

PAPER • OPEN ACCESS

The Capacity of Soil Bacteria, *Bacillus sp^{rif}* and *Pseudomonas sp^{rif}*, in solubilizing Soil Phosphate and Potassium

To cite this article: T. C. Setiawati *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **583** 012040

View the [article online](#) for updates and enhancements.

You may also like

- [Development of high yielding sugarcane varieties for rainfed areas: yield multilocation trial of promising sugarcane clones](#)
B Hellyanto, Djumali, Abdurrahman et al.
- [Compost derived from local organic materials as source of plant nutrients](#)
Riwandi, M Handajansih, Prasetyo et al.
- [Reassessment of forest area and its scoring as a permanent production forest](#)
T Sudarmadji and W Hartati



The Electrochemical Society

Advancing solid state & electrochemical science & technology

242nd ECS Meeting

Oct 9 – 13, 2022 • Atlanta, GA, US

Abstract submission deadline: **April 8, 2022**

Connect. Engage. Champion. Empower. Accelerate.

MOVE SCIENCE FORWARD



Submit your abstract



The Capacity of Soil Bacteria, *Bacillus sp^{rif}* and *Pseudomonas sp^{rif}*, in solubilizing Soil Phosphate and Potassium

T. C. Setiawati¹, M.H. Pandutama², M. Mandala³ dan C. Arta⁴
^{1,2,3,4} Soil Department, Faculty of Agriculture, The University of Jember

Email: candra.setiawati.faperta@unej.ac.id

Abstract, Increasing availability of phosphate (P) and potassium (K) in soil can be driven by microbial activities, which are specifically able to dissolve P and K, known as nutrients hard to dissolve. The objectives of this research were to study the solubilising activity toward soil P and K by P- and K- solubilizing bacteria in sterilized and non-sterilized condition of Oxisol and Inceptisol. Marking procedure was performed on P- and K- solubilizing bacteria to scrutinize their activities in the soil. Marking process was conducted by utilizing resistance toward rifampicin antibiotica concentration of 50 µg.ml⁻¹. The results of this study revealed that the increasing availability of P was evident in both soil conditions (sterilized and non-sterilized). In Oxisol, P availability increased by 48.86%, while in Inceptisol it reached an increase by 187.77%, compared to the initial concentration. Likewise, K availability in Oxisol increased by 4.53 times, and it rose by 5.26 times in Inceptisol. The activities of P solubilising bacteria, in addition to being able to increase soil P availability, were also able to enhance soil's K content. Similarly, the K solubilizing bacteria were also capable of increasing P availability in both soils.

Keywords: Oxisol, Inceptisol, Phosphate – Potassium solubilizing bacteria

1. Introduction

Soil is a dynamic system with high extent of microbial heterogeneity. Microorganism activity occurring in the soil exerts bearing impact on soil nutrient cycle. The availability of phosphorus and potassium nutrients is influenced by soil microbial activity in accelerating weathering and solubilisation processes. Potassium is present in four forms in soil, which are K ions (K⁺) in soil solution, as an exchangeable cation, tightly held on the surfaces of clay minerals and organic matter. Moreover, it is tightly held or fixed by weathered micaceous minerals and present in the lattice of certain K-containing primary minerals. Soil characteristics affecting the availability of K pertain to the number and type of clay minerals, cation exchange capacity, potassium buffer capacity, moisture, temperature, aeration, and soil pH. The inoculation involving bacteria, which can improve P and K availability in soils by producing organic acids and other chemicals, stimulates the growth and mineral uptake of plants [1].

A research result [2] corroborates that yeast *Torulaspora globosa* dissolves 38% of total alkaline ultramafic rock powder for 15 days of incubation, while *Aspergillus niger* dissolves 62% -70% of total ultramafic alkaline mineral, subsequent to 35 days of incubation [3]. The double inoculation of PSB (phosphate-solubilising bacteria), *Bacillus megaterium*, and KSB (potassium-solubilising bacteria) *Bacillus mucilaginosus* combined with P and K bearing mineral, significantly increases the availability



of P and K in the soil, marked by an increase of approximately 25% for P and 15% for K, compared to the control [4]. Another research finding [5] evinces 5 KSBs (potassium-solubilising bacteria) that produces organic acids such as Citric, Oxalic, Malic, Succinic, and Tartaric acid. A qualitative test in the study indicated a solubilisation index ranging from 1.04 to 1.66. In the previous research [6] proved the ability of KSB to produce organic acids, *inter alia*, citric acid, ferulate, malate, and coumarat, capable of accelerating K release from feldspar, leucite, and biotite. In addition, some KSBs produce enzymes, including Amylase, Protease, Lipase, Catalase, and Glucose.

