Nutrient Adsorption in Ultisols Soils Treated by Phototropic Bacteria

Aidee Kamal Khamis, Umi Aisah Asli, Siti Nazrah Zailani, Zulkifli Abdul Wahid, and Firdausi Razali

Abstract—Ultisols are generally high weathered and low in fertility. With the intensive agriculture activities, the soils condition is deteriorating. Thus, this work is aimed to remediate the Ultisols soils via natural way. A versatile phototropic bacterium called *Rhodopseudomonas palustris* was used as an agent to improve the metabolic of soils nutrient. The *R. palustris* bacterium were adhered on the dried pineapple leaf (DPL) before being applied on the soil (*Bungor* soil series). The isotherm and mechanism of nutrient adsorption were studied by observing the Na^{+} ion concentration with time through controlled soils condition (i.e. amount, compaction, temperature and moisture). The experiment was carried out in a water-soil permeability unit by allowing a 0.1 N of Natrium Chloride (NaCl) solution passed through a three different form of soils; i) *Bungor* soils, ii) *Bungor* soils with DPL and iii) *Bungor* soils with *R. palustris* bacterium adhered on DPL. In comparison, it is found that soil with *R. palustris* bacterium adhered on DPL has the highest adsorption capacity of Na+ cation. This result shows that *R. palustris* bacterium was able to increase the nutrient uptake in soils thus the soils acidity.

Keywords—Adsorption, Ultisols, *R. palustris*, *Bungor*, Malaysia.

I. INTRODUCTION

MALAYSIA land has a high composition of Ultisols, which are generally acidic, strongly leached and considered low in fertility. Mostly, Ultisols is lacking in organic matters or nutrient elements that essential for plant to grow. In nature, Ultisols are devoid of basic cations (Ca and Mg) and available P (as a result from a fixation by the oxides) [1]. The lack of nutrients in Ultisols is also influenced by the frequent heavy rainfall received which causing the leaching process. These factors contributes to the soil acidity of ultisols as high contents of H^{+} and Al^{3+} ions overflow in the soil solution and permeate into the ground. Soils acidity is one of the major concerns in the agriculture. Some plants cannot absorb nutrients in highly acidic soils hence affecting the productivity. Commonly, for agriculture purposes, high amount of costly fertilizers are intensively used in order to support and maintain the nutrients elements in the soil. However, the long term and excessive use of fertilizers, particularly the chemical based one, is destroying the nature of soil nutrient balance [2].

This work is attempted to resolve the nutrient imbalance in Ultisols by natural way where phototropic bacteria is applied as a "nutrient stabilizer". *R. palustris* bacteria is known as one of the most metabolically versatile which have an ability to convert carbon dioxide gas and nitrogen gas into ammonia and hydrogen. With this ability, the pH of soils can be exploited to reduce the soil acidity [3].

To elucidate the adsorption mechanism of soils, a trace analysis has been done. The of concentration profile of cation breakthrough curve soils bed was investigated. The adsorption phenomenon was compared to a Thomas Model, the most convenient and widely used model for soils. The Thomas Model is a derivation from the assumption Langmuir kinetics of adsorption-desorption and no axial dispersion. The expression for the Thomas Model for adsorption soils bed is given as Equation 1 [4] [5].

$$\frac{C_t}{C_0} = \frac{1}{1+exp\left[\left(\frac{K_{Th} q_e x}{Q}\right) - k_{Th} C_0 t\right]} \quad (1)$$

Where C_t,C_0 are concentration of effluent and initial solution (mg/l), K_{Th} is Thomas model constant (ml/min.mg), q_e is predicted adsorption capacity (mg/g), x *is* mass of adsorbent (g), Q *is* influent flow rate (ml/min) and t *is* time (day).

The linear form of Thomas model, which derived from (1) can be written as,

$$ln\left(\frac{C_t}{C_0} - 1\right) = \left(\frac{K_{Th} q_e x}{Q}\right) - k_{Th} C_0 t \quad (2)$$

II. MATERIALS AND METHODS

A. Dynamic Sorption

The experiment was carried out by flowing in 5.0 ml/min of 0.1N sodium chloride (NaCl) solution by a peristaltic pump into a stainless steel column (L = 100 cm, OD = 10 cm) compacted with soils sample. The effluent from the column was then collected at approximately 50 ml/day for a trace

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analysis. All column experiments were conducted at room temperature. The NaCl concentrations were determined spectrophotometrically at 500 nm.

