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Optimizing fertilizer packages and soil amendments for corn with *Chromolaena odorata* liquid organic fertilizer

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Abstract Result revealed that zeolite significantly increased soil pH. The 200 kg ha^{-1} PR + 100 kg ha^{-1} Urea treatment produced the highest LAI and corn yield, reaching 9.38 Mg ha^{-1} dry-shelled weight. The corn production exceeded the national average in Indonesia, which was only 5.8 tons per hectare. By applying 200 kg ha^{-1} PR and 100 kg ha^{-1} urea, along with 0 ml L^{-1} LOF for each application, the highest dry shelled corn yield reached 9.38 Mg ha^{-1}. It was not significantly different from the yield obtained with the application of 150 kg ha^{-1} zeolite, nor from the yield achieved with 200 kg ha^{-1} PR and 100 kg ha^{-1} urea, which reached 8.54 Mg ha^{-1}. Zeolite considerably raised the pH of the soil, according to data analysis using the F test and the LSD test at five percent significance. The highest yield of corn (9.38 Mg ha-1 dry-shelled weight) and LAI were obtained with the 200 kg ha-1 PR + 100 kg ha-1 Urea treatment. The amount of grain produced was more than the 5.8 tons per hectare national average in Indonesia. The maximum dry shelled corn yield was achieved by applying 200 kg ha^{-1} PR and 100 kg ha^{-1} urea, with 0 ml L^{-1} LOF for each treatment. It did not differ much from the yield of 8.54 mg ha^{-1} that was produced with the application of 150 kg ha^{-1} zeolite or from the yield obtained with 200 kg ha^{-1} PR and 100 kg ha^{-1} urea.

Keywords: Phosphate rock, *Chromolaena odorata*, Zeolite, Liquid organic fertilizer

Introduction

Corn is the second most important staple food commodity after rice. Corn productivity in Indonesia is still not sufficient for domestic needs. As a result, Indonesia will continue to import corn until 2023, reaching 20,000 tons (Sari and Ika, 2024). It is important to increase corn productivity through intensification activities, namely by improving soil quality using appropriate amendments and fertilizer packages. Corn cultivation in Indonesia, especially in West Sumatra, is

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carried out on sub-optimal land, which is in the medium to low soil fertility category (Ministry, 2007). Sufficient fertilization will make plants grow well and produce effectively, but if the soil quality is poor, then fertilization will be wasted. The rising cost of artificial fertilizers is a major problem for corn farmers in Indonesia. By supplementing the soil with a fertilization package that comprises zeolite, rock phosphate, artificial fertilizer, and liquid organic fertilizer, corn production is anticipated to increase output. All life forms require phosphorus (P), an element that cannot exist without it. The majority of P given to the soil is used as fertilizer, however this is ineffective since plants only use a tiny percentage of the P applied (Amarasinghe *et al.,* 2022). When compared to TSP fertilizer, Pavinato *et al.* (2020) shown that PR treated with acid boosts relative agronomic efficiency by more than 74%. The high Al and Fe concentration of tropical soils causes them to be very weatherable, acidic, and poor in phosphorus (P). P supplies must be sufficient to guarantee ideal soil and plant productivity. Because zeolites can fix Fe and Al in place of P, they must be added to acidic soils in order to increase the availability of P (Hasbullah *et al.,* 2020).

Silicate rocks can be a sub-optimal soil amendment or improver and restore soil pH (Bauwhede *et al*., 2024). GirijaVeni *et al*. (2021) explained that the application of zeolite can improve overall soil quality due to its unique cation exchange, adsorption, hydration-dehydration, and catalytic properties. Globally, several studies have been conducted to investigate the feasibility of using zeolite to increase crop yields, nutrient use efficiency, and water use efficiency. It is an alkaline and alkaline-containing microporous, crystalline, hydrated aluminosilicate with a high CEC and an internal pore structure that can retain water molecules and nutrients. It has the capacity to store nutrients like $NH4^{+}$ and K^{+} ions, which are then gradually released so that plants can continue to absorb them.

Zeolite's special structure—a framework made of silicon and aluminum atoms—is the reason for its high ion exchange capacity. There are a lot of exchange sites in this framework where ions can bind. The Si/Al ratio affects the zeolite's ability to exchange ions; a larger Al component produces more charge-balancing cations. When zeolite is mixed with fertilizers, it absorbs and retains ions, such as ammonium ions, from the soil. This process helps to prevent nutrient loss by reducing the leaching of these ions into the soil solution. The NH4+ ions can be bound by the zeolite surface's negative charge side, which prevents them from changing into NO3-mobile ions in the soil solution system. Because of their high ion exchange capacity, zeolites—such as nano-zeolites and Linde-type A zeolites—are excellent carriers of mineral fertilizers because they can retain and release essential nutrients for plant growth slowly, preventing nutrient loss and ensuring sustained availability in the soil (Vinayak *et al*., 2022; Faiz *et al*., 2023; Renata *et al.*, 2022). These porous aluminosilicates possess a network of interconnected chambers and channels that enable them to adsorb nutrients, water, and pollutants effectively, making them valuable in agriculture for enhancing soil fertility and nutrient utilization efficiency (Eleonora *et al*., 2021).

