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Effectiveness of Various Types of Manure and Inorganic Fertilizers on Populations of N-fixing and P-Solubilizing Bacteria and Nutrient Uptake of Maize in Inceptisol

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ABSTRACT

Bacteria are classified as non-symbiotic N-fixing and P-solubilizing play an important role in enhancing soil quality and plant growth. This study aims to analyze various types of manures and inorganic fertilizers on N-fixing and P-solubilizing bacteria population and their relationship with N and P uptake of maize in Inceptisol. The manure used was poultry, goat, and cow manure with doses of 0 t/ha, 10 t/ha, and 20 t/ha, respectively, and inorganic fertilizer NPK Phonska 15-15-15 dose 0 kg/ha; 150 kg/ha (50% of recommendation dose) and 300 kg/ha (100% of recommendation dose). Application of manure (poultry, goat, and cow manure) increased N-fixing and P-solubilizing bacteria population. The application of various types of manure and inorganic fertilizers has a significant impact on N and P uptake. The highest N and P uptake were 29.92 kg/ha and 2.63 kg/ha, respectively. Manure application can reduce inorganic fertilizer dose by up to 50%, increasing plant production efficiency and environmental sustainability.

1. INTRODUCTION

Corn (*Zea mays* L. *Saccharata* Sturt) is a staple food that also can be used as animal feed and industrial feedstocks. Therefore, the demand for corn is very high (Zubachtirodin *et al*., 2016). Dry land in Tawangargo Village, Karangploso Malang District, which has the main commodity sweet corn cultivated in Inceptisol has low production, with a productivity of 6.49 t ha^{-1} of total production, which should be an average of 15.5 t ha^{-1} (Statistics of Malang District, 2017). Apart from low productivity, Inceptisol has total N 0.18% (low), total P 40.90 mg/100g (high), available P 2.79 ppm (very low), and cation exchange capacity (CEC) 21.51 cmol/kg (moderate). However, total K 61.14 mg/100 g (very high) and base saturation 63.69% (high) are suitable for plant growth (Setiawati *et al*., 2022).

Inorganic fertilizers containing macro nutrients such as Phonska N, P and K are increasing. These fertilizers facilitate nutrient transport from the soil to plants. According to Statistics Indonesia (2013), the use of inorganic fertilizers is 86.41% and balanced fertilizers is 13.15%. However, the use of organic fertilizers is only 0.07%, which decreases soil fertility and results in less abundance of soil microorganisms due to low soil organic matter content. Excessive application of inorganic fertilizer negatively impacts the environment, such as soil acidity (Herdiyanto & Setiawan, 2015). Inorganic fertilizers, however, have the potential to disturb the soil's nutrient balance, resulting in nutritional imbalances and decreased soil quality (Kakar *et al*., 2020). On the contrary, organic materials from organic fertilizers positively impact the biological activity of microflora and microfauna. Not only biological activity but also improves soil structure (Jenira *et al*., 2016).

Inorganic fertilizer can be combined with organic fertilizer to improve soil organic matter (SOM) and soil quality without a slight yield decrease (Machfud *et al*., 2017). Adding organic fertilizer to the soil will improve physical (infiltration and water holding capacity), chemical (nutrient availability, both macro and micro, pH, and CEC), and biological (beneficial organism population and activity) properties of the soil (Nariratih *et al*., 2013). Moreover, adding organic fertilizer will increase the efficiency of inorganic fertilizers (Pangaribuan *et al*., 2017).

Farmyard manure is one of many sources of organic materials that are easily found by farmers. Manure generally has a low C/N, so it decomposes easily, such as poultry manure contains N 3.22%, C/N 4.07, P_2O_5 9.4%, K_2O 0.21%; cow manure N 2.95%, C/N 2.55, P_2O_5 3.92%, K_2O 0.17% (Masriyana *et al*., 2020); goat manure N 1.70%, C/N 8.70, P_2O_5 0.65%, K_2O 6.52% (Sinuraya & Melati, 2017). There is plenty of research related to inorganic and organic fertilizer in various types and doses. However, research focuses on the types and doses of manure and inorganic fertilizers, especially in Inceptisol with specific focus on the functional bacterial populations (N fixing and P solubilizing bacteria) and nutrient uptake (N and P), is still limited. The research aims to analyze various types and doses of manure and inorganic fertilizers on the population of N-fixing and P-solubilizing bacteria and their correlation with maize nutrients (N and P) uptake in Inceptisol.