Antibiotics resistance of KSB works against such antibiotics as Ampicillin, Tetracyclin, Amoxicillin, and Novoblocin. Antibiotics resistance has provided a potentially simple and effective method to genetically mark bacterial strains for monitoring after the introduction into complex ecosystems. The markers of microorganisms with antibiotics resistance are generally preferred methods for studying the activity of soil microorganisms. For example, Rifampicin resistance is the most commonly used marker to study population dynamics and survival of plant growth-promoting after their introduction in the rhizosphere [7] and disease-suppressing *Rhizoctonia solani* by *Pseudomonas Putida* strain 2C8^{rif} [8].

Investigated in previous studies, markers given to microorganisms through the exposure to antibiotics such as rifampicin did not affect their activity on rhizosphere. One of the previous studies [9] has confirmed the ability of mutant *Pseudomonas putida* bacteria with rifampicin antibiotics, which is potent in colonizing roots in non-sterilized conditions.

This study aimed to learn the solubility capability of phosphate-solubilising bacteria and potassium-solubilising bacteria (*Bacillus sp*^{rif} and *Pseudomonas sp*^{rif}) in increasing the availability of P and K nutrients in Inceptisol and Oxisol, within sterilized and non-sterilized condition.

2. Materials and Research Method

2.1 Isolate Marker

Testing the viability and activity of isolates *Bacillus sp* as phosphate-solubilising bacteria and *Pseudomonas sp* as potassium-solubilising bacteria under non-sterile conditions was marked by using antibiotic resistance Kirby-Bauer method. The administration of markers with the resistance test against Rifampicin antibiotics up to a concentration level of 50 µg.mL⁻¹ was carried out gradually. Both isolates that have been characterized are identified as *Bacillus sp*^{rif} and *Pseudomonas sp*^{rif}.

2.2 Solubility Test in Solid Selective Media by Marked Isolate

The test in this regard scrutinized the solubility of *Bacillus sp*^{rif} and *Pseudomonas sp*^{rif}, It was carried out in Aleksandrov and Pikovskaya solid medium by calculating the solubility index (SI) using the following formula on seventh days:

$$SI = \frac{\text{Clear zone diameter}}{\text{Colony diameter}}$$

2.3 The Examination on Soil's phosphate and potassium Solubility

The solubilisation activity test was performed on 2 soils with different characteristics (Table 1) and within two different conditions (sterilized and non-sterilized). Completely randomized design was made operative, which involved soil factors including sterilized Oxisol (O_S), non-sterilized Oxisol (O_N), sterilized Inceptisol (I_S) and non-sterilized inceptisol (I_N). The second factor was concerned with the isolates: control group (B₀); PSB (*Bacillus sp*^{rif}) and KSB (*Pseudomonas sp*^{rif}). The study operationalized 12 treatment combinations with three replications. 200 g soil was inoculated with each bacteria at cell density of 10⁷ per gram soil. The soil condition was maintained to resemble field capacity condition and was incubated for a month. Soil sterilization is done 2 times with autoclave at 121⁰C for 15-20 minutes at 1 atmosphere pressure.

Table 1. The Soil Characteristics

Type of Analysis	Unit	Value	
		Inceptisol	Oxisol
pH H ₂ O (1:2,5)		5,67	4,54
pH KCl (1:2,5)		4,78	3,85
Sand	%	21,44	41
Silt	%	29,81	26
Clay	%	48,76	33
Texture		Clay	Clay loam
K-available (Amonium acetate 1M pH 7)	(cmol+)/kg	0,08	0,07
P ₂ O ₅ (Bray)	mg.kg ⁻¹	23,00	7,10
P ₂ O ₅ (HCl 25%)	mg.100g ⁻¹	121,50	20,10
C-Organic	%	1,21	2,18

On regular basis, particularly on the tenth day, twentieth day, and thirtieth day, soil pH, phosphate concentration (Bray extract), and concentration of potassium (Citric acid extract) were analyzed.

3. Research Results

3.1 Antibiotica Resistance

The examination isolate resistance against Rifampicin antibiotica proved that the both bacteria under research were quite resistant at concentration of 50 µg.mL⁻¹. The use of rifampicin antibiotica was quite effective as a marker in bacteria tested in heterogeneous soil conditions. A previous research [9] corroborated that, for *Pseudomonas* ecology test in field, Rifampicin antibiotica resistance marker was applied to *Pseudomonas putida* strain WCS358 to a concentration of 250 µg.ml⁻¹ and it concluded that rifampicin was stable to be applied as a marker for *Pseudomonas putida* strain WCS358 in potato rhizosphere. Other studies [10; 8] also have concluded that the use of rifampicin in *Pseudomonas fluorescens* and *Pseudomonas putida* is useful material for ecological testing of mutants resulting therefrom. Continuous exposure to rifampicin antibiotica resulted in resistance arising from the mutations of β-RNA polymerase sub-unit gene and RNA polymerase, which changed due to normally functional mutation resistant to rifampicin-triggered inhibition.