Reducing N losses with zeolite application will increase N availability and higher NUE. To combat this kind of environmental contamination, numerous approaches have been examined; these include the utilization of minerals (e.g., clay minerals, zeolites, and natural silica adsorbents (Belviso, 2020). Research results (Riyanto *et al*., 2022) show that the application of zeolite minerals at all altitudes can increase nutrient availability and soil cation exchange capacity (CEC) by up to 70%. The use of artificial fertilizers is considered common in an effort to increase the growth and yield of corn plants. Efforts to provide amendments such as zeolite and natural phosphate can increase the agronomic efficiency of corn plants.

The use of liquid organic fertilizer also greatly helps increase plant growth on sub-optimal land. Poor plant root development in sub-optimal soil will be helped by nutrient uptake through the plant canopy from the application of liquid organic fertilizer. The importance of selecting the best raw materials as constituents in producing liquid organic fertilizer products, such as *Chromolaena odorata* (*C. odorata*), coconut fiber, manure, cow urine, and banana stems (Jamilah and Juniarti, 2014). The quality of the liquid organic fertilizer (LOF) has also been tested at pH 7; 0.66% N; 1.33% P_2O_5; 0.78% K_2O; 1.016% Ca; 1.4% Mg, and several micronutrients are available in sufficient levels (Jamilah *et al.,* 2015). Liquid Organic Liquid application has been carried out on rice plants with good results, increasing rice growth and yield and reducing grain emptying (Jamilah *et al.,* 2020). It is necessary to know its role in increasing the growth of corn plants whose soil is amended with zeolite or PR, as well as being able to reduce the dose of artificial fertilizer, which is increasingly expensive. The aim of the research was to obtain a fertilizer package for corn plants given *C. odorata* liquid organic fertilizer.

Materials and methods

Inceptisol Nagari Aua Kuniang, Pasaman District, West Pasaman Regency, at a height of 150 meters above sea level, was the site of experiments in 2023. The materials that were utilized were 28% P2O5-containing Belarusian Phosphate Rock (PR) and 36% P2O5-containing SP36. 51.71% SiO2 is present in three-sixpoin Zeofillite, which has a CEC of 112.57 cmol kg^{-1} and a fineness of 96.35%. A fully randomized design including two treatments and three replications was used to conduct the experiment. The combination of Zeolite and Urea (1:1) was used with the same dose. The second treatment was the concentration of *C. odorata* liquid organic fertilizer, as follows: 0 ml L^{-1}, 50 ml L^{-1}, and 100 ml L^{-1}. There were five levels in the initial fertilizer selection treatment: 100 kg PR ha^{-1} + 100 kg Urea ha^{-1} (P1); 200 kg PR ha^{-1} + 100 kg Urea ha^{-1} (P2); 50 kg Zeolite ha^{-1} + 50 kg ha^{-1} Urea + 75 kg SP-36 ha^{-1} (P3); 100 kg ha^{-1} Zeolite + 100 kg Urea ha^{-1} + 75 kg SP-36 ha^{-1} (P4); and 150 kg Zeolite ha^{-1} + 150 kg Urea ha^{-1} + 75 kg SP-36 ha^{-1} (P5). The same dosage was applied while using zeolite and urea (1:1). The obtained data were analyzed using the F test at a significance level of 5%. At a 5% significance level, the LSD test was conducted to assess whether the treatment's impact was statistically significant.The basic fertilizer application was 50 kg KCl ha^{-1}.

C. odorata liquid organic fertilizer is made using the main ingredient *C. odorata*, banana stem, coconut fiber, and manure in a volume ratio (V) of 1:1:1, which is covered for 1 month. The growth stimulant solution is made from coconut water, ripe papaya fruit, and palm sugar (10:0.2:0.01), which is fermented for 2 weeks. In the second month, the main ingredients are put into the fermenter tank, then a growth stimulant solution and *Trichoderma sp* are added, and it is fermented in an aerobic atmosphere for 2 months. *C. odorata* liquid organic fertilizer can then be harvested by filtering it and settling it to obtain a clear filtrate that can be applied as liquid fertilizer, which is sprayed onto the corn plant canopy.

The corn seeds used were Pioneer, which were planted 3 cm deep in the experimental field with a spacing of 75 x 25 cm and a plot size of 300 cm x 125 cm. A combination application of Zeolite and Urea was given 10 days after planting (DAP). Before being applied to the plants, the zeolite and urea were incubated in the same proportion according to the treatment for 12 hours, to increase the availability of N nutrients in the corn plants. The application of other basic fertilizers was given at 50% of the recommended dose, which is 75 kg ha^{-1} SP-36 and 50 kg ha^{-1} KCl. *C. odorata* liquid organic fertilizer was applied every 2 weeks starting at 7 DAP until the formation of corn cobs. Observation parameters included soil pH, leaf area index, corn plant stalk diameter at 45 DAP, weight of 100 seeds, and dry-shelled weight per hectare. Soil samples, approximately 5 cm in diameter, were collected from around the roots of corn plants to determine the soil pH.