2. MATERIALS AND METHODS

2.1. Study Site

This study was performed in the Greenhouse and Laboratory of the Faculty of Agriculture, Brawijaya University. Soil samples were collected from Tawangargo Village, Karangploso Regency, Malang. The soil order in the location is Inceptisol (Setyastika & Suntari, 2019). This study used 6 kg of soil and sweet corn seeds of Talenta variety. Manure that was used was poultry, goat, cow, and inorganic fertilizer was NPK Phonska containing 15% N, 15% P_2O_5, and 15% K_2O. Poultry used was obtained from Karangploso breeders, Malang, goat manure from Plaza ERP Brawijaya University, and cow manure from Bumiaji breeders, Batu City.

2.2. Experimental Design

The experiment was assembled in completely randomized design consisting of two factors. The first factor, manure type (PM = poultry manure, GM = goat manure, and CM = cow manure) consisted of six levels, namely P0 = 0 t/ha (control), P1 = 10 t/ha PM, P2 = 20 t/ha PM, P3 = 10 t/ha GM, P4 = 20 t/ha GM, P5 = 10 t/ha CM, P6 = 20 t/ha CM. The second factor, dose of NPK Phonska 15-15-15, involved three levels: A0 = 0 NPK (control), A1 = 150 kg/ha (50% of the recommended dose), and A2 = 300 kg/ha (100% recommended dose) (Kasno & Rostaman, 2013).

2.3. Water Requirement

Six kilograms of soil and manure were mixed evenly and placed into polybags (40 cm x 40 cm), then incubated for one week. Inorganic fertilizer was applied three days before planting. The polybags were arranged according to randomized arrangement, there were 21 treatments with 3 replications (total 63 experimental units). Every polybag was planted with three seeds, then the seedling was reduced, and only one plant left. The parameters measured were N-fixing and P-solubilizing bacteria population at 0 dan 90 days after planting (DAP) and N and P uptake at 90 DAP. Watering was done daily in such way to achieve soil field capacity (pF 2.5). Based on calculation, water requirement 2.28 L for 6000 g soil media.

2.4. Bacterial Enumeration

Five grams of soil samples were suspended into 45 mL of sterile distilled water for isolation of N-fixing and P-solubilizing bacteria, then vortexing for 2 min (dilution 10^{-1}). One milliliter of the suspension was inoculated into test tube filled with 9 mL of sterile NaCl solution, then homogenize using a vortex (dilution 10^{-2}). This step was conducted repetitively till dilution up to 10^{-6}. One milliliter of the serial dilutions was inoculated onto solid Nitrogen Free

Bromothymolblue (NFB) medium for N-fixing bacteria isolation, and Picovskaya medium for P-solubiliazing bacteria isolation. Each treatment was made in triplicate. The inoculated NFB media were incubated for a week (7 days) at 28 °C (room temperature). Positive results for N-fixing bacteria is indicated by a color change of the medium around the growing colonies from green to blue. The bacterial colonies were then enumerated using the standard plate method. For P-solubilizing activity, the inoculated media were incubated for 3 days at room temperature. A positive result was showed by clear zone formed around the colony. The colony was then enumerated according to the same method.

2.5. Analysis of N and P uptake

The Kjeldahl method was employed to determine nitrogen concentration. Nitrogen concentration in biomass was then multiplied with plant dry biomass to determine N uptake. Phosphorus concentration was analyzed by the colorimetric method using a spectrophotometer, P concentration in biomass then multiply with plant dry biomass to determine P uptake (Wieczorek *et al*., 2022). The plant samples for N and P uptake were taken from all representative parts of the above ground plant biomass at harvest time (90 DAP). Plant dry biomass (stems and leaves) were determine using gravimetric method (plant biomass were dried using oven at 50 °C until constant weight).

2.6. Data Analysis

Data was checked for its normality using the Saphiro-Wilk method. Normal distribution data were then analyzed of variance to determine the treatment effects of measured parameters at 5% significant level. If there is a significant difference, then follow with a post hoc test according to Duncan Multiple Range Test (DMRT) at α = 5%.

