 2018; Nouri et al., 2022). Thus, the greater the application of N in the

soil, the greater the possibility of N loss from the soil (Nouri et al., 2022).

Intensive application of inorganic fertilizers, especially those containing sodium (Na) and K, have a negative impact on soil pH, damaging soil structure, increasing salinization, groundwater contamination, eutrophication, greenhouse gas emissions, air pollution, decreasing crop yields, resulting in natural resources disturbance, thereby hindering sustainable food production. In addition, it can increase soil pollution due to the accumulation of chemicals and heavy metals in the soil (Savci, 2012).

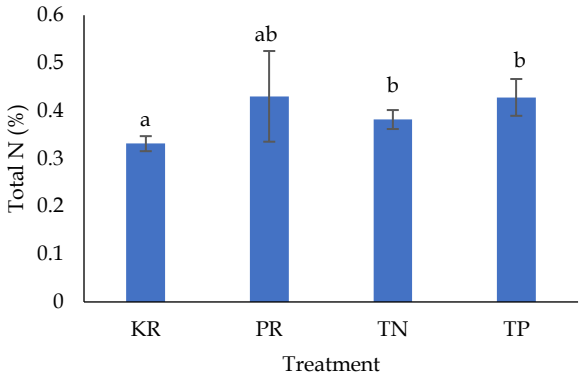

Figure 2. Soil Total N; KT = Control; PR = Fertilizer according to Indonesia Ministry of Agriculture recommendation; TN = Fertilizer Application Without Nitrogen; TP = Fertilizer Application Without Phosphate. Means followed with different letters are significantly difference based on Tukey test 5%

The repeated use of chemical fertilizers leads to the accumulation of toxic heavy metals such as arsenic (As), cadmium (Cd), and uranium (U) in the soil (Bisht & Singh, 2020). These toxic heavy metals not only pollute the soil but also accumulate in food grains, fruits, and vegetables. Ammonia fertilizers such as ammonium nitrate and ammonium phosphate contain nearly 50–60 mg/kg of As (Li, 2002), and N fertilizers also contain Cd (Fan et al., 2017). Fertilizer application without soil testing leads to soil degradation, nutrient imbalance, soil structure breakdown, and increased bulk density, oppositely testing the soil before applying fertilizer increases nutrient use efficiency and prevents soil and water pollution (Singh et al., 2021; Micha et al. 2023). Fertilizers, more than the recommended amounts lead to the formation, accumulation and concentration of mineral salts of fertilizers which lead to layer compaction and soil degradation (Sedlacek et al., 2020). The effect of chemical fertilizers on soil is enormous and irreversible in the long term (Chandini et al., 2019).

Soil Available P

This study showed that applying inorganic fertilizer significantly increased soil available P ($p<0.05$). It is proven that the application of inorganic fertilizers according to the recommendation of Indonesia Ministry of Agriculture in a compound fertilizer containing P was higher than the other treatments (Figure 3). Excessive inputs such as fertilizers and pesticides in the soil will accumulate those agrochemical product residues, and they may be transported to water bodies, contributing significantly to water and soil pollution around the agricultural environment (Khan et al., 2018). Phosphate is a nutrient that is difficult to dissolve in the soil, so farmers add inorganic fertilizer to meet the nutrient needs of cultivated plants. However, the efficiency of P fertilizer uptake by plants is only around 10% to 15% of the total fertilizer applied by farmers, while the rest remains in the soil and becomes an environmental pollutant due to fertilizer residues entering into water bodies (Rashmi et al., 2020). Therefore, pollution from fertilizers harms human and animal life, which will cause environmental degradation.

Phosphate fertilizers produced from rock phosphate (RP) contain Cd, which will increase the accumulation of Cd, As, and Pb, affecting soil health (Khan et al., 2018). This statement is supported by Lin (1996) which detected the amount of heavy metals contained in P fertilizers consisting of Cd 9.5–96.4 mg/kg, As 19.4–273.0 mg/kg, Pb 5.6–17.2 mg/kg, and Hg 0.01–0.42 mg/kg. These heavy metals in the soil consist of two inorganic and organic forms which are more easily uptaken by plants and accumulate in the plants' and animals' bodies (Rashmi et al., 2020). In addition to heavy metals, RP used in the fertilizer industry contains high concentrations of radionuclides, including U, radium (Ra), and radon (Rn) (Lopes et al., 2011). This fact is astonishing because the risk of exposure to radionuclide-rich fertilizers through human food consumption cannot be ignored (Nowak, 2013). Long-term application of P fertilizer results in heavy metals and radionuclides accumulation, potentially threatening the environment and organisms' health (Chen et al., 2020).