Determination of pH was carried out in the laboratory with a ratio of aquabidestylate water to soil (2.5:1), which was shaken using a shaker for 15 minutes, and then the pH was measured using a Hanna brand pH meter electrode made in Romania. Using a TAFFWARE 150 mm Stainless Digital Caliper

Vernier Caliper with an accuracy of up to 0.1 mm, measure the diameter of corn stalks 5 cm above the roots.

Results

Soil pH

Changes in pH occurred as a result of the influence of fertilizer packages given through the soil, as well as liquid fertilizer applied through the leaves, which affected soil pH. However, the two do not interact (Table 1 and Figure 1). Treatment with the application of 100 kg ha^{-1} (Zeolite + Urea) + 75 kg ha^{-1} SP-36 was significantly increased the pH and the highest compared to other fertilizer treatments. It was not significantly different from the application of 150 kg ha^{-1} (Zeolite + Urea) + 75 kg ha^{-1} SP-36. In general, the application of PR package fertilizer tended to increase soil pH, but it was still unable to exceed the influence of the application of Zeolite + Urea. Providing LOF increased soil pH; the higher the dose of LOF, the higher the resulting soil pH. pH levels ranging from 6.35 to 6.42 is supported better growth of corn plants in the field.

Table 1. Effect of fertilizer packages on changes in soil pH at 45 DAP

Fertilizer Packages	LOF Application (ml L^{-1})			Average
	0	50	100	
	pH			
0 kg ha^{-1} PR + 100 kg ha^{-1} Urea	6.27	6.23	6.30	6.27^{C}
100 kg ha^{-1} PR+ 100 kg ha^{-1} Urea	6.03	6.17	6.33	6.18^{C}
200 kg ha^{-1} PR+ 100 kg ha^{-1} Urea	6.46	6.13	6.40	6.33^{BC}
50 kg ha^{-1} Zeolite + 50 kg ha^{-1} Urea + 75 kg ha^{-1} SP-36	6.25	6.34	6.50	6.36^{B}
100 kg ha^{-1} Zeolite + 100 kg ha^{-1} Urea + 75 kg ha^{-1} SP-36	6.53	6.56	6.54	6.54^{A}
150 kg ha^{-1} Zeolite+ 150 kg ha^{-1} Urea +75 kg ha^{-1} SP-36	6.57	6.42	6.47	6.48^{AB}
Average	6.35^{b}	6.31^{b}	6.42^{a}	
CV (%)	2.04			

The LSD 5% significance threshold indicated no significant difference between the identical superscript lowercase letters in rows and the same uppercase letters in columns.

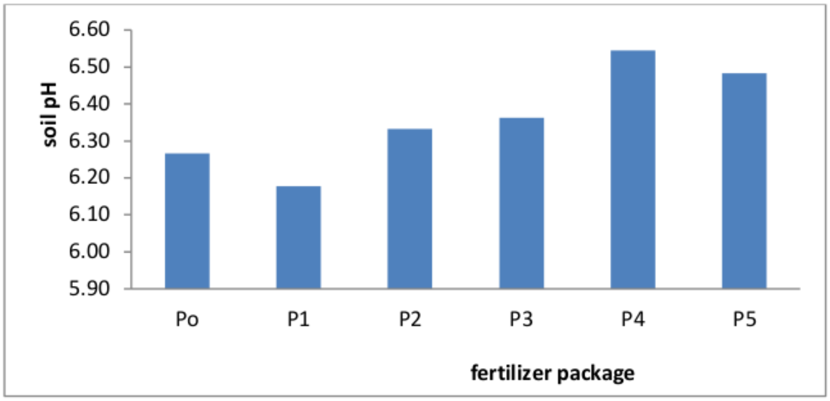

Figure 1. Soil pH influenced by fertilizer packages on 45 DAP corn plants

Plant height, Stalk diameter, and LAI

Plant height, stalk diameter, and leaf area index (LAI) of corn plants are mostly influenced by the fertilizer package received through the soil; liquid organic fertilizer applied through the leaves has minimal effect on these parameters. The treatment of 150 kg ha^{-1} (Zeolite + Urea) + 75 kg ha^{-1} SP-36 did not differ substantially from the application of 200 kg ha^{-1} PR + 100 kg ha^{-1} Urea, which had the greatest effect on plant height and LAI. The diameter of the stalks was greatly impacted when PR fertilizer was used in place of Zeolite + Urea (Table 2 and Figure 2).