3. RESULTS AND DISCUSSION

3.1. Nutrient Content in the Manure

The various types of manure used in this research were poultry, goat, and cow manure. The nutrient composition of various types of manure is presented in Table 1. Poultry and cow manure has a slightly acidic pH. However, goat manure has a neutral pH. The nutrients content in the three manures are relatively low, namely organic C, N-, P-, and K-total due to the concentration below the minimum limit requirements for solid organic fertilizer according to the regulation number 261/2019 from the Ministry of Agricultur**e**. The rate at which organic materials decompose is largely dependent on the C/N ratio. Organic materials with low C/N ratios will decompose faster than those with high C/N ratios. The C/N ratio of the manures meets the quality standards based on Agriculture Minister Decree No. 261/KPTS/SR.310/M/4/2019, a maximum of ≤25 (Menteri Pertanian, 2019). Poultry manure has higher N and P contents than cow and goat manure. However, goat manure contains higher organic C than poultry and cow manure but cow manure contains higher K than poultry and goat manure.

Table 1. Nutrient content in the manure used in this study.

Parameter	Poultry	Goat	Cow
pH	6.27*	7.51*	6.36*
C-Organic (%)	12.4	14.9	4.7
N-Total (%)	0.73	0.69	0.33
C/N (%)	16.95*	23.06*	14.23*
P_2O_5 (%)	1.91	0.67	0.78
K_2O (%)	0.78	0.71	1.51

*Meets the minimum standards for solid organic fertilizer according to the Agriculture Minister Decree No. 261/KPTS/SR.310/M/4/2019.

3.2. Effect of Treatment on the Bacteria Population

The impact of applying various types of manures and inorganic fertilizers on the total population of bacteria grouping as N-fixing and P-solubilizing is presented in Table 2. There were no significant different on the number of N-fixing bacteria as well as P-solubilizing bacteria following the application of various manure and inorganic fertilizer ($p>0.05$). According to Wan *et al*. (2014) soil microbial community structure is greatly determined by soil C:N ratio.

3.2.1. N-Fixing Bacteria

The population of N-fixing bacteria is a parameter of soil biological properties for predicting the presence of non-symbiotic bacteria fixing nitrogen in the soil after application of manure and inorganic fertilizer. The non-symbiotic N-fixing bacteria convert atmospheric nitrogen (N_2) into ammonium ($NH4^+$) through nitrogenase enzyme for plants to absorb. These bacteria typically thrive in the vicinity of non-legume plants, providing a pathway for N uptake (Widawati *et al*., 2010). This study revealed that the type and doses of manures and inorganic fertilizers did not affect the colony of N-fixing bacteria in Inceptisol (Figure 1). Nitrogen-fixing bacteria are bacteria that are able to fix free N in the form

Table 2. Effect of various types of manures and inorganic fertilizers on the population of N-fixing and P-solubilizing bacteria in Inceptisol at 0 and 90 DAP (day after planting).

Treatment	N-fixing bacteria 0 DAP (kg/ha)			N-fixing bacteria 90 DAP (kg/ha)		
	A0	A1	A2	A0	A1	A2
P0	22.90	30.60	25.80	29.10	35.90	26.30
P1	24.60	34.10	43.40	28.80	43.50	43.00
P2	30.70	35.70	33.70	31.60	69.90	75.40
P3	45.70	36.30	39.10	68.30	65.70	57.70
P4	**52.70**	**49.70**	**63.50**	64.10	63.80	**84.80**
P5	28.00	20.80	29.10	56.40	30.90	47.20
P6	44.80	35.80	36.70	**80.10**	**74.50**	78.10

Treatment	P-solubilizing bacteria 0 DAP (kg/ha)			P-solubilizing bacteria 90 DAP (kg/ha)		
	A0	A1	A2	A0	A1	A2
P0	25.50	25.63	27.25	26.50	39.75	32.63
P1	29.50	21.90	27.40	52.25	47.30	46.40
P2	**52.25**	**38.25**	**38.88**	**52.50**	49.63	42.75
P3	27.63	29.40	33.63	36.88	**60.63**	**54.63**
P4	24.10	37.90	31.00	44.20	58.10	56.30
P5	28.60	38.20	33.10	47.70	37.60	38.90
P6	27.90	34.70	35.00	48.70	47.10	47.70

Remarks: Means in bold are the highest population of bacteria grouped in N-fixing and P-solubilizing following the application of manure and inorganic fertilizers. P0 (no manure), A0 (no inorganic NPK), A1 (50% of the standard dose of inorganic NPK), A2 (100% of the standard dose of inorganic NPK), P1 (10 t/ha PM), P2 (20 t/ha PM), P3 (10 t/ha GM), P4 (20 t/ha GM), P5 (10 t/ha CM), P6 (20 t/ha CM).