3.2 Solubility Index

The activity of the two mutant bacteria in the solubilisation of P and K in vitro setting within both Pikovskaya and Alexandrov's media was still detected. Fine solubilizing capability was shown by two mutant bacteria namely *Bacillus sp^{rif}* and *Pseudomonas sp^{rif}*. Solubilisation by PSB_{rif-b} (*Bacillus sp*) has a solubility index (SI) of 2.5 with the widest clear zone diameter of 0.75 cm on Pikovskaya media, while KSB_{rif-p} (*Pseudomonas sp*) displayed an SI value of 3.3 with maximum clear zone diameter of 1 cm on Alexandrov's media. The solubility index evinced the bacteria's ability to dissolve the sources of P and K present in the media. Based on the criteria applied by the researchers on the results of previous studies [6], both bacteria possessed intermediate-degree solubilising capabilities (SI ≤ 2.00 ≤ 4.00), but their rates of solubilisation were dissimilar in that PSB (*Bacillus sp^{rif}*) was found at *fast solubilising* category (<3 days) whereas KSB (*Pseudomonas sp^{rif}*) was proven to be at *slow solubilising* category (5 days).

3.3 The Test on Soil's P Solubility

Oxisol and Inceptisol tested have low P and K concentrations, acid conditions with low organic content (Table 1). The soil conditions affect the activity of the isolates, because for activities it takes

nutrients and organic carbon. The test results concerned with soil solubility activity showed an increase in all treatments up to the 30th day in Oxisol and Inceptisol soils (Figure 1).

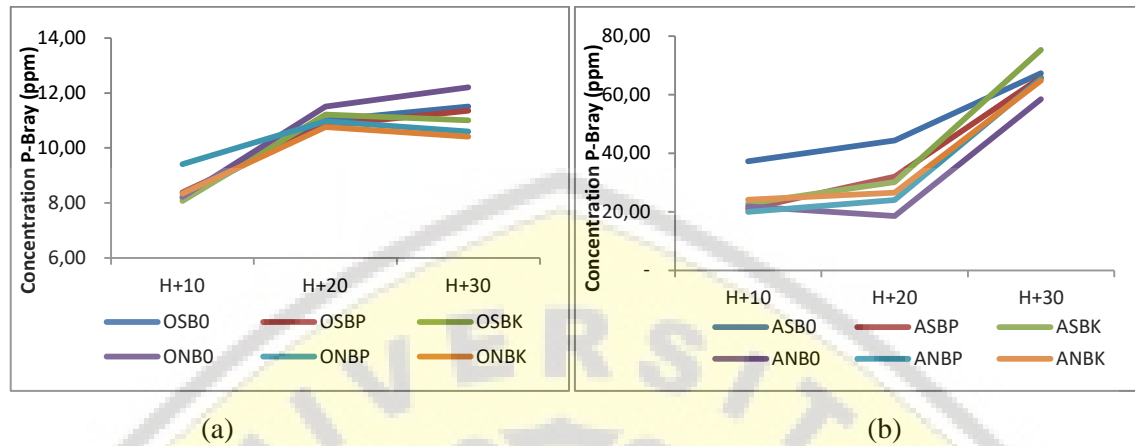


Figure 1. The Concentration of P-Available in Oxisol (a) and Inceptisol (b)

The presence of microbial activity of both PSB (*Bacillus sp^{rif}*) and KSB (*Pseudomonas sp^{rif}*) in Oxisol soil caused P concentration to be lower than that of the control treatment with no microbial activity, although at the end of incubation the P concentration was still found higher than was the initial concentration (Figure 1). The high ratio of organic carbon to the availability of P in the soil led to the immobilization of P. Under the condition characterized by C : P ratio < 200, the mineralization of P started to occur [11], while the initial data showed C: P ratio available > 200. This condition resulted in a larger immobilization net and showed P in the soil solution used by the existing microbes, thereby declining the P concentration in the soil solution. Oxisol constitutes highly weathered soil, so the phosphate is bound to Al, Fe or occluded-Fe, making it unavailable to plant.

The pattern of P solubilisation between Oxisol and Inceptisol was different, although the concentration at the end of incubation in both soils increased, compared to the initial soil concentrations (Figures 1a and 1b). In Inceptisol, substantial increase was evident after the 20th day. The dissolved phosphate in Inceptisol soils was greater than that of Oxisol. Besides, P immobilization through the use of phosphate by microbes still maintained the concentration of P available in the soil solution. In Inceptisol, C: P ratio was lower than that in Oxisol. The lower the C: P ratio was, the more likely mineralization of P was to occur and the lower net immobilization would become.