Table 2. Effect of fertilizer packages on height, stalk diameter and LAI of corn plants at 45 DAP

Fertilizer Packages	Plant height	Stalk diameter	LAI
	cm	mm	
0 kg ha^{-1} PR + 100 kg ha^{-1} Urea	225.22^{B}	21.23^{A}	2.81^{ABC}
100 kg ha^{-1} PR+ 100 kg ha^{-1} Urea	235.33^{AB}	21.07^{A}	2.88^{AB}
200 kg ha^{-1} PR+ 100 kg ha^{-1} Urea	253.67^{A}	21.90^{A}	3.03^{A}
50 kg ha^{-1} Zeolite + 50 kg ha^{-1} Urea + 75 kg ha^{-1} SP-36	237.11^{AB}	17.78^{B}	2.86^{AB}
100 kg ha^{-1} Zeolite + 100 kg ha^{-1} Urea + 75 kg ha^{-1} SP-36	216.00^{B}	17.77^{B}	2.56^{C}
150 kg ha^{-1} Zeolite+ 150 kg ha^{-1} Urea +75 kg ha^{-1} SP-36	241.11^{A}	18.86^{B}	2.75^{BC}
CV (%)	8.02	8.05	9.51

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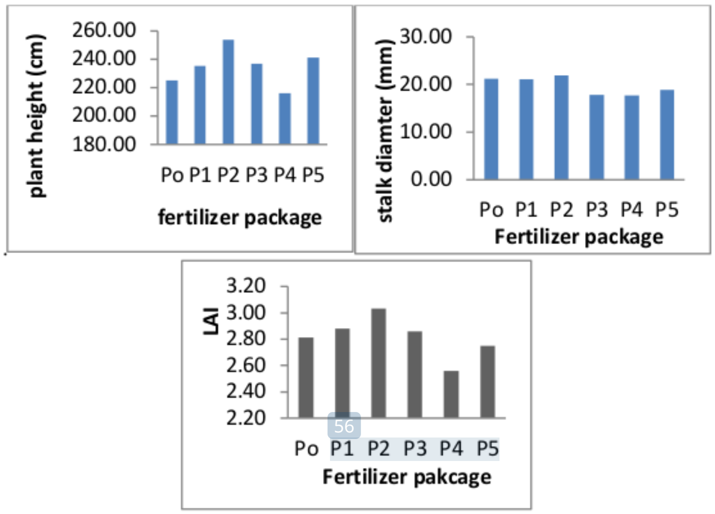


Figure 2. Plant height, stalk diameter and LAI influenced by fertilization packages at 45 DAP

It is observed that the bar diagram patterns for plant height, stalk diameter, and LAI are similar. In general, the highest values in all three graphs were produced from treatment P2 (200 kg ha^{-1} PR + 100 kg ha^{-1} Urea) as shown in Figure 2.

Weight of 100 corn kernels

The weight of 100 corn seeds showed a connection between fertilization from the soil and leaves. The maximum weight of 100 corn seeds was obtained with the fertilizer treatment of 100 kg ha^{-1} (Zeolite + Urea) + 75 kg ha^{-1} SP-36 and 0 ml L^{-1} LOF. This treatment did not differ substantially from the treatment of 200 kg ha^{-1} PR + 100 kg ha^{-1} Urea + 50 kg ha^{-1} KCl along with 100 ml L^{-1} LOC (Table 3 and Figure 3).

Diameter of corn cobs and weight of dry corn shells

There was an interaction between the fertilizer package and LOF application on cob diameter and dry corn shell weight. It turned out that the application of PR was superior in increasing the size of corn cob diameter and corn yield significantly compared to the application of Zeolite + Urea. If PR contains 28% P_2O_5, then in the treatment with the highest dose of 200 kg ha^{-1} of

PR, this is equivalent to 56 kg of P_2O_5. The plants applied with Urea and Zeolite, the SP-36 dosage showed the same for all with an application of 75 kg ha^{-1} SP-36, which was equivalent to 27 kg ha^{-1} P_2O_5. It has been shown that the availability of P2O5 in plants treated with zeolite was only met by 48% as compared to maize plants that got 200 kg ha^{-1} PR. As much as plants given Zeolite + Urea that received 75 kg ha^{-1} SP-36 (27 kg ha^{-1} P2O5), when compared to a dose of 100 kg ha^{-1} PR containing 28 kg ha^{-1} P2O5.

Table 3. Effect of fertilizer package and LOF on the weight of 100 corn seeds

Fertilizer Packages	LOF Application (ml L^{-1})		
	0	50	100
	------------------------ g----------------		
0 kg ha^{-1} PR + 100 kg ha^{-1} Urea	26.37^{ABa}	24.93^{BCa}	24.64^{Ba}
100 kg ha^{-1} PR+ 100 kg ha^{-1} Urea	24.99^{Ba}	25.19^{BCa}	25.39^{ABa}
200 kg ha^{-1} PR+ 100 kg ha^{-1} Urea	25.31^{ABab}	24.99^{BCb}	27.49^{Aa}
50 kg ha^{-1} Zeolite + 50 kg ha^{-1} Urea + 75 kg ha^{-1} SP-36	24.86^{Bab}	23.66^{Cb}	26.89^{ABa}
100 kg ha^{-1} Zeolite + 100 kg ha^{-1} Urea + 75 kg ha^{-1} SP-36	27.74^{Aa}	26.02^{Ba}	26.93^{ABa}
150 kg ha^{-1} Zeolite+ 150 kg ha^{-1} Urea +75 kg ha^{-1} SP-36	25.14^{Bab}	28.81^{Aa}	26.38^{ABab}
VC (%)	5.88		

The LSD 5% significance threshold indicated no significant difference between the identical superscript lowercase letters in rows and the same uppercase letters in columns.