B. Soils Properties

In this work, *Bungor* soils series was used. The soil characteristics as indicated in Table 1.

TABLE 1
CHARACTERISTICS OF SOIL SERIES

Parameters	Amount
pH	4.10
C/N ratio	9.42
Cation exchange capacity (C.E.C), m_{eq}/100g	10.10
Electrical conductivity (EC), µS	69.20
Clay, %	47.00
Silt, %	9.00
Coarse sand, %	6.00
Fine sand, %	38.00

Three different soils sample were studied, which are i) *Bungor* soils, ii) *Bungor* soils with DPL and iii) *Bungor* soils with *R. palustris* bacterium adhered on DPL. All soils sample were from *Bungor* series purchased from FELDA Sdn. Bhd. soil laboratory. The soil was compacted in the column fixed to 1.0 kN/m^2 by the standard Proctor compaction test, ASTM.D.698(1933) [6].

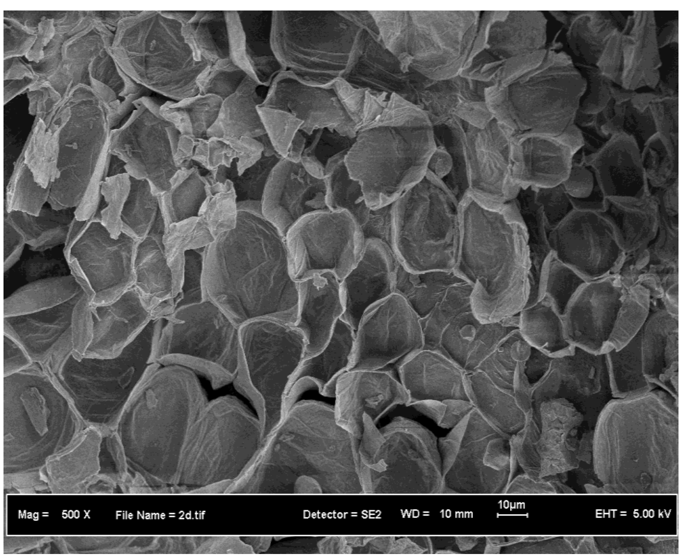


Fig. 1 FESEM image of Dried Pineapple Leaf (DPL)

The moisture contents all of the soil samples on average 12.0% dry basis. The adhesion of bacteria onto DPL was done by soaking the leaves (70µm) with *R. palustris* in sterilized deionised water and further natural drying for 1 to 2 days in dessiccator. To confirm the attachment of *R. palustris* bacteria on the DPL, the leaves were analyzed by FESEM imaging technique. Fig. 1 and Fig. 2 show the image of DPL before and after the adhesion with *R. palustris* bacterium. The soils electrical conductivity (EC) of soils with attachment with DPL and DPL + bacteria was then measured by Camlab CW6220 portable conductivity meter. The value of soils EC is 102.4 µS after *Bungor* soils mixed with DPL 273.7 µS after Bungor soils were mixed with *R. palustris* bacterium adhered on DPL.

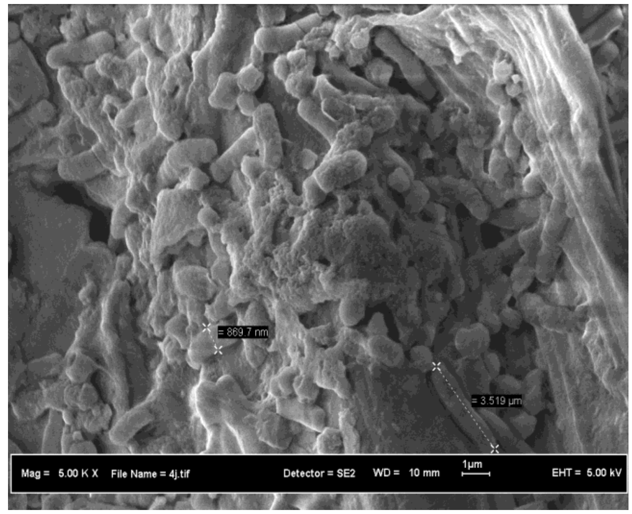
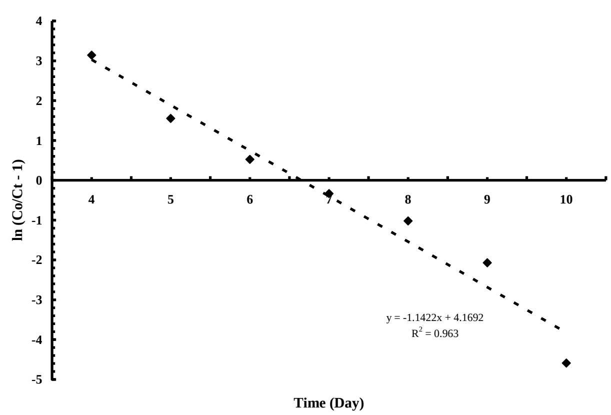


