Ilmu Pertanian (Agricultural Science)
http://journal.ugm.ac.id/jip
Vol. 7 No. 2 August, 2022: 99–111| DOI: doi.org/10.22146/ipas.71374

Effects of nano guano, nano phosphate rock, and SP-36 fertilizers on maize growth and phosphorus uptake in inceptisol

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Article Info

Received : 19th December 2021
Revised : 3rd March 2022
Accepted: 29th March 2022

Keywords:
Inceptisol, maize, nano guano, nano phosphate rock, phosphorus

Abstract

Nanotechnology fertilizers are fertilizers associated with objects measuring 1 nm to 100 nm capable of controlling or manipulating at an atomic scale. Phosphorus is one of the essential nutrients needed by plants in large amounts. Maize is a strategic commodity requiring optimal nutrients. Inceptisol is soil that has relatively low fertility and chemical properties. The addition of P nutrients to the soil plays an important role in improving soil quality. This study aimed to compare the types of P fertilizers of nano guano, nano phosphate rock, and SP-36 with various doses of P_2O_5 and determine the most effective type. This research was arranged in a completely randomized design (CRD) with two factors. The first factor is the type of fertilizer, consisting of nano guano, nano phosphate rock, and SP-36. The second factor is the dose of P_2O_5 with four treatment levels, namely 0 kg.ha^{-1}, 50 kg.ha^{-1}, 100 kg.ha^{-1}, and 150 kg.ha^{-1}. The results showed that nano phosphate rock was the most effective fertilizer for maize in Inceptisol. The optimum dose of P fertilizer was 100 kg.ha^{-1}, which was able to produce the highest plant height (215.67 cm) and phosphorus uptake (0.4765 g/plant).

INTRODUCTION

Phosphorus (P) is one of the essential nutrients needed by plants in large amounts. However, its solubility and concentration in the soil are relatively low, thereby limiting plant growth and development (Sharpley et al., 2003). Phosphorus (P) in the soil is generally less than 0.3 µg/g, which is slow-moving and relatively rare compared to other macronutrients (Winarso, 2005). The function of phosphorus in the soil cannot be replaced in the form of other nutrients, and it is also involved in the metabolic and biochemical processes of plant cells. Thus, phosphorus must be available to plants (Firmansyah et al., 2017).

Soil is a natural body resulting from various processes and formation factors. As a result, soils are classified based on their property similarities because they range from one location to the next. One of the most widespread soil orders in Indonesia is Inceptisol. This soil order is estimated to have an area of 70.52 million hectares or occupies 40% of the total land area in Indonesia (Priambodo et al., 2019). Although Inceptisols have low fertility and chemical qualities, they can still be improved with careful management and technology (Sudirja et al., 2017). Problems with Inceptisols include a relatively low pH (4.5–6.5) and available P due to the high solubility of Al and Fe elements binding phosphate ions to become insoluble and unavailable to plants (Damanik et al., 2010).

One of the effective efforts in improving soil quality, especially P content, is by adding nutrients. High-quality natural phosphate is an effective and inexpensive natural source of P that can increase soil productivity (Musaad, 2018). Some phosphate fertilizers from natural phosphates that can be used to increase the availability and uptake of phosphorus are guano, phosphate rock, and SP-36. However, each of them has different levels of P_2O_5 and P solubility. SP-36 is a low-hygroscopic

How to cite: Herlina, N., Utami, S.N.H., and Wulandari, C. (2022). Effects of nano guano, nano phosphate rock, and SP-36 fertilizers on maize growth and phosphorus uptake in inceptisol. *Ilmu Pertanian (Agricultural Science)*, 7(2), pp. 99–111.

ISSN 0126-4214 (print) ISSN 2527-7162 (online)

phosphate chemical fertilizer manufactured from phosphate rock acidified with phosphoric acid in granular form (Chuaca et al., 2017). Excessive use of factory-made fertilizers will result in the efficiency of fertilizer use, thus causing waste of fertilizer use and reducing soil quality (Tando, 2018). The addition of an excessive dose of P fertilizer will result in the soil solution being concentrated and unable to be absorbed by plants (Nuryani et al., 2019).

The direct application of guano and phosphate rock as P fertilizer is still limited due to several influencing factors, including mineralogical properties, particle size, free carbonate content, total P_2O_5, dose, and type of natural phosphate deposit (Hartatik et al., 2004). P fertilizers from soluble natural phosphates require high costs, waste energy, and require large amounts of chemicals such as sulfuric acid and phosphoric acid. Meanwhile, natural phosphate fertilizers used directly generally have low solubility. Therefore, it is necessary to increase the efficiency of P fertilizer from natural phosphate (Sugiono and Purwanti, 2019). One of the technologies that can increase the effectiveness and efficiency of natural phosphate fertilizers is nanotechnology (Ariningsih, 2016).

Nanotechnology is a technology that deals with objects measuring 1 nm to 100 nm (1 nm = 10^{-9} m) and has properties superior to the micro-scale. The nanoparticle is so small that it has a very high surface area. Nanotechnology is capable of controlling or manipulating at an atomic scale. The principle is to maximize yields by minimizing the use of fertilizer and applying it directly to the target so that nothing is wasted. Some of the advantages of using nanoparticles are increasing absorption and increasing stability. The finer the phosphate particle size up to 100 nm, the higher the availability of P in the soil (Gulsun et al., 2009).

Nano-sized phosphate particles can move in the soil and reach plant roots through mass flow easily when approaching the roots, making P depletion promote the release of hydroxyapatite nanoparticles. Thus, there will be less contact of free orthophosphate-P in the soil compared to phosphorus is soluble in water, thereby minimizing the opportunity for P fixation (Montalvo et al., 2015). The pattern of P release in each soil and P uptake of each plant is different (Habi et al., 2017). Application of nanoparticle phosphate rocks 7.5% of soil weight can reduce P retention in Andisol soil from 95.15% to 87.22%, indicating that nanoparticle phosphate rocks can release fixed P (Rina et al., 2018). Nano phosphate rock treatment of 6% by weight of soil gave a significantly different effect on available P in Inceptisol (Nugroho et al., 2020). Phosphate rock has a high negative charge, which can block the negative location of P-absorbing minerals, thereby reducing the ability of these minerals to maintain P retention (Ridine et al., 2014). The application of 50% guano combined with 50% NPK fertilizers positively affected soil and crops, leading to sustainable maize production. The macronutrient source of guano functions well to add soil nutrients (Sridhar et al., 2006).