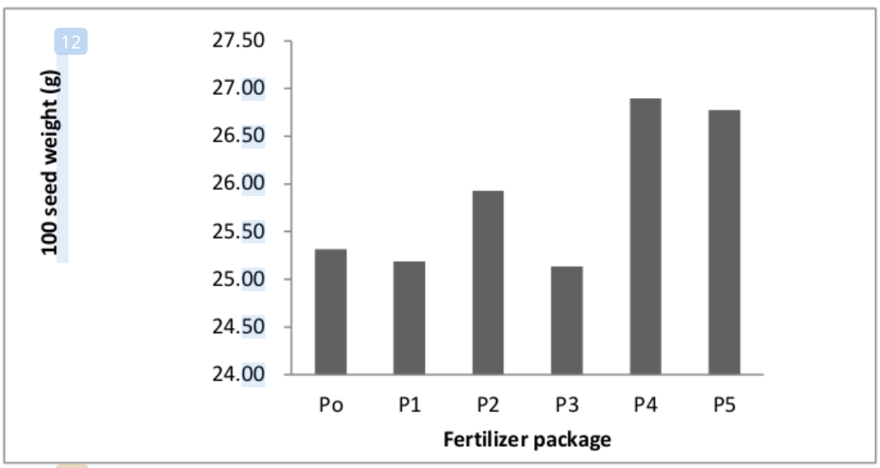


Figure 3. Effect of fertilizer packages on the weight of 100 corn seeds

Table 4. Effect of fertilizer package and LOF on corn cob diameter

Fertilizer Packages	LOF Application (ml L^{-1})		
	0	50	100
	---------------- mm ----------------		
0 kg ha^{-1} PR + 100 kg ha^{-1} Urea	47.50^{Ba}	49.27^{Ba}	50.47^{Ba}
100 kg ha^{-1} PR+ 100 kg ha^{-1} Urea	52.87^{ABa}	52.77^{Aa}	59.47^{Aa}
200 kg ha^{-1} PR+ 100 kg ha^{-1} Urea	56.17^{Aa}	56.83^{ABa}	55.43^{ABa}
50 kg ha^{-1} Zeolite + 50 kg ha^{-1} Urea + 75 kg ha^{-1} SP-36	48.23^{Ba}	49.15^{Ba}	49.08^{BCa}
100 kg ha^{-1} Zeolite + 100 kg ha^{-1} Urea + 75 kg ha^{-1} SP-36	52.53^{ABa}	42.20^{Cb}	45.27^{Cb}
150 kg ha^{-1} Zeolite+ 150 kg ha^{-1} Urea +75 kg ha^{-1} SP-36	51.00^{Ba}	47.03^{BCa}	49.17^{BCa}
VC (%)	6.02		

The LSD 5% significance threshold indicated no significant difference between the identical superscript lowercase letters in rows and the same uppercase letters in columns.

Dry shelled weight of corn

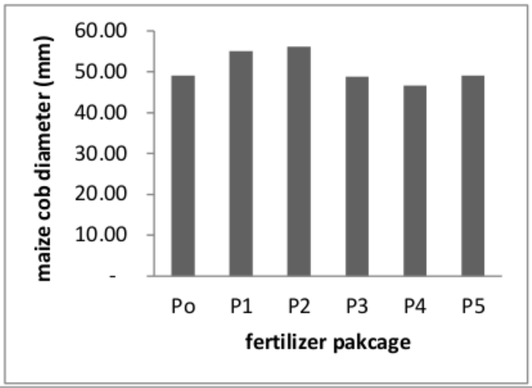
The maize plants treated with Rock Phosphate fertilizer and LOF had the maximum dry-shelled weight. Liquid organic fertilizer doses from 0 to 100 ml L^{-1} did not significantly differ in the results of dry corn shelling. However, LOF was significantly affected, when the fertilizer was given at 50 kg ha^{-1} Zeolite + 50 kg ha^{-1} Urea. The dose of Zeolite + Urea increased, the effect of LOF decreased. 150 kg ha^{-1} of Zeolite + Urea is applied, a dose of 50 ml L^{-1} LOF was the best. Similarly, 50 kg ha^{-1} Zeolite + Urea is applied, then the appropriate dose of LOF was 100 ml L^{-1}.