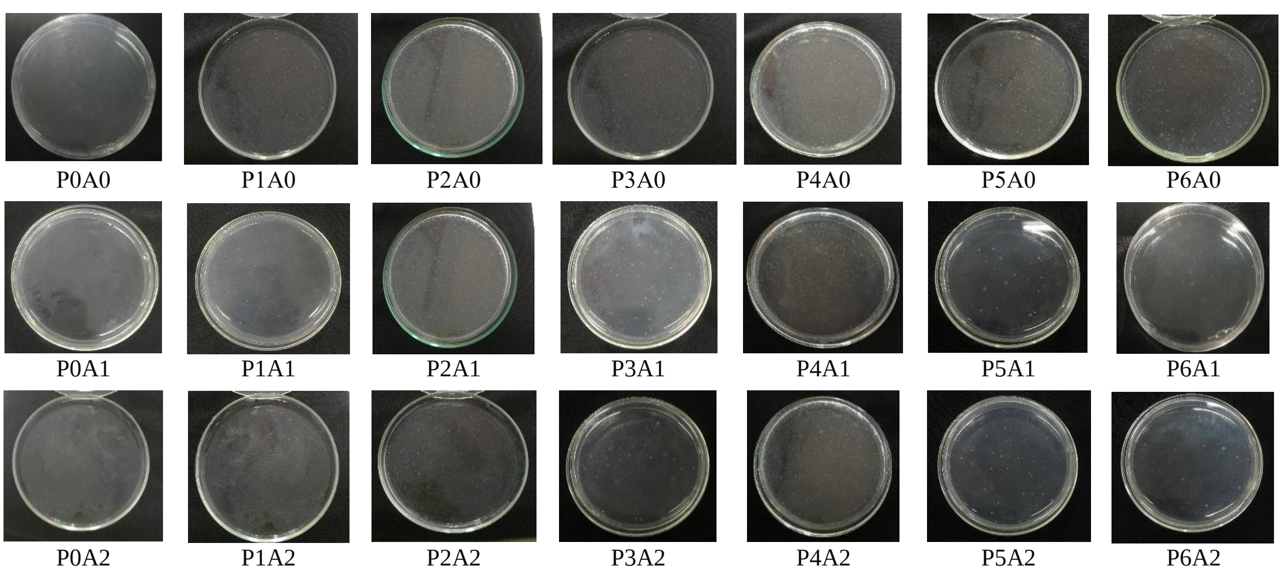

Figure 1. Population of bacteria N-fixing group in solid NFB medium in treatments without fertilization and after manure application: P0 (no manure), A0 (no inorganic NPK), A1 (50% of the standard dose of inorganic NPK), A2 (100% of the standard dose of inorganic NPK), P1 (10 t/ha PM), P2 (20 t/ha PM), P3 (10 t/ha GM), P4 (20 t/ha GM), P5 (10 t/ha CM), P6 (20 t/ha CM).

of ammonium or nitrate, so that it can be utilized by plants (Sapalina *et al*., 2022). The highest N-fixing bacteria population at 0 DAP was found at P4A2 (20 t/ha goat manure 100% inorganic fertilizer) 21.17×10^5 CFU/g.

Nitrogen-fixing bacteria population at the same treatment was fluctuate. The population on N-fixing bacteria decreased at 90 DAP (28.27×10^5 CFU/g). This shows that N-fixing bacteria are also influenced by inorganic fertilization because inorganic fertilization provides N to support the cell division for bacteria (Purwanto *et al*., 2022). This is in line with the result of this study at 0 DAP, the availability of N from inorganic fertilizer is abundance as the fertilizer was applied as base fertilizer. However, in certain situations the availability and concentration of plants nutrients originating from the application of NPK fertilizer causes nutrients in the soil to increase, in contrast it reduces the population of bacteria in the soil (Sofatin *et al*., 2016).