Maize is used as an indicator plant because it can visually show a nutrient deficiency in the soil and is sensitive to P uptake. Besides, maize is also a strategic commodity, which has economic value and potential to be developed because of its position as a second source of carbohydrates and protein after rice. In addition, maize can be used as animal feed, industrial raw material, and bioenergy (Sulistyaningsih, 2019). Maize has considerable potential to be developed in Inceptisols if adequate fertilization technologies and management efforts are used. However, the optimal type and dose of natural phosphate fertilizers with nanotechnology, compared to SP-36 fertilizer, for maize P uptake in Inceptisols are still unknown. This study aimed to determine the most effective type of phosphate fertilizer and the optimal dose for the growth and absorption of phosphorus in maize. This research is expected to inform about the optimal dosage of nano guano, nano rock phosphate, and SP-36 fertilizers to increase growth and absorption of phosphorus in maize.

MATERIALS AND METHODS

This study was carried out in the Department of Soil Science greenhouse, Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta, from December 2020 to September 2021. The manufacture of nano-tech fertilizers was carried out at the Laboratory of Production, Universitas Muhammadiyah Yogyakarta. The materials used in this study were hybrid maize seeds of Bisi 2 variety, urea (300 $kg.ha^{-1}$), KCl (100 $kg.ha^{-1}$), nano guano (25.29% P_2O_5), nano phosphate rock (30.03% P_2O_5), SP-36 (36% P_2O_5), and chemicals for the analysis of chemical properties of soil, fertilizer, and plant tissues. The tools used in this research were pH meter, UV-VIS Spectrophotometer 1240 Shimadzu, scales, oven, label paper, ruler, sieve, stationery, and other laboratory equipments in the Laboratory of General Soil and Laboratory of Chemistry and Soil Fertility, Department of Soil Science, Faculty of Agriculture, Universitas Gadjah Mada.

This research was arranged in a factorial Completely Randomized Design (CRD). The first factor is the types of phosphate fertilizer, namely nano guano, nano phosphate rock, and SP-36. The second factor is the doses of P_2O_5, consisting of 0, 50, 100, and 150 kg.ha^{-1}. There were 12 treatment combinations, and each treatment consisted of three replications, resulting in 36 experimental units. Soil samples were collected from Patuk, Gunung Kidul, at a depth of 0 – 20 cm (random sampling). Soil taken from several points was then composited and air-dried for two weeks. Afterward, the soil was filtered using a 2 mm sieve. The fertilizers were manufactured by processing guano and phosphate rock into nano-size using a ball mill, with a ratio of steel balls, guano or phosphate rock, and water of 500 g, 100 g, and 60 ml. The milling process was carried out for six hours. Before being applied at the beginning of planting, the fertilizers were mixed thoroughly with the soil and incubated for two weeks (Ladiyani et al., 2011).

Urea and KCl were applied at 7 and 30 days after planting. The observation made includes the characterization of nanoparticles using Scanning Electron Microscopy (Manikandan and Subramanian, 2014), which was continued with analysis using image-J. Variables observed include available P, plant height, the number of leaves, shoot and root fresh weight, shoot and root dry weight, root Cation Exchange Capacity (CEC), root volume, and P uptake of maize plants. The data were analyzed using ANOVA and continued with Duncan's Multiple Distance Test (DMRT) at α=5% and correlation.

Table 1. Physical and chemical properties of Inceptisol

Parameter	Unit	Value	Category
Bulk Density (BD)	g.cm^{-3}	1.12	Low$^{3)}$
Specific Weight (SW)	g.cm^{-3}	2.21	
Porosity	%	50.70	
Texture			
Sand	%	33.43	Silt loam
Silt	%	57.63	(*lempung debuan*)$^{1)}$
Clay	%	8.94	
Available P	[mg.kg^{-1}]	7.00	Low$^{1)}$
Total P	%	0.16	-
Potential P	[mg/100 g]	34.70	Moderate$^{1)}$
pH			
H_2O		5.60	Slightly acidic$^{1)}$
KCl		4.01	Extremely acidic$^{1)}$
CEC	[cmol (+).kg^{-1}]	15.98	Low$^{1)}$
Organic C	%	1.82	Low$^{1)}$
Organic matter	%	3.13	Low$^{1)}$
Total N	[g/100 g]	0.14	Low$^{1)}$
Available K	[cmol (+).kg^{-1}]	0.25	Low$^{1)}$
Available Na	[cmol (+).kg^{-1}]	0.44	Moderate$^{1)}$
Available Ca	[cmol (+).kg^{-1}]	0.47	Extremely low$^{1)}$
Available Mg	[cmol (+).kg^{-1}]	1.61	Moderate$^{1)}$
Base saturation	%	17.33	Extremely low$^{1)}$
Al and Fe - Oxalic acid extract			
Al	%	1.58	High$^{2)}$
Fe	%	0.61	Low$^{2)}$

Remarks: Rating based on (Balai Penelitian Tanah, 2009)$^{1)}$ Rating based on (Blackmore et al., 1981)$^{2)}$ Rating based on (Hunt and Gilkes, 1992)$^{3)}$.

RESULTS AND DISCUSSION

The bulk density of mineral soil ranges from 0.6–1.3 g.cm^{-3} (Maas et al., 2018). The value of specific weight (SW) of the Inceptisol used was 2.21 g.cm^{-3} (Table 1). Clay minerals generally have a particle density of 2.2–2.6 g.cm^{-3}. In general, the average density of mineral soils is 2.6 g.cm^{-3} (Afrianti et al., 2019). Soil specific weight has varying values, depending on the mineral composition of the soil (Balai Penelitian Tanah, 2006). The ratio of BD and SW of soil is commonly used to calculate soil porosity. Porosity is the proportion of total pore space contained in a volume unit of soil occupied by water and air (Pardosi et al., 2017).

Porosity is defined as the proportion of total pore space occupied by water and air in a unit volume of soil. It is an indicator of soil aeration and drainage conditions (Manfarizah et al., 2011). The availability of phosphorus in the soil is influenced by soil aeration by overhauling organic matter by soil microorganisms. In dense soil or low oxygen availability, the phosphorus absorption process will be disrupted (Neira et al., 2015). The Inceptisol in the study area had a dusty clay texture, with low to moderate levels of available P, potential P, and total P (Balai Penelitian Tanah, 2006). The low available P was related to Al and Fe oxides in the soil, which were the most dominant components of P fixing (Freese et al., 1992). When the three variables are compared, their presence in the soil is total P > potential P > available P. The soil pH was slightly acidic. Meanwhile, the values of soil EC, organic C, total N, available K, and available Na are classified as low (Balai Penelitian Tanah, 2009). The available Ca, available Mg, and base saturation of the soil are extremely low, moderate, and extremely low, respectively. Al and Fe oxide compound extracted with 0.2 M ammonium oxalate pH ± 3 obtained an amorphous fraction of the oxide compound (Blackmore et al., 1981).

Al and Fe oxides extracted from ammonium oxalate pH of 3 were measured at 1.58% and 0.61%, respectively, with high and low values according to Blackmore et al. (1981). The levels of Al and Fe oxides are influenced by soil genesis, including parent material, climate, topography, organisms, and time (Freese et al., 1992). This high Al content is due to the halloysite clay mineral factor, along with gibbsite, which dominates the soil (Raharjo and Sarmili, 2016).