The sterilized and non sterilized soil conditions did not make a significant difference on the solubilisation of P due to the microbial activity applied. PSB (*Bacillus sp^{rif}*) and KSB (*Pseudomonas sp^{rif}*) were able to perform well in any soil conditions. As a corollary, the ability to compete against indigenous microbes was quite sound. Based on table 2, KSB (*Pseudomonas sp^{rif}*) also possessed the ability to solubilise P from both Oxisol and Inceptisol.

In their activity, bacteria secreted several metabolites, including organic acids. The results of a previous study [6] point out that KSB produces organic acids such as *Citric*, *Ferulic* and *Coumaric*. In the same vein, another study [5] corroborates that KSB produces *Citric*, *Oxalic*, *Malic*, *Succinic* and *Tartaric* acid. Furthermore, PSB also produces organic acids in its activities, encompassing *Citric*, *Oxalic*, *Malic*, *Succinic* [12], *Citrate*, *Oxalate*, *Succinate*, *Fumarate*, *Acetate*, *Propionate*, and *Butyrate* [13]. One of the mechanisms of solubilising P, especially resulting from the presence of organic anions, is done through several mechanisms, *inter alia* (1) organic anions competing against orthophosphates ion on the surface of the positively-charged colloidal site; (2) the release of orthophosphate ion from metal-P bond through the formation of organic metal complexes [14]; and (3) the modification of surface charge of the site by organic ligands [15].

Table 2. The Concentration of P-Available at the End of Incubation (ppm)

Innoculant	Oxisol		Inceptisol	
	sterilized	non sterilized	sterilized	non sterilized
PSB (<i>Bacillus sp^{rif}</i>)	11,36	10,59	67,15	69,17
KSB (<i>Pseudomonas sp^{rif}</i>)	11,01	10,41	75,25	69,28

According to [14] the presence of certain organic anions derived from the decomposition of organic matter, microbial activity, or root secretion may affect the absorption of P through the competition of surface site or lower the adhesion site through solubilisation. In addition, organic acids with low molecular weight lowered P by Al oxide, Fe or allofan clay minerals due to their high affinity [16]. The addition of organic acids with low molecular weight also effectively triggered Al and Fe from Fe-P and Al-P, allowing the solubilisation of P to occur [17]. Organic ligands such as tartaric, oxalate, malate, and citrate containing carboxyl (COOH), aliphatic-OH, phenolic-hydroxyl groups were proven highly effective in mineral solubilisation and chelate formation enriched with such elements as Al, Fe, Ca, and other elements, and declining pH level of media [18].

The reaction of phosphate solubilisation by organic acids is formulated as following.

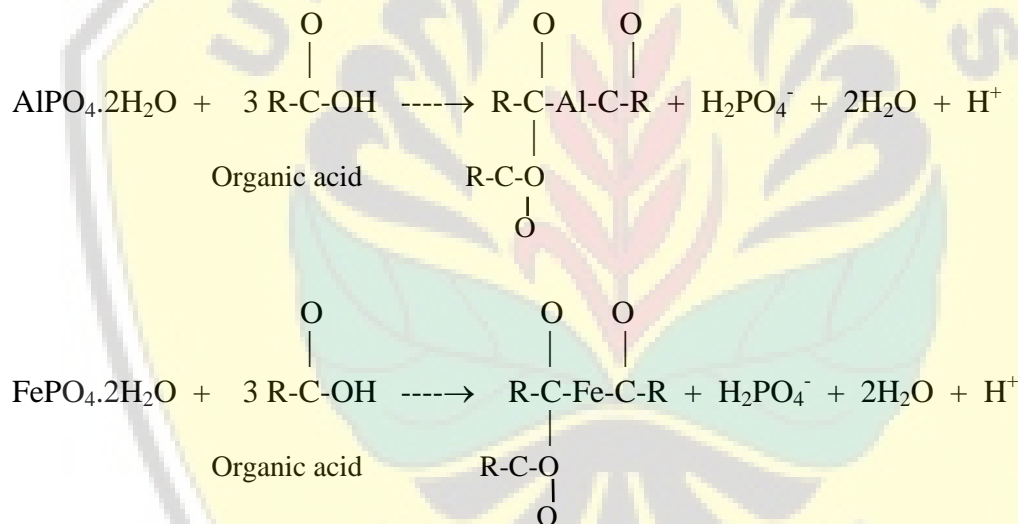


Table 3. Phosphate Released from soils by Inoculant after 30 Days of Incubation (mg.kg⁻¹)