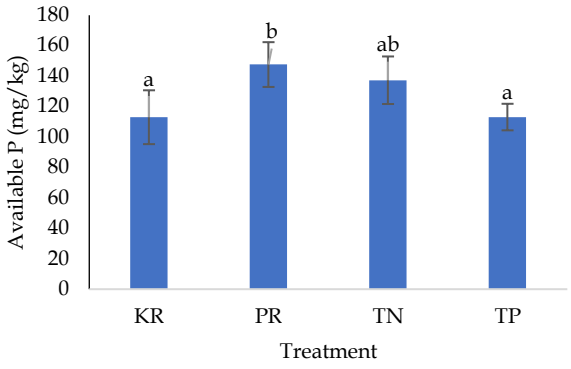

Figure 3. Soil Available P; KT = Control; PR = Fertilizer according to Indonesia Ministry of Agriculture recommendation; TN = Fertilizer Application Without Nitrogen; TP = Fertilizer Application Without Phosphate. Means followed with different letters are significantly difference based on Tukey test 5%

Brassica chinensis Shoot Length

This study showed an increase in shoot length due to the application of inorganic fertilizers ($p<0.05$). The application of inorganic fertilizers according to Indonesia Ministry of Agriculture significantly increased shoot length of *B. chinensis* (Figure 4). However, there were no significant differences between the treatments, except TN and PR on 1 WAP. Removing N fertilizer significantly reduced *B. chinensis* shoot length. The results of this study explained that the application of compound inorganic fertilizer consisting of N, P, and K increased the shoot length of *B. chinensis* by 15.15% compared to the control. Oppositely the lowest shoot length of *B. chinensis* was in the treatment without the application of N fertilizer.

The low shoot length of B. *chinensis* in the treatment without applying N fertilizers explains that the role of N for plants is crucial in synthesizing amino acids, nucleic acids, nucleotides, coenzymes, and proteins. Most importantly, protein builds protoplasm and forms plant organs (Adamczyk et al., 2010) Wan et al., 2023). In addition, N also plays a role in the formation of chlorophyll which functions to synthesize carbohydrates through photosynthesis which will support plant growth and increase plant biomass (Fathi, 2022). So the treatment without applying N fertilizers will result in nutrient deficiencies in plants, as indicated by stunted, chlorosis (yellowish leaves), and low plant biomass. In the treatment without the application of P fertilizer, the difference in plant height was only around 2.67% compared to the application of compound fertilizer. This condition occurred due to the ability of N to increase root growth and development so that plants were able to absorb P more effectively and besides this N is also the main constituent of the phosphatase enzyme, which is involved in P mineralization in the soil (Fahmi et al., 2010).

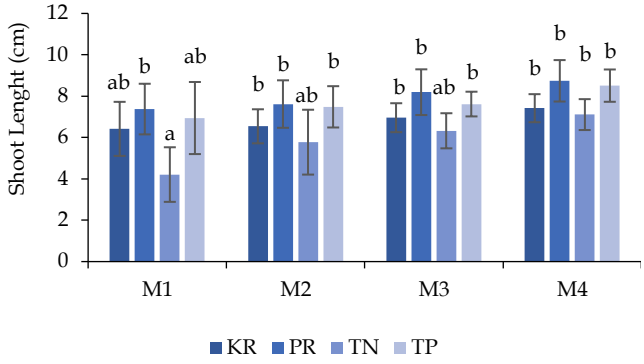

Figure 4. Shoot Length of *B. chinensis*; M1 = 1 week after planting (WAP); M2 = 2 WAP; M3 = 3 WAP, and; M4 = 4 WAP; KT = Control; PR = Fertilizer according to Indonesia Ministry of Agriculture recommendation; TN = Fertilizer Application Without Nitrogen; TP = Fertilizer Application Without Phosphate. Means followed with different letters are significantly difference based on Tukey test 5%

Number of Leaves

This study showed that fertilizer application significantly increased the number of *B. chinensis* leaves ($p<0.05$). However, there was no significant difference between the tested treatments. The application of fertilizer according to Indonesia Ministry of Agriculture resulted in the treatment having more leaves than the other treatments. The increase in the number of leaves in PR treatment was 9.37% compared to the control, while TN treatment had fewer leaves than all treatments due to N deficiency. Nitrogen plays a role in increasing the size of cells and the speed of their division due to the carbon use efficiency and glucose formation through photosynthesis, significantly increasing plant growth (Ghani et al., 2022). Nitrogen functions as an important constituent of chlorophyll, protoplasm, and protein, enhancing the growth and development of all tissues (Pamungkas, 2017). This increase in the photosynthesis rate also increases plants' carbohydrate content. Plants use the produced carbohydrates to continue cell division. Young plants that undergo cell division have a higher cell content and have cell walls that are not too thick or thin (Nuraeni et al., 2019).