Characteristics of fertilizer using nano guano, nano phosphate rock, and SP-36

Based on the results of further testing using the Image-J software, guano was split into smaller particles, consisting of 0.63% measuring 1–10 nm, 20.53% measuring 10–20 nm, 75.17% measuring 20–100 nm, 2.40% measuring 100–250 nm, 1.17% measuring 250–1000 nm, and 0.11% measuring >1000 nm (Table 2). The average nano guano formed was 36.08 nm. Meanwhile, the phosphate rock formed consisted of 0.18% measuring 0–10 nm, 25.01% measuring 10–20 nm, 71.49% measuring 20–100 nm, 3.05% measuring 100–250 nm, 0.18% measuring 250–1000 nm, and 0.09% measuring >1000 nm (Table 2). The average size of the nano phosphate rock formed was 38.63 nm. The manufacture of nanomaterials is successful if 50% or more of the particles produced are 1–100 nm in size (Khan et al., 2021).

The total amount of guano and phosphate rock with a size of 1–100 nm was 96.33% and 96.68%, respectively. Thus, the manufacture of nanomaterials was successful. Guano and phosphate rock became nano-sized due to the collision between the particles and the steel ball for 6 hours. Synthesis of nanoparticles

Table 2. Particle size of nano guano and nano phosphate rocks

Diameter (nm)	Guano		Phosphate rocks	
	Quantity	Percentage (%)	Quantity	Percentage (%)
0-10	11	0.63	4	0.18
10-20	367	20.53	465	25.01
20-100	1344	75.17	1615	71.49
100-250	43	2.40	69	3.05
250-1000	21	1.17	4	0.18
>1000	2	0.11	2	0.09
	Mean = 36.08		Mean = 38.63	

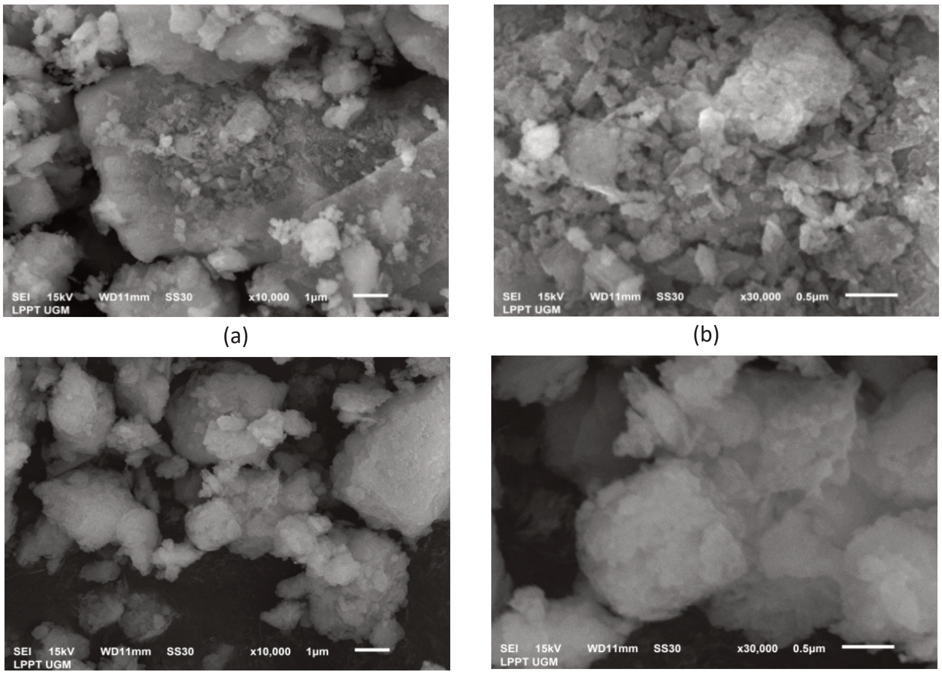
Remarks: Results of the further testing using Image-J software.

using physical methods, especially using high-energy ball milling, can change the particle size into nano. Figure 1 shows the morphology of the nano guano and phosphate rock fertilizers with a magnification of 10,000× and 30,000× (Subramanian et al., 2015).

Synthesis of nanoparticles through a physical approach using ball milling with high energy is able to change the particle size into nano. After milling for 1, 2, 4, and 6 hours, the particle size was reduced to 1078, 475, 398, and 203, resulting in surface areas of 41, 55, 72, 83, and 110 m^2.g^{-1}, respectively. This result shows that the smaller the nano size, the larger the surface area (Subramanian et al., 2015). The total P of nano guano, nano phosphate rock, and SP-36 were 25.29%, 30.03%, and 36%, respectively (Table 3). The phosphate content of natural phosphate is expressed in the form of phosphorus pentaoxide (P_2O_5). Fertilizers derived from natural phosphates suitable for application to the soil contain more than 20% total P_2O_5 and have high reactivity with P_2O_5 levels soluble in 2% citric acid, which is more than 6% (Arifin et al., 2017).

Based on the analysis results, P dissolved in citric acid of nano guano, nano phosphate rock, and SP-36 fertilizers were 11.06%, 14.19%, and 34%, respectively. Meanwhile, the moisture content in nano guano, nano phosphate rock, and SP-36 fertilizers were 3.15%, 4.03%, and 3.89%, respectively. The results of the fertilizer pH analysis were 7.15, 7.18, and 7.05, respectively. The total Ca obtained were 26.92%, 29.82%, and 18.65%, respectively. The total Mg yields were 0.18%, 0.27%, and 0.49%, respectively. Natural phosphates such as phosphate rocks and guano contain lots of free carbonates such as calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$), which can provide Ca and Mg intake in slightly acidic to very acidic soils (Fayiga and Obigbesan, 2017). These levels of Ca and Mg cause the pH to become neutral through the release of the OH^- group from both elements.

Natural phosphate-containing materials, such as guano, phosphate rock, and SP-36, can be utilized to improve soil Ca levels and pH as well as promote P nutrients into the soil (Shaaban et al., 2015). The total N and K of the fertilizers tested were 3.82 and 0.24%, 2.07 and 0.28%, and 0.99 and 0.51%, respectively. Meanwhile, the Al_2O_3 and Fe_2O_3 values of nano guano, nano phosphate rock, and SP-36 fertilizers used were 7.65 and 11.07 ppm, 6.89 and 5.26 ppm, and 4.80 and 6.41 ppm, respectively. Although large amounts of minerals and other impurities were removed during beneficiation, natural phosphate from nano guano, nano phosphate rock, and SP-36 still contained some of the original impurities (Fayiga and Obigbesan, 2017). These impurities include silica, Cd, Pb, calcite and iron



(a) (b)

(c) (d)

Figure 1. The results of the SEM analysis of (a) nano phosphate rocks at 10,000× magnification, (b) nano phosphate rocks at 30,000× magnification, (c) nano guano at 10,000× magnification, (d) nano guano at 30,000× magnification.