Treatments	Oxisol (sterilized)	Oxisol (non sterilized)	Inceptisol (sterilized)	Inceptisol (non sterilized)
Control	4.00±0.65	4,69±0,57	44.29±3.82	40.82±10,00
PSB (<i>Bacillus sp^{rif}</i>)	3.85±0,46	3.08±0,34	44.15±2.28	46.17±5.49
KSB (<i>Pseudomonas sp^{rif}</i>)	3,50±0,22	2.90±0,58	52.25±4.82	46.28±6.35

During the 30-day incubation, the average of P concentration in Inceptisol increased considerably to a maximum extent of 187.77%, while in Oxisol similar increment peaked to a maximum extent of 48.86%. The activity of innoculant, especially PSB (*Bacillus sp^{rif}*) release phosphate at Oxisol maximum 4.31 mg.kg⁻¹ while at Inceptisol 51.66 mg.kg⁻¹ (table 3). Oxisol was highly weathered soil, making possible P to be precipitated with Al or Fe. Besides, P also bound with Fe and Al oxides, as well as in the form of occluded P. In Inceptisol, some adsorption complexes were predominantly Ca and Fe ions, so P bound to Ca and/or Fe. Beside P-organic form, P-inorganic form in soil consists of

several fraction. The proportion or percentage of each fraction is influenced by several factors, including the type of soil. The distribution of inorganic P fraction (%) in some soil types in Malaysia and Indonesia [19] shows the fractionation of P in Oxisol and Inceptisol soils as follows:

Table 4. The Fraction Distribution of Inorganic P (%)

Soil Order	The Distribution of P-inorganic (%)					
	Soluble P	Ca-P	Fe-P	Al-P	Occ Fe-P	Occ Al-P
Oxisol	0,15	3,9	35,6	4,5	50,8	4,9
Inceptisol	0,9	21,3	38,9	5,6	39,4	6,1

Soil dominant form P bound with Occluded Fe (OP) is more difficult to dissolve (table 4). The results [20] show that the OP is not dissolved with the addition of soil amendment so the concentration is still high, while the other P form increases its solubility. The fractionation of P in Oxisol of West Java was obtained by the sequence of the greatest as follows: reductan Fe-P> Fe-P> Occluded-P> Ca-P> Al-P> soluble-P [13], therefore release of P on Oxisol is lower than Inceptisol.

The soil acidity indicated an increase at all treatments until the end of incubation in both Oxisol and Inceptisol (see Figure. 2). Organic acid was generally produced by phosphate-solubilising bacteria and potassium-solubilising bacteria. However, the presence of organic acid did not diminish the pH level of both soil types. The carboxyl groups from organic acid developed negative charge as the positively charged H was removed. When the pH of a soil was increased, the release of H from carboxyl groups aided in sustaining the increase of pH and at the same time created the CEC (negative charge). The presence of negative charge on the surface of the clay mineral would attract Ca, Fe or Al cations, consequently increasing phosphate availability.

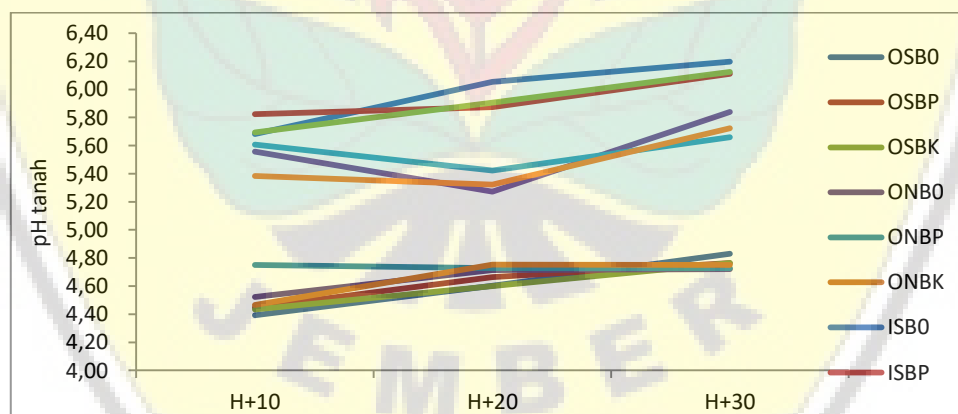


Figure 2. The Change of Soil pH in Oxisol and Inceptisol

3.4 Potassium Solubilisation

The concentration of K-soluble citric acid in two soil types increased along with increasing period of incubation in the same pattern (Figure 3). The sterilized and non-sterilized soil conditions also did not affect the activity of the two solubilising bacteria in both soil types, resulting in increased concentration of K. PSB (*Bacillus sp^{rif}*) and KSB (*Pseudomonas sp^{rif}*), both of which are mutant bacteria against rifampicin resistance. The enhanced concentration, however, did not affect the capacity of bacteria as K-solubilising agent. Findings of a research [21] using antibiotica resistant against Mutant potassium-releasing bacterial strain of *Bacillus edaphicus* NBT with rifampicin antibiotica (150 mg.l⁻¹) also reveal fine activity in increasing P and K concentrations in soil, so that P