Soil microbial activity is influenced by organic matter, water content, aeration and drainage, and fertilizer use (Ardiyaningsih *et al*., 2010). Organic material is a source of energy for bacteria so that the increase occurs due to the addition of manure (Sinaga *et al*., 2018). Factors support the growth of bacteria in soil not only organic material as source of nutrients buat also soil pH (Susilawati *et al*., 2013).

3.2.2. P-Solubilizing Bacteria

The availability of P-solubilizing bacteria in the soil can be determined from the population of these bacteria, which is influenced by various types of manure and inorganic fertilizers. These bacteria aid in the dissolution process, making P is available for plant (Fatmala *et al*., 2015). The function of P-solubilizing bacteria is to provide plants with available P by solubilizing P from chelators such as Ca^{2+}, Al^{3+}, and Fe^{3+} (Khan *et al*., 2009). Bacteria generally dissolve inorganic P through mineralization and immobilization mechanisms. The process of solubilizing P in the form of PO_4 employs the enzyme phosphotase, which causes a clear zone to grow surrounding the colony of the P-solubilizing bacteria. The greater the bacterial population, the higher P available for plant to absorb (Niswati *et al*., 2008). Difference type of fertilizer, either organic or inorganic fertilizer, affected P-solubilizing bacteria population in Inceptisol (Tabel 2 and Figure 2). The highest P-solubilizing bacteria population after manure and inorganic fertilizer at 0 DAP was found at P3A1 (10 t ha^{-1} chicken manure + 50% inorganic fertilizer) 20.21×10^5 CFU g^{-1}. This is because poultry manure contains P elements of 1.91% (Table 1).

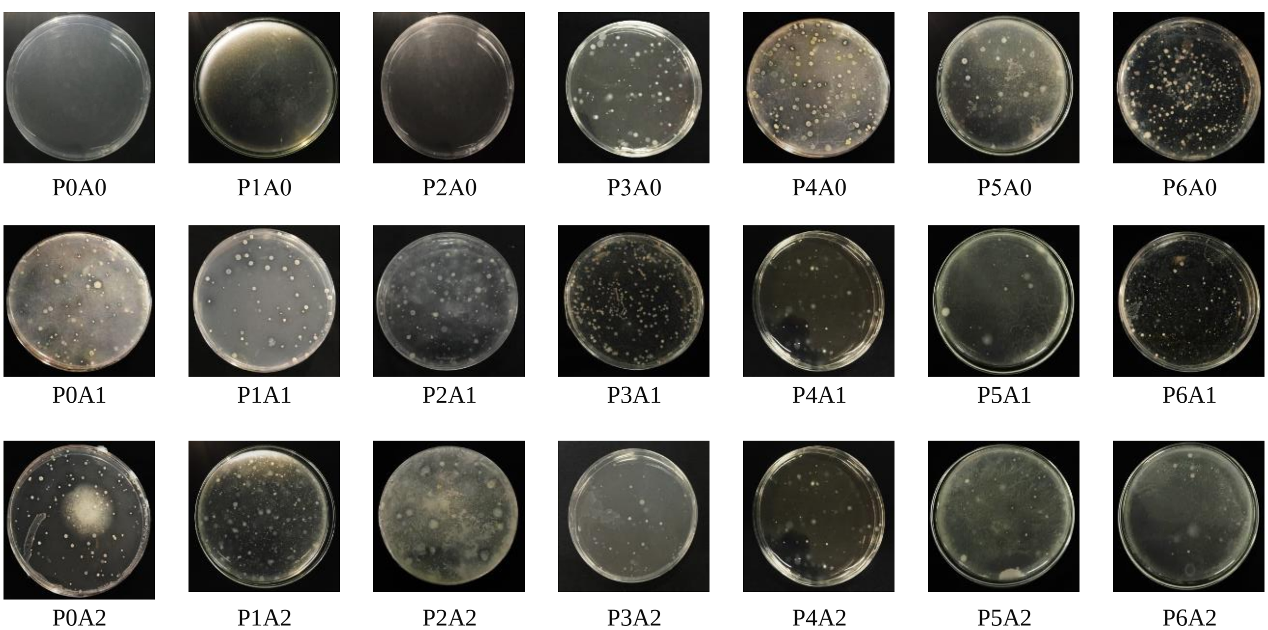

Figure 2. The population of P-solubilizing bacteria in solid Picovskaya medium in treatments without fertilization and after manure application. P0 (no manure), A0 (no inorganic NPK), A1 (50% of the standard dose of inorganic NPK), A2 (100% of the standard dose of inorganic NPK), P1 (10 t/ha PM), P2 (20 t/ha PM), P3 (10 t/ha GM), P4 (20 t/ha GM), P5 (10 t/ha CM), P6 (20 t/ha CM).