Table 3. The chemical properties of nano guano, nano phosphate rock, and SP-36

No	Parameter	Unit	Nano guano	Nano phosphate rock	SP-36
1	Total P	%	25.29	30.03	36.00
2	P solubility in 2% citric acid	%	11.06	14.19	34.00
3	Moisture content	%	3.41	4.03	3.89
4	pH	-	7.15	7.18	7.05
5	Total Ca	%	26.92	29.82	18.65
6	Total Mg	%	0.18	0.27	0.49
7	Total N	%	3.82	2.07	0.99
8	Total K	%	0.24	0.28	0.51
9	Al_2O_3	ppm	7.65	6.89	4.80
10	Fe_2O_3	ppm	11.07	5.26	6.41
11	Total Cd	ppm	0.033	0.028	0.031
12	Total Pb	ppm	0.066	0.062	0.029
13	Total Si	%	2.07	0.76	0.41

Table 4. Effects of the types and doses of phosphate fertilizer on the available P mg.kg^{-1})

Dose P_2O_5 kg.ha^{-1}	Types of phosphate fertilizer			Average
	Nano guano	Nano phosphate rock	SP-36	
0	7	7	7	7 c
50	17	20	10	16 b
100	41	42	27	37 a
150	42	43	40	42 a
average	27 a	28 a	21 b	(-)

Remarks: Means followed by the same letters are not significantly different according to Duncan's Multiple Range Test (DMRT) at α=5%.

oxide (Fe) hydrates, and aluminum oxide (Al) hydrates in varying combinations and concentrations. Some of these impurities may have an effect characterized by the effect of natural phosphate applied directly into the soil (Musaad, 2018).

Available P

Based on Table 4, there was a significantly different effect between treatments based on the variance scale. Treatment of nano phosphate rock showed significantly different results than SP-36 but not substantially different from that of nano guano. The highest available P was found in the nano phosphate rock treatment, with an average of 28 mg.kg^{-1}, and the lowest available P was found in the SP-36 treatment, with an average of 21 mg.kg^{-1}. The analysis results showed that the overall available P increased with the application of each P fertilizer depending on the dose given. The P_2O_5 dose treatment showed significantly different results in the available soil P. The highest available P was found at a dose of 150 kg.ha^{-1}, but not significantly different at 100 kg.ha^{-1}, namely 42 mg.kg^{-1} and 37 mg.kg^{-1}, respectively. The lowest available P was found at a dose of 0 kg.ha^{-1}, with an average of 7 mg.kg^{-1}. The analysis results showed that a dose of 100 kg.ha^{-1} was the optimum dose to increase the availability of P in Inceptisol.

The most effective type of fertilizer treatment to increase available soil P was nano phosphate rock, and the lowest result was observed in SP-36. This is presumably because the use of nano-sized fertilizers (1 nm = 10^{-9} m) is more reactive and is easily absorbed by plants (Betty et al., 2017). The use of nano-sized natural phosphate fertilizers can accelerate reactions that can increase the movement of soil solution ions to improve soil chemical properties, including growing soil available P (Nugroho et al., 2020). Nano-tech fertilizers can make it easier for plant roots to absorb nutrients. This happens because the smaller the size of an object causes, the larger surface area. A large

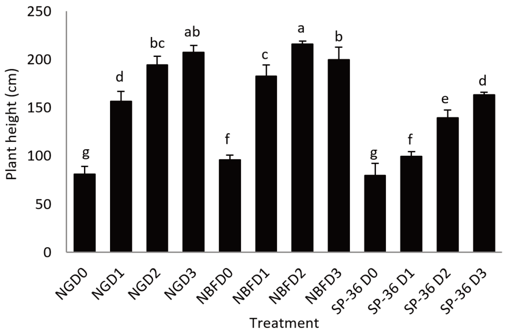


Figure 2. Plant height of maize, NG (Nano guano), NBF (nano phosphate rock), and (SP-36). D0, D1, D2, D3 (dose 0, 50,100, and 150 kg.ha^{-1} P_2O_5).

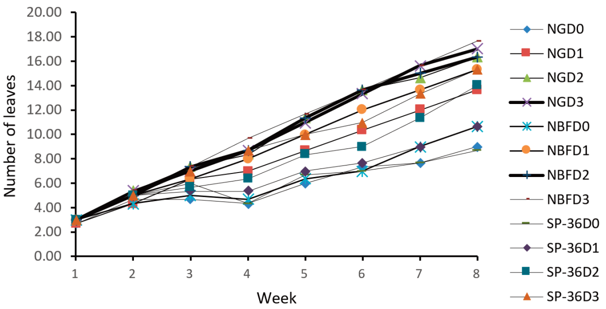


Figure 3. Number of leaves, NG (Nano guano), NBF (nano phosphate rock), and (SP-36). D0, D1, D2, D3 (dose 0, 50,100, and 150 kg.ha^{-1} P_2O_5).

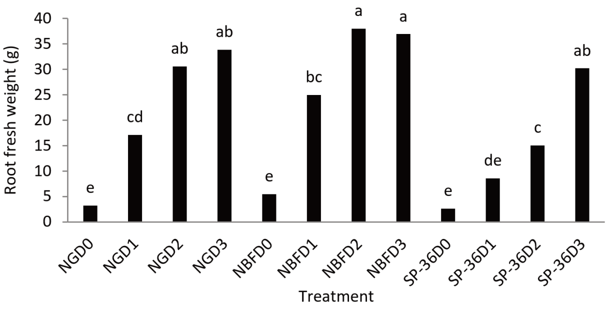


Figure 4. Root fresh weight of maize as affected by various types of phosphate fertilizers and doses of P_2O_5, NG (Nano guano), NBF (nano phosphate rock), and (SP-36). D0, D1, D2, D3 (dose 0, 50,100, and 150 kg.ha^{-1} P_2O_5).

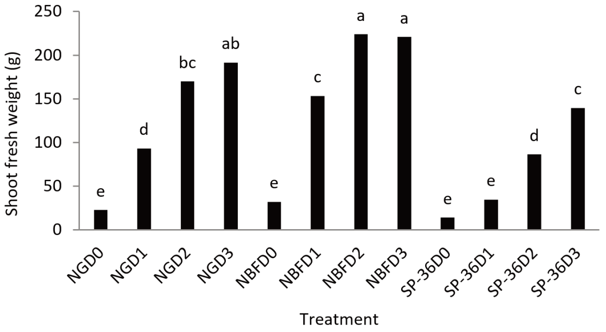


Figure 5. Shoot fresh weight of maize as affected by various types of phosphate fertilizers and doses of P_2O_5, NG (Nano guano), NBF (nano phosphate rock), and (SP-36). D0, D1, D2, D3 (dose 0, 50,100, and 150 kg.ha^{-1} P_2O_5).