Table 5. Effect of fertilizer package and LOF on dry shelled weight of corn

Fertilizer Packages	LOF Application (ml L^{-1})		
	0	50	100
	------------- Mg ha^{-1} -------------		
0 kg ha^{-1} PR + 100 kg ha^{-1} Urea	8.74^{Aa}	8.54^{Aa}	8.47^{ABa}
100 kg ha^{-1} PR+ 100 kg ha^{-1} Urea	9.14^{Aa}	8.17^{Aa}	8.36^{ABa}
200 kg ha^{-1} PR+ 100 kg ha^{-1} Urea	9.38^{Aa}	8.66^{Aa}	9.26^{Aa}
50 kg ha^{-1} Zeolite + 50 kg ha^{-1} Urea + 75 kg ha^{-1} SP-36	6.53^{Bb}	8.35^{Aa}	7.62^{BCab}
100 kg ha^{-1} Zeolite + 100 kg ha^{-1} Urea + 75 kg ha^{-1} SP-36	7.03^{Ba}	7.40^{Aa}	6.99^{Cab}
150 kg ha^{-1} Zeolite+ 150 kg ha^{-1} Urea +75 kg ha^{-1} SP-36	6.53^{Bb}	8.35^{Aa}	7.62^{BCab}
VC (%)	7.19		

The LSD 5% significance threshold indicated no significant difference between the identical superscript lowercase letters in rows and the same uppercase letters in columns.

The high application of urea and zeolite could not increase corn yields when compared to the role of phosphate. It turned out that the application of 200 kg ha^{-1} PR + 100 kg ha^{-1} Urea was superior to plants receiving an application of 150 kg ha^{-1} Zeolite + 150 kg ha^{-1} Urea + 75 kg ha^{-1} SP36.



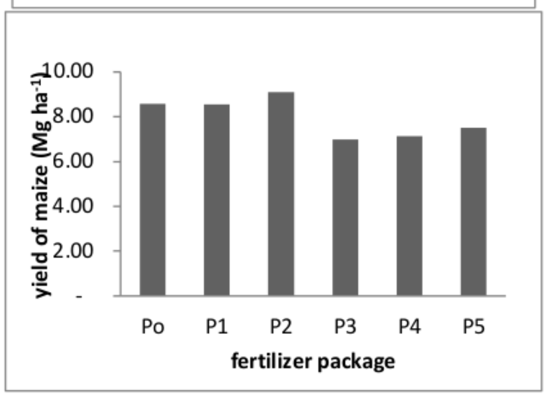


Figure 4. Effect of fertilizer packages on the diameter of corn cobs and dry shells at harvest

Discussion

Similar to how fertilization through the soil has a major impact on pH variations, LOF also has an impact on pH variations in maize plants at 45 DAP. The pH was elevated to 6.48–6.54 by applying Zeolite + Urea fertilizer at doses ranging from 100 to 150 kg ha^{-1}. The largest soil pH increase, 6.42, was achieved with a 100 ml L^{-1} LOF dose when compared to the effects of a lower LOF dose.

Zeolite's capacity to raise the soil's Cation Exchange Capacity (CEC) may be the reason for its influence on pH variations in the soil as zeolite has a CEC of 112.57 cmol kg^{-1}. A high cation exchange capacity increases the release of OH ions in the soil and absorbs more protons (H^+), consequently increasing soil pH. The location of the activity in West Pasaman Regency, dominated by type 1:1 clay minerals with a CEC < 20 cmol kg^{-1}, indicates that zeolite can positively impact soil reactions. An increase in soil pH is expected to enhance the availability of base ions as nutrients for corn plants. Zeolite amendments effectively increase soil pH, reduce exchangeable aluminum levels, and enhance nutrient availability and absorption by plants, ultimately leading to increased productivity (Isna *et al.,* 2020). Additionally, zeolites dissolve phosphate rock, increasing phosphorus availability to plants, essential for growth and development (Gina *et al.*, 2022).

Zeolites possess a high cation exchange capacity, allowing them to exchange more H^+ ions with base ions (such as Na^+, Ca^{2+}, and Mg^{2+}), directly reducing soil acidity (Nur *et al.,* 2020). Zeolite releases sodium ions (Na^+) or other basic cations into the soil, replacing H^+ ions in the soil cation exchange complex, effectively increasing pH compared to relying solely on calcium (Ca^{2+}) release from phosphate rock (Alberto *et al.*, 2021).

The lowest soil pH resulted from the application of PR up to a dose of 100 kg ha^{-1}. Despite containing Ca, PR did not significantly alter pH due to its composition. However, PR provides valuable phosphorus nutrients for plants. This slightly acidic pH enhances fertilizer solubility and phosphorus availability in corn plants. This phenomenon has been elucidated by (Amarasinghe *et al.*, 2022), who demonstrated the inefficiency of most P applied to soil in the form of SP-36 fertilizer, with only a small portion being utilized by plants. Rock phosphate decomposition reaction in acid soil presented in formula 1.