Microbial colonies in soil are affected by abiotic factors such as soil texture, humidity, temperature, and nutrient availability and concentration in the soil as the source of food for the microbes (Simanungkalit *et al.*, 2012). The same treatment (P3A1) at 90 DAP, elevated the bacteria population of P-solubilizing group up to 20.21×10^5 CFU/g. This shows that the combination of goat manure and mineral fertilizer can increase the population of P-solubilizing bacteria and can substitute the use of inorganic fertilizer by 50%. Phosphate solubilization depends on the population of these bacteria in the soil. There are two types of P unavailability, namely in organic form and inorganic form. The organic form is including humus, and will available after mineralization of orthophosphate that are released into the soil solution and can be uptake by plants or soil organisms, or form bonds with other compounds (Handayanto *et al.*, 2017). Therefore, the amount of P available in the soil increases with the number of P-solubilizing bacteria.

Lovitna *et al.* (2021) stated that phosphate solubilizing bacteria in their metabolic processes use organic material in the soil. According to Marista *et al.* (2013), bacteria need organic material as a nutrient source by decomposing organic material that contains carbon. Therefore, the more organic C in the soil, the more bacterial populations will be found. The activity of P-solubilizing bacteria is impacted by soil pH, this affects P mineralization because pH affects the metabolism of microorganisms (Ginting *et al.*, 2006). It is possible to provide various types of manure as organic material to stimulate the growth of soil organisms according to their function.

3.3. Plant Nutrient Uptake

Types of manures and inorganic fertilizers significantly affected P-uptake ($p<0.05$). However, there were no significant different on the application of different manures and mineral fertilizers on N-uptake ($p>0.05$). Table 3 displays the impact of applying different types of manure and inorganic fertilizer on P-uptake in maize grown in Inceptisol. Treatment P4A1 20 t/ha of goat manure can increase plant P-uptake and reduce inorganic fertilizer by 50% (Table 3). Plants uptake N as either ammonium (NH_4^+) or nitrate (NO_3^-) (Tando, 2019). The amount of N uptake depends on the quantity of fertilizer applied and the decomposition rate of soil organic matter (Damanik *et al.*, 2013). Providing a variety of manure and mineral fertilizers impacts the uptake of N in plants significantly. The P4A1 treatment, comprising of 20 t/ha of goat manure and 50% inorganic fertilizer at 150 kg/ha NPK Phonska, exhibited the highest level of plant N uptake at 29.92 kg/ha. In contrast, the P0A0 (control treatment) had the lowest N uptake at 0.93 kg/ha (control). This study demonstrates that using only half of the recommended dose of inorganic fertilizer leads to reduced plant N uptake. However, when combined with 20 t/ha of goat manure, N uptake can increase by 29.92 kg/ha. N is one of the elements often lacking in tropical soils for increasing plant production (Marschner, 2012).

Plants uptake P in the form of $H_2PO_4^-$ (primary orthophosphate) and a smaller amount in the form of secondary orthophosphate (HPO_4^{2-}) (Barker & Pilbeam, 2007). Providing a variety of inorganic fertilizers and types of manure significantly impacts plant P uptake. The treatment with the highest P uptake was P4A1 (2.3 kg/ha), which involved the application of 20 t/ha goat manure along with 50% inorganic fertilizer (150 kg/ha NPK 15-15-15). However, this treatment did not significantly different from poultry and cow manure with 100% inorganic fertilizer. The control treatment was the lowest P uptake (0.31 kg/ha). Plant P uptake is influenced by the amount of P available in the soil, as plants can uptake. Novizan (2005) stated that a small part of the nutrients from organic fertilizer can be directly utilized

Table 3. Effect of manures and inorganic fertilizer on N and P uptake.