Remarks: Bars followed by the same letters are not significantly different according to Duncan's Multiple Range Test (DMRT) at α=5%.

surface can guarantee an increasingly intensive nutrient exchange or release process (Havlin et al., 2005). SP-36 fertilizer, easily soluble in slightly acidic to acidic soil like Inceptisol, undergoes dissolution faster. This dissolution causes a re-conversion of phosphate from the solution phase to poorly soluble forms, such as variscite and strengite, so they are not available to plants (Habi et al., 2017).

Plant height

Based on Figure 2, the application of nano guano, nano phosphate rock, and SP-36 at various doses of P_2O_5 increases plant height linearly every week. The maize plant height was observed until the maximum vegetative phase, which was from 7 to 56 days after planting. Highest plant growth was found in the nano phosphate rock treatment at a dose of 100 kg.ha^{-1}, while the lowest one was found in the SP-36 treatment at a dose of 0 kg.ha^{-1}. Plant height is strongly influenced by available P in the soil, which serves as a component of ATP (aerobic atmosphere) or $NADPH_2$ (anaerobic atmosphere) and serves as an energy source for plant metabolisms such as photosynthesis and respiration (Xue et al., 2014).

Number of leaves

Based on Figure 3, the number of leaves of maize plants increased every week. Although there was a decline at one point, it was because the leaves were old and had dried and fallen, resulting in a reduction in the number of leaves, which was not significant. Increasing doses of nano guano, nano phosphate rock, and SP-36 fertilizers tended to increase the number of leaves. This result was obtained because the phosphate fertilizer given was able to increase the availability of phosphorus. The highest and lowest number of leaves were obtained in the nano phosphate rock and SP-36 treatment, respectively. The highest number of leaves was obtained in the application of nano phosphate rock fertilizer at the doses of 100 kg.ha^{-1} and 150 kg.ha^{-1}. The higher the P_2O_5 dose, the higher the number of leaves. Guano and nano-sized phosphate rock have a high surface area, so they are more reactive and easily absorbed by plants. Primary and secondary macronutrients, such as nitrogen, phosphorus, potassium, silicon, and calcium, are essential in increasing soil fertility and promoting plant growth (Khan et al., 2021).

Shoot and root fresh weight

The application of nano phosphate rock fertilizer at the doses of 100 kg.ha^{-1} and 150 kg.ha^{-1} resulted in the most significant root fresh weight. Meanwhile, the lowest one was discovered at a dose of 0 kg.ha^{-1} on all types of P fertilizer (Figure 4). Similarly, the highest shoot fresh weight was found when nano phosphate rock fertilizer was applied at the doses of 100 kg.ha^{-1} and 150 kg.ha^{-1}. Meanwhile, the lowest one was observed in the phosphate fertilizer treatment at a dose of 0 kg.ha^{-1} and was not significantly different from the SP-36 treatment at 50 kg.ha^{-1} (Figure 5). The fresh weight of the plant describes the photosynthate content or product of the photosynthesis process in the soil. Several factors, including sunlight intensity and soil nutrient content, can influence fresh plant weight. The addition of phosphate rock as a source of P using nanotechnology can increase P supply in the soil, making P available and influencing plant growth (Arifin et al., 2017).

Shoot and root dry weight

The effects on the root dry weight varied significantly between treatments. P_2O_5 doses of 100 kg.ha^{-1} and 150 kg.ha^{-1} significantly increased root and shoot dry weight. The lowest root and shoot dry weight was obtained at a P_2O_5 dose of 0 kg.ha^{-1}. The highest dry weight was found in nano phosphate rock, which had a significantly different effect than nano guano and SP-36 treatments (Figure 6). Meanwhile, the highest shoot dry weight was found in the nano phosphate rock treatment at a dose of 100 kg.ha^{-1}, and the lowest was found in the SP-36 fertilizer treatment at 0 kg.ha^{-1} (Figure 7). The nutrient with the most significant impact on plant dry weight is phosphorus. The more P plants take in, the more other elements the plant take. The more nutrients the plant can absorb, the more significant the impact on the plant's dry weight. Furthermore, the water content of the tissue biomass

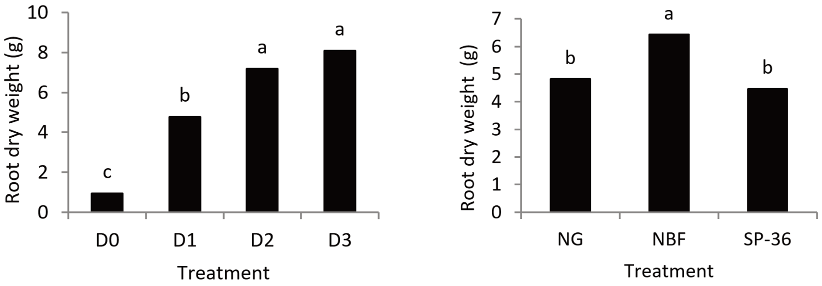


Figure 6. Root dry weight of maize as affected by various types of phosphate fertilizers and doses of P_2O_5, NG (Nano guano), NBF (nano phosphate rock), and (SP-36). D0, D1, D2, D3 (dose 0, 50,100, and 150 kg.ha^{-1} P_2O_5).

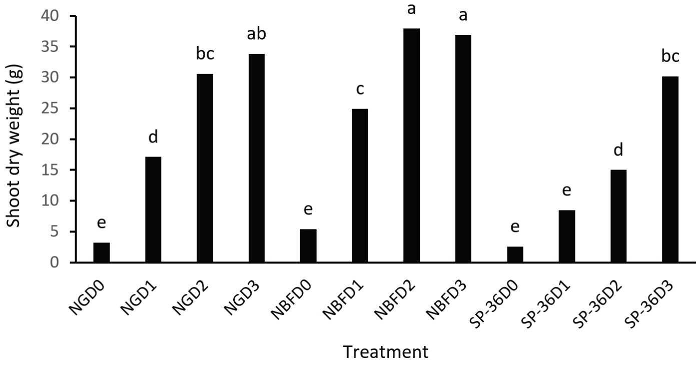


Figure 7. Shoot dry weight of maize as affected by various types of phosphate fertilizers and doses of P_2O_5, NG (Nano guano), NBF (nano phosphate rock), and (SP-36). D0, D1, D2, D3 (dose 0, 50,100, and 150 kg.ha^{-1} P_2O_5).

Remarks: Bars followed by the same letters are not significantly different according to Duncan's Multiple Range Test (DMRT) at α=5%.

Table 5. Effects of the types and doses of phosphate fertilizer on the Root CEC (cmol(+).kg^{-1})

Dose P_2O_5 kg.ha^{-1}	Types of phosphate fertilizer			Average
	Nano guano	Nano phosphate rock	SP-36	
0	0.01	0.02	0.01	0.01 c
50	0.14	0.20	0.18	0.17 b
100	0.44	0.45	0.22	0.37 a
150	0.47	0.51	0.43	0.47 a
average	0.27 a	0.29 a	0.21 a	(-)

Remarks: Means followed by the same letters are not significantly different according to Duncan's Multiple Range Test (DMRT) at α=5%.

affects the plant's dry weight (Winarso, 2005).