$Ca_5(PO_4)3F+10H^++3H_2O \rightarrow 5Ca^{2+}+3H_2PO_4^- + F^-$ ……………………….(1)

The mechanism for raising soil pH is through the following reaction, presented in formula 2:

$Ca^{2+}+2H^+ \rightarrow 2Ca^{2+}+ 2H_2O$…………………………..………………….(2)

The mechanism for raising soil pH involves the exchange of calcium ions with H^+ in the soil cation exchange complex, reducing free hydrogen ion concentration in the soil solution and thereby lowering acidity. Zeolites, with their porous structure, act as effective ion exchangers and can significantly increase soil pH when introduced into acidic soils (Chompoonut *et al.*, 2019). Combining zeolite with other soil amendments, such as powdered limestone, enhances nutrient availability, promotes plant growth, and increases crop yields (Kulasekaran *et al.*, 2011).

The vegetative growth of corn plants requires a balanced availability of N and P nutrients, exemplified by the application of 200 kg ha^{-1} PR + 100 kg ha-

[1] Urea (P_2). Rock Phosphate positively impacts corn plant growth, especially when accompanied by sufficient N fertilizer. Adequate N fertilizer not only stimulates corn plant growth but also fosters the development of phosphate-solubilizing microbes naturally present in the root rhizosphere. Similar findings were reported by (Rehman and Qayyum, 2020), indicating that PR combined with organic sources of fertilizer enhances its effectiveness.

Likewise, (Yasmeen *et al.,* 2022) demonstrate that the potential for planting on abandoned agricultural land can be increased by using nano-rock phosphate combined with phosphate-solubilizing microbes. However, if plants do not receive PR fertilization, then the treatment of 150 kg ha^{-1} Zeolite + 150 kg ha^{-1} Urea + 75 kg ha^{-1} SP-36 can have a similar effect, but not as pronounced on stem enlargement, as stated in the shape of the stalk diameter. It comes out that applying PR + 100 kg ha^{-1} Urea has a significant impact on stem size. The unfavorable effect of zeolite on the stalk diameter and LAI of corn plants may be due to its high CEC, reducing the availability of N, which is incubated together before application. According to (Belviso, 2020), zeolite has the potential to act as an adsorbent, thereby reducing the availability of the nutrients it absorbs. Sarangi and Jena (2020) explained that in the P method, maximum dissolution in single PR treatments (T2 and T7) occurred at 30 to 60 HST in peanut and corn plants. In contrast, when plants received PR + single superphosphate in different ratios, maximum phosphorus release was recorded at 30 DAT.

Leaf Area Index (LAI) is a vital parameter for corn productivity, reflecting its photosynthetic capacity and biomass, essential for growth monitoring and yield prediction. Remote sensing technologies play a crucial role in efficiently and non-destructively estimating LAI in crops like corn. Studies have shown that the fusion of spectral, structural, and texture features derived from remote sensing images can significantly enhance LAI estimation accuracy (Hongyu *et al*., 2023a). Additionally, the use of UAV multispectral data, hyperspectral data, and LiDAR in constructing LAI prediction models has been explored, with findings indicating that the fusion of hyperspectral and multispectral data can notably improve predictive abilities, especially when using advanced machine learning algorithms like XGBoost (Sergey *et al*., 2023; Hongyu *et al*. 2023b; Fangjiang *et al.,* 2023). These approaches provide valuable insights for optimizing LAI estimation in corn, aiding in better crop management decisions and enhancing overall productivity.

The increased dose of up to 200 kg ha^{-1} PR has a significant impact on the Leaf Area Index (LAI) of corn crops. Research indicates that the application of 150 kg ha^{-1} of SP-36 leads to an increase in growth variables, specifically on the LAI (Naomi *et al.,* 2021). Additionally, studies on the application of Hazara rock phosphate (HRP) show a substantial increase in wheat grain and biomass yield with doses of 250 to 1500 kg HRP ha^{-1}, demonstrating the positive effect of rock phosphate on crop production. Furthermore, the residual effect of rock phosphate application on succeeding crops, such as maize, has been reported to increase grain and biomass yield, with higher doses showing better results compared to lower doses (Nandan *et al*., 2022). These findings collectively highlight the significance of increased rock phosphate doses in improving the LAI and overall growth of corn crops.

The weight of 100 corn seeds was highest in the treatment of 150 kg ha^{-1} zeolite + 150 kg ha^{-1} Urea + 75 kg ha^{-1} SP-36, accompanied by 50 ml L^{-1} LOF. It turns out that with this treatment, the nutrients received by the corn plants are balanced, resulting in the highest weight of 100 seeds compared to other treatments (Arafat *et al*., 2016). This is due to the application of zeolite, which has a high CEC, capable of binding $NH4^{+}$ ions and releasing them again when plants need them (Widyanto *et al.,* 2013). Zeolite also plays a role in increasing the availability of P absorbed by plants.

The weight of 100 corn kernels is higher in the Urea zeolite treatment compared to the Rock phosphate urea application due to the enhanced nutrient uptake and soil conditions facilitated by zeolite. Research has shown that zeolite application significantly increases soil pH, cation exchange capacity (CEC), and nutrient uptake, leading to improved corn growth and yield (Ahmed *et al.,* 2022). Additionally, the use of zeolite in combination with urea has been found to increase corn weight by enhancing soil moisture content and reducing nitrification rates, ultimately benefiting corn growth (James *et al*., 2011). Furthermore, studies have demonstrated that the application of liquid urea at specific frequencies can significantly improve corn yield and nitrogen use efficiency, further supporting the superior performance of the Urea zeolite treatment in promoting corn kernel weight (Isna *et al*., 2020).