and K uptake by cotton plants and Rape is greater than those without inoculation. Re-isolation at the end of incubation performed on non-sterilized soil conditions showed the presence of both mutant bacteria. In the 5th week, mutant potassium-releasing bacterial strain of *Bacillus edaphicus* NBT was still established in cotton and rape rhizosphere. One of the mechanisms for solubilising the soil potassium by the microorganisms activity resulted from excreted organic acids, therefore triggering the organic cation to be stimulated by Si ions and releasing K in the solutions.

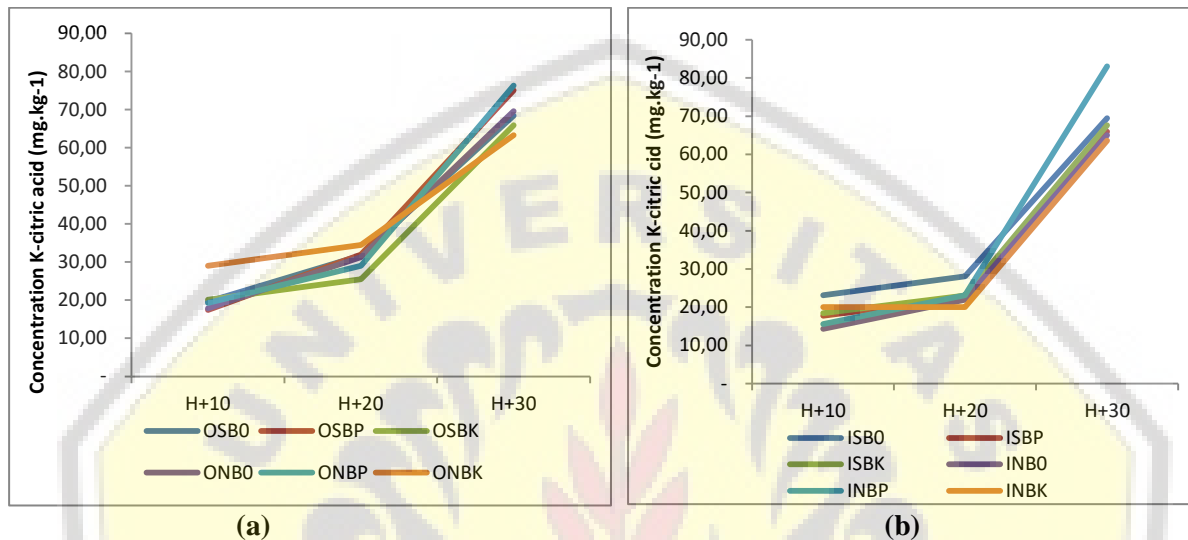


Figure 3. The Concentration of Potassium Solubilisation (Citrate Acid extract) in Oxisol (a) and Inceptisol (b)

The concentration of potassium in Oxisol increased by 3.78 to 4.53 times greater than its initial concentration, whereas Inceptisol rose by 4.32 to 5.26. The increase in Inceptisol was more intense than that in Oxisol, because Inceptisol generally was dominated by smectite clay minerals and some kaolinite and it was derived from clay sediment main material [22]. The concentration of soil K was dependent on the amount of smectite clay minerals in soil. Clay mineral Smectite could fixate K at that mineral layer interspace where the fixated K was reserved exch-K for plants through release and desorption processes, resulting in greater release of K in Inceptisol. The availability of soil K relied on the process and dynamic of K in soil, especially sorption and desorption process. Sorption and desorption of K in soil were determined especially by the type and amount of clay minerals. Clay mineral type 2:1 adsorbed K and released K more intensely than did other clay minerals, such as type 2: 1: 1, 1: 1, oxyde, and alophane [22]

In general, mineral composition and chemical properties of red soil include the presence of Oxisol particularly in humid tropical area, characterized by sand mineral dominated by quartz and opaque, while clay mineral is dominated by kaolinite with additional mineral gibbsite, goethite, and hematite [23]. By contrast, according to another research [24], the clay fraction of Oxisols is dominated by (a) 1: 1 phyllosilicates; (b) oxides of Fe and/or Al, or the mixtures of (a) and (b). Clay minerals in soils of tropical climates such as Oxisols and Ultisols are dominated by kaolinite and halloysite, in addition to gibbsite and sesquioxides. The soil with dominance of kaolinite clay and halloysite is characterized by the presence or position of K ion which is not on the interspace layer because there is only one octahedral layer and one tetrahedral layer. Consequently, K fixated as a K-reserve which can be released in solution is also low (Figure 4).