Root cation exchange capacity (CEC) (cmol(+).kg^{-1})

Table 5 shows no interaction effects of treatments on the cation exchange capacity of maize roots based on the analysis of variance. There was no significant difference in the treatment of phosphate fertilizers. The nano phosphate rock treatment resulted the highest root CEC value, averaging 0.29 cmol(+).kg^{-1}, while the SP-36 fertilizer treatment resulted in the lowest value, averaging 0.21 cmol(+).kg^{-1}. The P_2O_5 dose treatment produced significantly different results. The highest root CEC was found at a dose of 150 kg.ha^{-1} but not significantly different at a dose of 100 kg.ha^{-1}, which were 0.47 cmol(+).kg^{-1} and 0.37 cmol(+).kg^{-1}, respectively. Meanwhile, the lowest root CEC was found at a dose of 0 kg.ha^{-1} (0.01 cmol(+).kg^{-1}), which was significantly different from that at a dose of 50 cmol(+).kg^{-1} (0.17 cmol(+).kg^{-1}). The root CEC is related to the available soil P.

The results showed that the most effective fertilizer treatment to increase root CEC was nano phosphate rock, and the lowest was SP-36. This is presumably because the use of nano-sized fertilizers (1 nm = 10^{-9} m) is more reactive and is easily absorbed by plants (Betty et al., 2017). Meanwhile, SP-36 fertilizer is easily soluble, and it reacts with clay minerals, oxides, hydroxides, aluminum, and iron so that it is not available to plants (Brady and Weil, 2014). Nano-tech fertilizers can make it easier for plant roots to absorb nutrients. This happens because the smaller the size of an object causes, the larger surface area. A large surface can guarantee an increasingly intensive nutrient exchange or release process (Havlin et al., 2005). The root CEC value was higher in soils with high available P, especially in the rhizosphere (Mahanta et al., 2018). The high availability of P will increase the number and length of more active roots and have more pectin substances to directly increase the root CEC (Mahanta et al., 2014).

Root volume

Based on the analysis of variance, there was no interaction effect of the treatments on the root volume (Table 6). The application of phosphate fertilizer types and P_2O_5 doses showed significantly different results. The highest root volume was observed in the nano phosphate rock treatment, which was an average of 20 ml/plant. Meanwhile, the lowest root volume was

Table 6. Effects of the types and doses of phosphate fertilizer on the root volume (ml/plant)

Dose P_2O_5 kg.ha^{-1}	Types of phosphate fertilizer			Average
	Nano guano	Nano phosphate rock	SP-36	
0	1.67	2.33	1.50	1.83 c
50	13.33	18.00	9.00	13.44 b
100	25.67	29.67	21.67	25.67 a
150	26.00	30.00	25.67	27.22 a
Mean	16.67 ab	20.00 a	14.46 b	(-)

Remarks: Means followed by the same letters are not significantly different according to Duncan's Multiple Range Test (DMRT) at α=5%.

found in the treatment of SP-36 fertilizer, resulting in an average of 14.46 ml/plant. Based on doses effect, the lowest root volume was observed at a dose of 0 kg.ha^{-1}, resulting in an average of 1.83 ml/plant, while the highest one was at a dose of 150 and 100 kg.ha^{-1}. The low root volume at a dose of 0 kg.ha^{-1} was thought to be due to the low availability of P nutrients in the soil, whereas the high root volume at a dose of 100 and 150 kg.ha^{-1} was due to the high availability of phosphorus. This result is in line with the research by Camacho et al. (2002), stating that the low root volume was due to the low availability of P in the soil. This is because the root system is the main organ that affects nutrient absorption, changes in morphology, and root physiology that will affect phosphorus nutrient uptake.

Phosphorus (P) uptake of maize plants

According to the analysis of variance, there was an interaction effect between the types of P fertilizer and the P_2O_5 doses (Table 7). The nano phosphate rock treatment had the highest P uptake at a dose of 100 kg.ha^{-1}, namely 0.4765 g/plant, and the SP-36 treatment had the lowest P uptake at a dose of 0 kg.ha^{-1}, namely 0.0023 g/plant. The P uptake of nano phosphate rock was higher than that of nano guano, which is presumably because the nano phosphate rock has higher Ca and P soluble in 2% citric acid. The SP-36 fertilizer treatment produced the lowest value, presumably because SP-36 has high solubility and can be easily absorbed by plants and is also easily fertilized by Al and Fe oxides, making it unavailable to plants. Meanwhile, fertilizers using nanotechnology have the advantage of being able to make fertilizers more reactive and effective (Betty et al., 2017).

Nano-sized natural phosphate fertilizers could accelerate reactions that improve soil chemical characteristics like pH and available P by increasing the mobility of soil solution ions. Increasing the movement of P in the soil is very important to increase P uptake because P is not mobile in the soil. The higher the

Table 7. Effects of the types and doses of phosphate fertilizer on the P tissue uptake (g/plant)

Dose P_2O_5 kg.ha^{-1}	Types of phosphate fertilizer			Average
	Nano guano	Nano phosphate rock	SP-36	
0	0.0026 c	0.0046 c	0.0023 c	0.0032
50	0.0674 c	0.1230 c	0.0222 c	0.0709
100	0.3057 b	0.4765 a	0.0870 c	0.2897
150	0.3480 b	0.4652 a	0.3128 b	0.3753
Mean	0.1809	0.2673	0.1061	(+)

Remarks: Means followed by the same letters are not significantly different according to Duncan's Multiple Range Test (DMRT) at α=5%.

Table 8. Correlation of available phosphorus with plant growth and phosphorus uptake in maize

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
P1	1	.878**	.888**	.876**	.954**	.912**	.867**	.856**	.918**	.886**
P2	.878**	1	.949**	.949**	.929**	.895**	.903**	.869**	.877**	.825**
P3	.888**	.949**	1	.928**	.935**	.898**	.904**	.875**	.902**	.812**
P4	.876**	.949**	.928**	1	.971**	.940**	.927**	.832**	.906**	.907**
P5	.926**	.954**	.935**	.971**	1	.947**	.932**	.850**	.910**	.914**
P6	.912**	.895**	.898**	.940**	.947**	1	.927**	.869**	.948**	.923**
P7	.867**	.903**	.904**	.927**	.932**	.927**	1	.863**	.936**	.843**
P8	.856**	.869**	.875**	.832**	.850**	.869**	.863**	1	.886**	.751**
P9	.918**	.877**	.902**	.906**	.910**	.948**	.936**	.886**	1	.843**
P10	.886**	.825**	.812**	.907**	.914**	.923**	.843**	.751**	.843**	1

Remarks: (**) = significant (P<0.01); P1 = Available Phosphorus ; P2 = Plant Height ; P3 = Number of Leaves ; P4 = Shoot Fresh Weight ; P5 = Shoot Dry Weight ; P6 = Root Fresh Weight ; P7 = Root Dry Weight ; P8 = Root CEC; P9 = Root Volume ; P10 = Phosphorus Uptake available P in the root zone, the more P is absorbed by plant roots so that the tissue P concentration increases (Nugroho et al., 2020).