Treatment	N-Uptake (kg/ha)			P-Uptake (kg/ha)		
	A0	A1	A2	A0	A1	A2
P0	26.50	39.75	32.63	0.31 a	1.40 bcd	1.72 bcd
P1	52.25	47.30	46.40	1.86 bcd	1.68 bcd	2.10 bcd
P2	52.50	49.63	42.75	1.60 bcd	2.27 bcd	2.01 bcd
P3	36.88	60.63	54.63	0.84 ab	2.00 bcd	2.62 d
P4	44.20	58.10	56.30	0.87 abc	2.63 d	2.52 d
P5	47.70	37.60	38.90	1.18 abcd	2.40 cd	2.07 bcd
P6	48.70	47.10	47.70	2.39 cd	1.66 bcd	2.26 bcd

Remark: P0 (no manure), A0 (no inorganic NPK), A1 (50% of the standard dose of inorganic NPK), A2 (100% of the standard dose of inorganic NPK), P1 (10 t/ha PM), P2 (20 t/ha PM), P3 (10 t/ha GM), P4 (20 t/ha GM), P5 (10 t/ha CM), P6 (20 t/ha CM). Numbers followed by the same letter are not significantly different at 5% significant level by Duncan.

utilized by plants, but some of it decomposes in a longer time. The decomposed nutrients can then be utilized by plants using the help of microorganisms in the soil. The organic material will be converted into a simple form that can be uptake by plants. This availability of P is, in turn, impacted by soil pH, which can be affected by the addition of various types of manure and mineral fertilizer.

Phosphates play a vital role in cell division and tissue development in the meristem. Phosphate stimulates vegetative growth, increasing the uptake of essential nutrients (Nuryani *et al*., 2019). Plants uptake $H_2PO_4^-$ that is commonly present in acidic soil, with the HPO_4^{2-} form dominating at higher pH levels (Karamina *et al*., 2017). Yuniarti *et al*. (2020) demonstrated that the application of organic fertilizers and NPK had a significant impact, leading to increased soil pH, available P, and plant P uptake in Jatinangor Inceptisol. This supported this study that the addition of goat manure 20 t/ha and decreasing inorganic fertilizer by 50% can still maintain P uptake in maize. Havlin *et al*. (2005) stated that above pH 7.5, P is fixed by Ca and Mg in the form of complex compounds, whereas under acidic to slightly acidic pH, P is fixed by Fe or Al. Phosphorus availability is also influenced by the population of bacteria P-solubilizing. Phosphorus fixed in the soil due to the presence of Al, Fe, Mg, Ca will be dissolved by P-solubilizing bacteria such that available for plants (Rahman *et al*., 2015).

3.4. Correlation of N-Fixing Bacteria and N-Uptake

The results of correlation analysis show that the population of N-Fixing bacteria has a positive correlation with plant N uptake (r = 0.93) with a regression of $R^2 = 0.07$ (Figure 3). An increase in the number of N-fixing bacteria correlated with an increase in plant N uptake. Nutrient absorption essentially refers to the amount of nutrients that enter plant tissue. Novizan (2005) stated that a small portion of the nutrients from organic fertilizer can be used directly by plants, but there are also those that decompose over a long time and can be used by plants. With the help of microorganisms in the soil, organic material is converted into a simpler form so that it can be absorbed by plants (Musnamar, 2006).

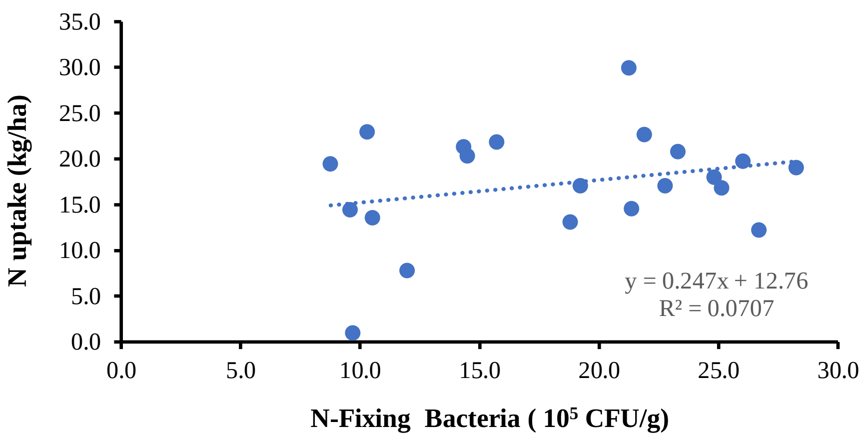

Figure 3. Correlation between N-fixing bacteria populations and plant N uptake.