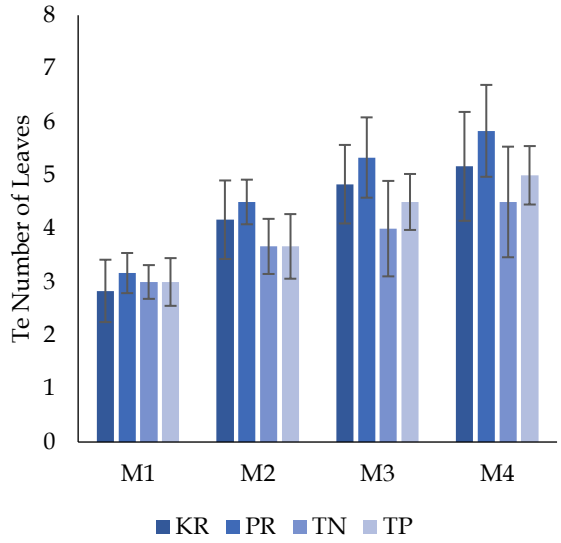

Figure 5. The Number of Leaves; M1 = 1 week after planting (WAP); M2 = 2 WAP; M3 = 3 WAP, and; M4 = 4 WAP; KT = Control; PR = Fertilizer according to Indonesia Ministry of Agriculture recommendation; TN = Fertilizer Application Without Nitrogen; TP = Fertilizer Application Without Phosphate.

Plant Dry Weight

This study showed a significant increase in plant dry weight due to applying inorganic fertilizers ($p<0.05$). There was also a significant difference in plant dry weight among the treatments. In the compound inorganic fertilizer application treatment, the plant's dry weight was higher than in other treatments. The dry weight reflects the accumulation of organic compounds successfully synthesized by plants. Plant dry weight can explain the nutritional status of a plant and is also an indicator that determines a plant's growth and development and is closely related to nutrient availability (Sitorus et al., 2014). The highest plant dry weight was in PR treatment, while the lowest was in TN treatment. The low dry weight in TN treatment was caused by N deficiency.

Nitrogen plays an important role in preparing proteins and lipids, influencing carbohydrates in plants (Muratore et al., 2021). Nitrogen directly affects the synthesis of carbohydrates in plant cells and will further affect plant vigor and increased vegetative growth. Increased plant growth will affect plant dry weight (Sawan, 2013). Plants with optimal N fertilizer will grow optimally (Nuraeni et al., 2019). However, excessive fertilizer application will increase fertilizer residue and heavy metals concentration, as well as soil and water pollution. Thus, applying agrochemicals wisely is required to support plant growth and production without further environmental problems.

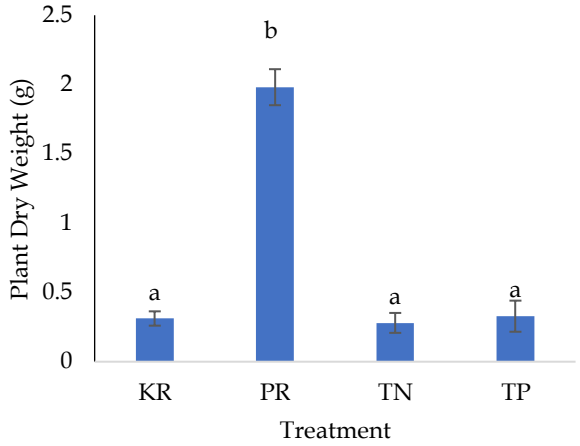

Figure 6. Plant Dry Weight; KT = Control; PR = Fertilizer according to Indonesia Ministry of Agriculture recommendation; TN = Fertilizer Application Without Nitrogen; TP = Fertilizer Application Without Phosphate. Means followed with different letters are significantly difference based on Tukey test 5%

Conclusion

Farmers' habits (business as usual) in applying fertilizers and pesticides are considered intensive farming which leads to an increase in Pb concentration in plants up to 31.46 mg/kg. Also, excessive inorganic fertilizers increase fertilizer residues in the soil by up to 65%, thus causing environmental pollution even though it can increase plant growth and production. Thus wisely applying agrochemicals is required in order to support plant growth and production without further environmental problems.

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Author Contributions

All authors contributed to every stage of research, have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors have declared that no there are no conflict of interest associated wirh the publication of this paper.

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