Correlation of available phosphorus with plant growth parameters and P uptake in maize

The analysis results showed a positive correlation with a solid and significant relationship between the availability of phosphorus nutrients and the growth and P nutrient uptake of maize (Table 8). This shows that the higher the phosphorus nutrient content available in the soil, the higher the plant nutrient uptake, thereby affecting plant growth. The increase in the dry weight of the plant canopy is related to the increase in plant height, which is influenced by the availability of phosphorus in the soil so that the formation of plant tissue is better (Rizky et al., 2019). This research shows that the success rate of growth and uptake of maize plants is highly dependent on increasing soil fertility and productivity, mainly available P.

CONCLUSIONS

The effectiveness of phosphate rock fertilizer with nanotechnology for maize plants in Inceptisol was better than that of nano guano and SP-36 fertilizers. The optimum dose of P fertilizer was 100 kg.ha^{-1}, which could increase plant growth, resulting in the highest plant height of 215.67 cm and phosphorus uptake of 0.4765 g/plant.

ACKNOWLEDGMENT

Authors are highly grateful to the Faculty of Agriculture, Universitas Gadjah Mada and Universitas Muhammadiyah Yogyakarta for providing facilities.

REFERENCES

Afrianti, S., Purba, M.P., and Napitupulu, K. (2019). Karakteristik sifat fisika tanah pada berbagai kelas umur tegakan kelapa sawit di Pt. Pp. London Sumatera Indonesia, Tbk Unit Sei Merah Estate. *Agroprimatech*, 2(2), pp. 2599–3232.

Arifin, M., Yuniarti, A., and Dahlian, D. (2017). The Effect of sinabung volcanic ash and phosphate rock in nanoparticle form on p-retention, delta ph and base saturation on Ciater's Andisols, West Java. *Jurnal Agroekoteknologi*, 9(1), pp. 75–85.

Ariningsih, E. (2016). Prospects of nanotechnology application in agriculture and food processing in Indonesia. *Jurnal Forum Penelitian Agro Ekonomi*, 3(4), pp. 1–20.

Balai Penelitian Tanah. (2006). *Sifat fisik tanah dan metode analisisnya*. 1st ed. Bogor: Balai Penelitian Tanah, pp. 283.

Balai Penelitian Tanah. (2009). *Petunjuk teknis analisis kimia tanah, tanaman, air, dan pupuk*. 2nd ed. Bogor: Balai Penelitian Tanah, pp. 211.

Betty, N.F., Mahfud, A., Rina, D., Anni, Y., Rachmat, H., and Mariska, A.S. (2017). P-retension and cation exchange as affected by nanoparticle of volcanic ash and application of phosphate solubilizing bacteria on andisol Ciater, West Java Indonesia. *AIP Proceedings*, 1927, pp. 030025.

Blackmore, L.C., Searle, P.L., and Daly, B. K. (1981). *Methods for chemicals analysis of soils*. 1st ed. New Zealand: Lower Hutt, pp. 10.

Brady, N. C. and Weil, R. R. (2014). *Elements of the nature and properties of soils*. 3rd ed. New Jersy: Prentice Hall, pp. 638–645.

Camacho, R., Malavolta, E.J., Guerrerro, A., and Camacho, T. (2002). Vegetative growth of grain sorghum in response to phosphorus nutrition. *Scienta Agricola*, 6(1), pp. 771–776.

Chuaca, R.L., Damanik, M.M.B., and Marbun, P. (2017). Application of SP-36 and cow manure on the availability of phosporus and phosphorus uptake on inceptisol taken from Kwala Bekala. *Jurnal Agroekoteknologi FP USU*, 5(1), pp. 167–177.

Damanik, M.M.B., Effendi, B., Fauzi., Sarifuddin., and Hanum, H. (2010). *Kesuburan tanah dan pemupukan*. 2nd ed. Medan: Universitas Sumatera Utara Press, pp. 40.

Fayiga, A.O. and Obigbesan, G. O. (2017). Physico-chemical characterization of ogun and sokoto phosphate rocks. *Global Journal of Pure and Applied Sciences*, 23(1), pp. 27–34.

Firmansyah, I., Syakir, M., and Lukman, L. (2017). The influence of dose combination fertilizer N, P, and K on growth and yield of eggplant crops (*Solanum melongena* L.). *Journal of Horticulture*, 27(1), pp. 69–78.

Freese, D., Zee, S.V.D., and Riemsdijk, W. H. (1992). Comparison of different models for phosphate sorption as a function of the iron and aluminum oxides of soils. *Journal Soil*, 43(1), pp. 729–738.

Gulsun, T., Gursoy, R.N., and Oner, L. (2009). Nanocrystal technologi for delivery of poorly water-soluble drug. *Pharmacy Science*, 34(1), pp. 55–65.

Habi, L, M., Jeanne, I N., Marasabessy, D., and Kalay, M, M. (2017). Ketersediaan fosfat, serapan fosfat, dan hasil tanaman jagung (*Zea mays* L.) akibat pemberian kompos granul ela sagu dengan pupuk fosfat pada inceptisols. *Agrologia,* 7(7), pp. 2301–7287.

Hartatik, W., Idris, K., Sabiham, S.D., and Adiningsih, J. S. (2004). Peningkatan ikatan P dalam kolom tanah gambut yang diberi bahan amelioran tanah mineral dan beberapa jenis fosfat alam. *Jurnal Tanah dan Lingkungan*, 6(1), pp. 22–30.

Havlin, J.L., Beaton, J.D., Tisdale, S.L., and Nelson, W. L. (2005). Soil Fertility and Fertilizers. In: D Beaton, ed. *An Introduction To Nutrient Management*, 7th ed. New Jersy: Upper Saddle River, pp. 14.

Hunt, N. and Gilkes, B. (1992). *Farm monitoring handbook.* 1st ed. Western Australia: Soil Management, pp. 86–99.

Khan, M.Z.H., Islam, M.R., Nahar, N., Al-Mamum, M.R., Khan, M.A.S., and Matin, A. M. (2021). Synthesis and characterization of nanozeolite based composite fertilizer for sustainabe release and use efficiency of nutrients. Heliyon, 7(1), pp. 06091.

Ladiyani., Husnin., and Hartatik, H. (2011). Peluang formulasi pupuk berteknologi nano. Prosiding Seminar Nasional Teknologi Pemupukan dan Pemulihan Lahan Terdegredasi. Balai Peneltian Tanah, 159, pp. 307–316.