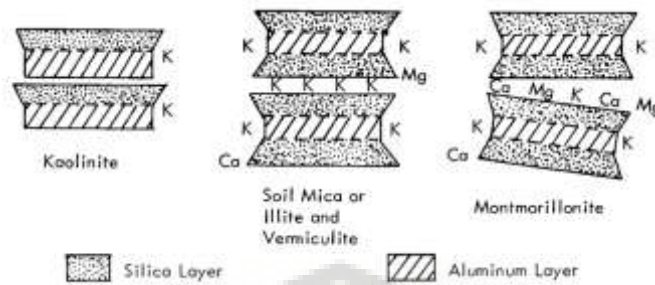


Figure 4. The Illustration of clay Mineral Structure (type 1:1), Illite (type 2:1 non exchangeable), and montmorillonit (type 2:1 exchangeable)

Both PSB (*Bacillus sp^{rif}*) and KSB (*Pseudomonas sp^{rif}*) were able to solubilise phosphate and potassium in both soils although each had distinctive solubility capability. This is line with the study [25] which proves the ability of *Bacillus mucilaginosus* in increasing P and K availability. The same finding is obtained in another research [4] using phosphate solubilizing bacteria, (PSB) *Bacillus megaterium* var. *Phosphaticum* and potassium solubilizing bacteria (KSB) *Bacillus mucilaginosus*. The mechanism of solubilising phosphate and soil potassium was relatively similar in that it was carried out through acidification, chelation, and exchange reactions [26], as well as through the production and excretion of organic acids.

4. Conclusion

Both isolates of PSB (*Bacillus sp^{rif}*) and KSB (*Pseudomonas sp^{rif}*) have been found effective to solubilise the phosphate and potassium of Oxisol and Inceptisol soils in both sterilized and non-sterilized conditions. Phosphate or potassium solubilizing in Inceptisol soil has been proven greater than that in Oxisol. The sterilized and non-sterilized soil conditions have revealed no bearing impact on the solubilizing activity in both isolates.

Acknowledgements

The authors are grateful to the Ministry of Research, Technology and Higher Education for funding this research. The authors would like to thank Dr. Wiwik Hartatik from Soil Research Center for providing Oxisol.

Conflict of interest

The authors declare that they have no conflicts of interest.

REFERENCES

- [1] Girgis, M.G.Z., H.M.A. Khalil and M.S. Sharaf. 2008. "In vitro evaluation of rock phosphate and potassium solubilizing potential of some *Bacillus* Strains," *Aust. J. Basic Applied Sci.*, 2: 68-81.
- [2] Rosa-Magri, M.M., S.H. Avansini, M.L Lopes-Assad, S.M Tauk-Tornisielo and S.R Ceccato-Antonini. 2012. Release of Potassium from Rock Powder by the Yeast *Torulaspora globose*. *Brazilian Archives of Biology and Technology*. Vol.55, n. 4: pp.577-58
- [3] Maria Leonor Lopes-Assad A, Simoni Helena AvansiniA; Greice ErlerA; Márcia Maria RosaA; José Ruy Porto de Carvalho B and Sandra Regina Ceccato-Antonini. 2010 Rock powder solubilization by *Aspergillus niger* as a source of potassium for agroecological systems. 19th World Congress of Soil Science, Soil Solutions for a Changing World 1 – 6 August 2010, Brisbane, Australia.219-221