Nitrogen is available abundantly in the air, approximately 78% in the form of N_2, but N_2 cannot be directly utilized by plants (Widiyawati *et al*., 2014). The N_2 should be converted to nitrate (NO_3^-) and ammonium (NH_4^+) by bacteria. However, this study revealed that there is no relationship between N-fixing bacteria population and N-uptake. It can be assumed that during the plant growth, N is sufficiently available for plant after the application of manures and inorganic fertilizers. Thus, N-fixing bacteria fixed N and used N during their growth and development. Tania *et al*. (2012) stated plants with enough N, the chlorophyll content in their leaves will rise, leading to optimal photosynthesis.

3.5. Correlation of P-Solubilizing Bacteria and P Uptake

The results of correlation analysis show that the population of P-solubilizing bacteria has a positive correlation with plant P uptake (r = 0.601) with a regression of ($R^2 = 0.361$) (Figure 4). The increasing of P-solubilizing bacteria is correlated with the increase in P uptake. P-solubilizing bacteria activity releases organic acids, including glutamic acid, citric acid, lactic acid, and succinic acid. Then, the organic forms complex compounds with Fe and Al ions, which in turn releases P in available form that can be uptaken by plants. Phosphorus plays an important role in storing and transferring energy as well as as a component of proteins and nucleic acids. Phosphorus uptake by plants to stimulate root growth, flowering and fruit ripening (Marschner, 2012).

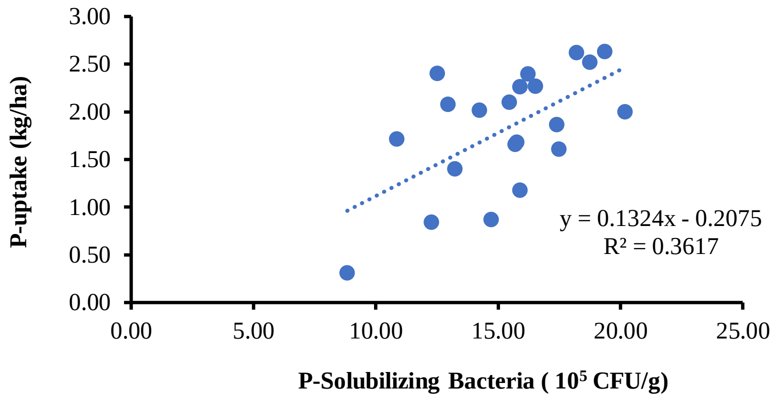

Figure 4. Correlation between P-solubilizing bacteria populations and plant P uptake

Phosphorus in the soil exists in various forms such as Ca-P, Mg-P, Fe-P, and Al-P (Roesmarkam & Yuwono, 2002). Phosphate-solubilizing bacteria can aid the provision of P that dissolve the fixed P and make them available to plants. The organic acids released by P-solubilizing bacteria react with Ca^{2+}, Fe^{3+}, and Al^{3+} cations to form a readily available form of P for plants (Widawati & Suliasih, 2006). This correlation proves that P-solubilizing bacteria activity can escalate the availability of P in the soil. A high P-solubilizing bacteria population leads to increase available P in the soil for plants uptake.

4. CONCLUSION

Application of manure (poultry, goat, and cow manure) increased the population of N-fixing and P-solubilizing bacteria. The highest population of N-fixing bacteria at harvest time was found at P6A0 (20 t/ha cow manure; 25.86×10^6 CFU/g), and the highest population of P-solubilizing bacteria was found at P4A0 (20 t/ha goat manure; 17.62×10^5 CFU/g). Application of various types of manure and inorganic fertilizers had a significant effect on N and P uptake. The highest N uptake at harvest time was at P4A1 (20 t/ha goat manure + 50% inorganic fertilizer; 29.92 kg/ha), and the highest P uptake was at P4A1 (20 t/ha goat manure + 50% inorganic fertilizer; 2.63 kg/ha). Application of manure can reduce inorganic fertilizer dose by up to 50% that will increase plant production efficiency and environmental sustainability.

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