Maas, A., Yudoyono, P., Masyhuri, C., Sumardiyono., and Yuwono, T. (2018). P*engantar ilmu pertanian.* 3*rd* ed. Yogyakarta: Gadjah Mada University Press, pp. 354.

Mahanta, D., Rai, R.K., Dhar, S., Varghese, E., Raja, A., and Purakayastha, T. J. (2018). Modification of root propertis with phosphate solubilizing bacteria and arbuscular myrorrhiza to reduce rock phosphate application in soybean-wheat cropping system. *Ecological Engineering*, 111, pp. 31–43.

Mahanta, D., Rai, R.K., Mishra, S.D., Raja, A., Purakayastha, T.J., and Varghese, E. (2014). Influence of phosphorus and biofertilezer on soybean and wheat root growth andproperties. *Field Crop*, 166, pp.1–9.

Manfarizah., Syamaun., and Nurhaliza, S. (2011). The Characteristics of soil physical properties at the University Farm Station Bener Meriah. *Journal Agrista*, 15(1), pp.1–2.

Manikandan, A. and Subramanian, K. S. (2014). Fabrication and characterisation of nanoporous zeolite based N fertilizer. *Academic Journal*, 9(1), pp. 276–277.

Manikandan, A. and Subramanian, K. S. (2015). Nano-fertilizer for balanced crop nutrition. *Academic Journal*, 9(1), pp. 276–277.

Montalvo, D., Mclaughlin, M.J., and Degryse, F. (2015). Efficacy of hydroxyapatite nanoparticles as phosphorus fertilizer in andisols and oxisols. *Soil Science Society of America Journal,* 79(2), pp. 551.

Musaad, I. (2018). *Potensi dan teknologi pemanfaatan fosfat alam sebagai pupuk fosfat-plus*. 1st ed. Malang: Brainy Bee, pp. 60.

Neira, J., Ortiz, M., Morales, L., and Acevedo, E. (2015). Oxygen diffusion in soils: Understanding the factors and processes needed for modeling. *Chilean Journal of Agricultural Research*, 7(5), pp. 35–44.

Nugroho, P.D., Arifin, M., and Devnita, R. (2020). Response of volcanic ash nano particles and phosphate rocks application on selected chemical properties of inceptisols in Cilembu, West Java. *Jurnal Tanah dan Iklim*, 44(2), pp. 1410–7244.

Nuryani, E., Haryono, G., and Historiawati, H. (2019). Pengaruh dosis dan saat pemberian pupuk P terhadap hasil tanaman buncis (*Phaseolus vulgaris* L.) tipe tegak. *Jurnal Ilmu Pertanian Tropika dan Subtropika*, 4(1), pp. 14–17.

Pardosi, S.C.P., Sumono., and Munir, A. P. (2017). Kajian sifat fisika dan kimia tanah pada lahan karet dengan beberapa jenis vegetasi yang tumbuh di Kebun PTP. Nusantara III Gunung Para. *Jurnal Rekayasa Pangan*, 5(2), pp. 432–431.

Priambodo, S.R., Susila, K.D., and Soniari, N. N. (2019). Pengaruh pupuk hayati dan pupuk anorganik terhadap beberapa sifat kimia tanah serta hasil tanaman bayam cabut (*Amaranthus tricolor*) di tanah tanah inceptisol Desa Pedungan. *Jurnal Agroekoteknologi Tropika*, 8(1), pp. 149–150.

Raharjo, P. and Sarmili, L. (2016). The occurence of high plasticities smectite clay mineral on Cirebon Waters, West Java. *Jurnal Geologi Kelautan,* 14(1), pp. 61.

Ridine, W., Ngakou, A.M., Mbaıguınam, F., Namba, and Anna, P. (2014). Changes in growth and yield attributes of two selected maize varietes as influenced by application of chemical (NPK) and organic (bat's manure) fertilizers in pala (chad) grown field. *Pakistan Journal of Botany*, 46(5), pp. 1763–1770.

Rina D., Benny, J., Mahfud, A., Hudaya, R., and Oktaviani, N. (2018). Application of nanoparticle of rock phosphate and biofertilizer in increasing some soil chemical characteristics of variable charge soil. *AIP Conference Proceedings*, 1927, pp. 030027.

Rizky, T,O., Setiawati, T, C., and Winarso, S. (2019). The increasing availibility and uptake of P in maize crops on polluted solid lime waste soil (lime mud) through addition of organic matter. J*urnal Agroteknologi Universitas Andalas,* 2(2), pp. 19-24.

Shaaban, M., Peng, Q.R., Hu, Y., Wu., Lin, S., and Zhao, J. (2015). Dolomite application to acidic soils: a promising option for mitigating N_2O emissions. *Environmental Science and Pollution Research,* 22, pp. 19961–19970.

Sharpley, A.N., Weld, J.L., Beegle, D.B., Kleiman, P.J.A., Gburek, W.J., Moore, P.A., and Mullins, G. M. (2003). Depelopment of phosphorus indices for nutrient management planning strategies in The United States. *Soil Water Conser*, 58, pp.137–152.

Sridhar, K.R., Ashwini, K.M., Seen, S., and Sreepada, K. S. (2006). Manure quality of guano of insectivorous cave bat hipposideros speoris. *Tropical and Subtropical Agroecosystems*, 6, pp. 103–110.

Sudirja, R., Joy, B., Yuniarti, A., Trinurani, E., Mulyani., O and Mushfiroh, A. (2017). Beberapa sifat kimia tanah inceptisol dan hasil kedelai (*Glycine max* L.) akibat pemberian bahan amelioran. *Prosiding Seminar Hasil Penelitian Tanaman Aneka Kacang dan Umbi, Universitas Padjadjaran*, 7(1). pp. 199.

Sugiono and Purwanti, E. (2019). Effectiveness of natural phosphate fertilizers on maize (*Zea mays*. L) growth and production. *Jurnal Agriekstensia,* 18(1), pp. 10.

Sulistyaningsih, C. R. (2019). Kajian faktor yang berpengaruh pada produksi jagung di Kabupaten Wonogiri. *Jurnal Ilmu-Ilmu Pertanian*, 3(1), pp. 53.

Tando, E. (2018). Upaya efisiensi dan peningkatan ketersediaan nitrogen dalam tanah serta serapan nitrogen pada tanaman padi sawah (*Oryza sativa* L.). *Buana Sains*, 18(2), pp. 171–180.

Winarso. (2005). *Tanah kesuburan tanah; dasar kesehatan dan kualitas tanah*. 1st ed. Yogyakarta: Gaya Media, pp. 269.

Xue, A., Xiao, H.G., Qian, Z., Huijun, Z., Hai, Y.W., Zhao, H.Z., Xiao, R.H., Ming, H.Z., and Fu, X. (2014). Effect of phosphorus fertilization to P uptake and dry matter accumulation in soybean with different P efficiencies. *Journal of Integrative Agriculture*, 13(2), pp. 326–334.