- [4] Han H.S. and K.D. Lee. 2005. Phosphate and Potassium Solubilizing Bacteria Effect on Mineral Uptake, Soil Availability and Growth of Eggplant . Research Journal of Agriculture and Biological Sciences 1(2): 176-180
- [5] Prajapati K.B. And H.A. Modi. 2012. Isolation and Characterization of Potassium Solubilizing Bacteria From Ceramic Industry Soil. Cibtech Journal of Microbiology. Vol. 1 (2-3) Jul.-Sept. & Oct.-Dec., Pp.8-14
- [6] Setiawati, T.C., and Laily Mutmainah. 2016. Solubilization of Potassium Containing Mineral by Microorganisms From Sugarcane Rhizosphere. International Conference on Food, Agriculture and Natural Resources, IC-FANRes 2015. Agriculture and Agricultural Science Procedia. Volume 9, Pages 108-117
- [7] Kloepper J.W., M.N. Scrouth and T.D. Miller. 1980. Effects of Rhizosphere colonisation by Plant Growth promoting Rhizobacteria on Potato Plant Development and Yield. Phytopathology. 70:1078-1082
- [8] Yu-Huan Gu And Markmazzola. 2001. Impact of Carbon Starvation on Stress Resistance, Survival in Soil Habitats and Biocontrol Ability of *Pseudomonas Putida* strain 2C8. Soil Biology and Biochemistry Volume 33, Issue 9, July 2001, Pages 1155-1162
- [9] Glandorf, D.C.M., I. Brand, P.A.H.M. Bakker and B. Schippers L. 1992. Stability of Rifampicin Resistance as A Marker for Root Colonization Studies of *Pseudomonas Putida* in The Field. Plant and Soil 147: 135-142.,
- [10] Geoffrey Compeau, 'T Boutros Jadoun Al-Achi,' Evangelia Platsouka,' and Stuart B. Levy'. 1988. Survival of Rifampin-Resistant Mutants of *Pseudomonas Fluorescens* and *Pseudomonas Putida* in Soil Systems. Applied and Environmental Microbiology. P. 2432-2438 Vol. 54, No. 10
- [11] Stevenson, F.J., 1986. Cycles of Soil. John Wiley and Sons. New York
- [12] Setiawati, T.C., dan. A.M.Paniman. 2004. Identifikasi dan Kuantifikasi Metabolit Bakteri Pelarut Fosfat dan Pengaruhnya Terhadap Aktivitas Rhizoctonia Solani Pada Tanaman Kedelai. Jurnal TANAH TROPIKA (Journal of Tropical Soils) 13 (3)
- [13] Setiawati, T.C. 2008. Peran Bakteri Pelarut Fosfat Dalam Media Organik Terhadap Dinamika Fosfat Pada Oxisol. disertasi. Universitas Brawijaya
- [14] Earl K. D., J. K. Syers And J. R. McLaughlin. 1979. Origin of the Effects of Citrate, Tartrate, and Acetate on Phosphate Sorption by Soils and Synthetic Gels. Soil Sci Soc Am J 43:674-678.
- [15] Tisdale, S.A., W.L. Nelson, J.M. Beaton and J.L. Havlin. 1993. Soil Fertility and Fertilizers. Macmillan Publishing co. New York.
- [16] Pigna, M., A. Violante and M.Ricciardella. 2002. Adsorption of phosphate and sulphate on metal oxides and variable charge soils as affected by organic ligands. Word Congress Soil Science, 17th. Thailand. Symposium 06, paper 134.
- [17] Srivastava S., M. T. Kausalya, G. Archana, O. P. Rupela and G. Naresh-Kumar. 2007. Efficacy of organic acid secreting bacteria in solubilization of rock phosphate in acidic Alfisols. First International Meeting on Microbial Phosphate Solubilization, 117-124.
- [18] Violante, A., and L. Gianfreda. 2000. Role of biomolecules in the formation of variable charge minerals and organo-mineral complexes and their reactivity with plant nutrients and organic in soil. In J.B. Bollag and G. Stotzky (Eds). Soil Biochemistry Vol 10:207-270. Marcell Dekker New York
- [19] De Datta, S.K., T.K. Biswas and C. Charoenchamratcheep. 1990. Phosphorus requirements and management for low land rice. In Phosphorus Requirements for Sustainable Agriculture in Asia and Oceania. International Rice Research Institute. 307-324.
- [20] Hejazi, M., H. Shariamatdari, M.Afyuni and M. Kalbasi. 2005. The effect of organic amandements on different phosphorus form in a calcareous soil. Proceeding of International Conference on Human Impacts on Soil Quality Attributes.

- [21] Sheng X.F.. 2005. Growth promotion and increased potassium uptake of cotton and rape by a potassium releasing strain of *Bacillus edaphicus*. *Soil Biology & Biochemistry* 37: 1918–1922
- [22] Nursyamsi D., K. Idris, S. Sabiham, D.A. Rachim, and A. Sofyan. 2008. Dominant Soil Characteristics Influencing Available Potassium On Smectitic Soils. *Indonesian Journal of Agriculture* 1(2): 121-131
- [23] Prasetyo B.H.. 2009. Red Soils from Various Parent Materials in Indonesia: The Prospect and Their Management Strategic. *Jurnal Sumberdaya Lahan* Vol. 3 No.1.
- [24] Allen B.L. , D.S. Fanning, 2014. Oxisol. in *Developments in Soil Science*, in *Advances in Agronomy*.
- [25] Sugumaran, P. and B. Janarthanam,. 2007. Solubilization of potassium obtaining minerals by bacteria and their effect on plant growth. *World J. Agric. Sci.*, 3(3) : 350- 355.
- [26] Gerke L. 1992: Phosphate, aluminum, and iron in the soil solution of three different soils in relation to varying concentrations of citric acid. *Z. Pfl.-Ernähr. Bodenkd*, 155: 17–22