The diameter of corn cobs is likely larger in crops treated with PR compared to those treated with zeolite and urea due to the different effects these fertilizers have on plant growth. Rock Phosphate, when combined with nitrogen sources, has shown low agronomic effectiveness for spot application, leading to reduced plant growth and nutrient uptake (André *et al*., 2023). On the other hand, zeolite application has been linked to significant increases in crop yield, plant height, and stalk diameter, improving nutrient use efficiency and the economic effectiveness of urea fertilization (Sembiring *et al*., 2020; Rafael *et al.,* 2017). Additionally, zeolite has been found to positively impact soil properties, such as enhancing the adsorption of essential nutrients such as phosphorus, magnesium, and potassium, which can further contribute to improved plant growth and cob development (Nicolás *et al*., 2015).

Applying 200 kg ha^{-1} PR and 100 kg ha^{-1} urea, along with 0 ml L^{-1} LOF for each application, resulted in the highest dry shelled corn yield, reaching 9.38 Mg ha^{-1}. This was not significantly different from the treatment where the LOF rate was increased to 100 ml L^{-1}. The application of 0 kg ha^{-1} PR and 100 kg ha^{-1} urea resulted in a dry corn yield of 8.54 Mg ha^{-1}, which was not significantly different from the yield obtained with the application of 150 kg ha^{-1} zeolite, 150 kg ha^{-1} urea, and 75 kg ha^{-1} SP-36, which amounted to 8.35 Mg ha^{-1}SP-36 fertilizer has high P nutrient availability, but because the soil is acidic, there is still an impact of Al and Fe on the uptake of P in the soil that comes from SP-36, while from PR, nutrient availability is easier because there is the influence of Ca which neutralizes the impact of fixation of Fe and Al in acid soil (Herry *et al.*, 2009). The decomposition of rock phosphate in acid soil, presented in formula 3:

$$Ca_5(PO_4)_3F+7H^+ \rightarrow 5Ca^{2+}+3H_2PO_4^-+F^-+2H_2O \quad \text{...(3)}$$

PR fertilizer contains 3 molecules per molecule. PR fertilizer contains 3 molecules of H_2PO4^- per molecule of $Ca_5(PO_4)_3F$. The solubility of SP36 fertilizer in acid soil, presented in formula 4.

$$Ca(H_2PO_4)_2 \cdot H_2O+2H^+ \rightarrow Ca^{2+}+2H_2PO_4 \quad \text{... (4)}$$

The SP-36 fertilizer contains 2 molecules of $H_2PO_4^-$ per molecule of $Ca(H_2PO_4)_2$. Therefore, PR can supply more phosphorus than SP-36 fertilizer. This is due to the higher phosphate content in apatite (rock phosphate) compared to calcium dihydrogen phosphate (SP-36 fertilizer). This is in accordance with the statement of Achmad *et al.* (2015). The PR availability is greater than SP-36 in acidic soil. Furthermore, Wijanarko (2015) has proven that the application of rock phosphate increases soil available phosphorus, total phosphorus, and pH while reducing exchangeable aluminum, ultimately increasing corn yields in acidic soils. Therefore, in acidic soil conditions, rock phosphate emerges as a promising alternative due to its effectiveness and cost efficiency compared to SP-36 fertilizer.

Even with an increase in the urea dosage to 150 kg ha^{-1} with 75 kg ha^{-1} of SP36 fertilizer, the plants still receive less urea than those that receive only 100 kg ha^{-1} of urea plus 100 kg ha^{-1} of PR. Phosphorus availability is often the main limiting factor for corn plant growth. Rock phosphate, with its gradual release of phosphorus, can provide a more stable and sustainable source of phosphorus compared to nitrogen fertilizers such as urea. Therefore, rock phosphate can play a greater role in increasing corn crop yields in acidic soils. Although nitrogen is essential for plant growth because it is a major component of protein and chlorophyll, in acid soils, phosphorus availability is often the main limiting factor. Without sufficient phosphorus, corn plants cannot utilize nitrogen effectively. As has been proven by (Debasis *et al.,* 2020) and Suraj *et al*. (2017) PR significantly increases corn grain yield and nutrient absorption, surpassing the impact of N fertilizer such as urea. In addition, (Rafael *et al.,* 2017) proved that the combination of PR with an N source has been found to increase P solubilization and plant P bioavailability, leading to higher plant growth and yield compared to treatment with PR alone.

The role of zeolite is shown to be greater than PR fertilizer in raising soil pH. The application of 200 kg ha^{-1} PR + 100 kg ha^{-1} Urea was able to produce the highest LAI as compared to other treatments, supporting the increased weight of 100 corn kernels, which in turn resulted in the highest corn yield reaching 9.38 Mg ha^{-1} dry shelled weight.

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