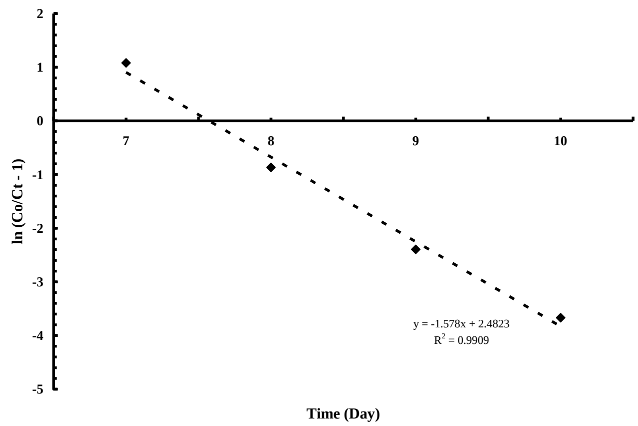
Fig. 2 FESEM image of DPL adhered with *R.palustris* bacterium (rod-shaped structures). The number of colony forming unit (CFU) of *R. palustris* used in this experiment was 6×10^7 which was freshly prepared.

III. RESULT AND DISCUSSION

All three sets of experimental data for (a) *Bungor* soils (b) *Bungor* soils with DPL and (c) *Bungor* soil with *R. palustris* adhered on DPL were fitted into (2) as shown in Fig. 3 (a), (b) and (c). The fitness of the plot was satisfied enough where the values of R^2 obtained were 0.9630, 0.9099 and 0.8910 accordingly. The calculated value of the kinetic coefficient, K_{th} and adsorption capacity of the soils, q_e , (listed in Table III) from the linear plot, were used into (1) to generate a model curve for a breakthrough profile for each sets of experimental data. The breakthrough profiles are presented in Figure 4 (a) to (c).



(a)



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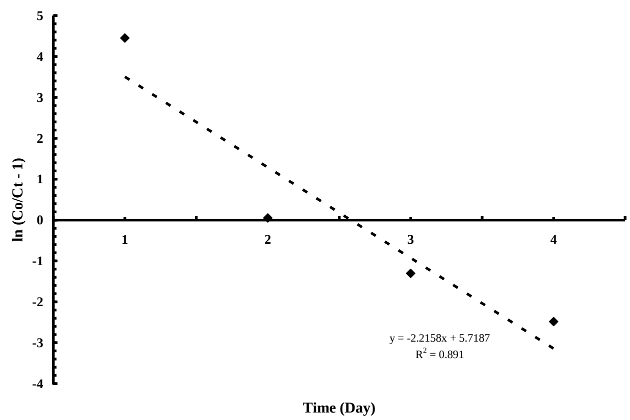
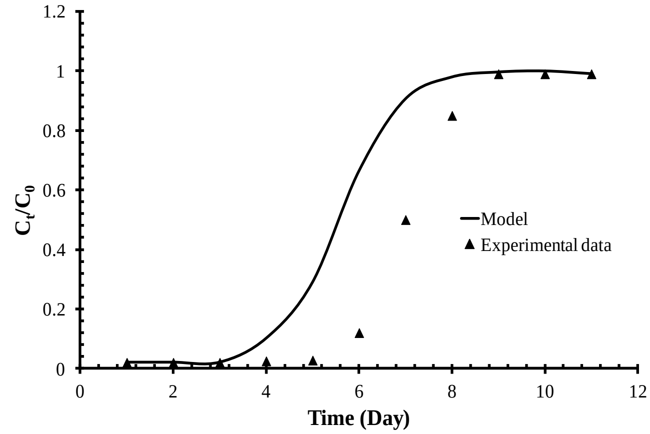
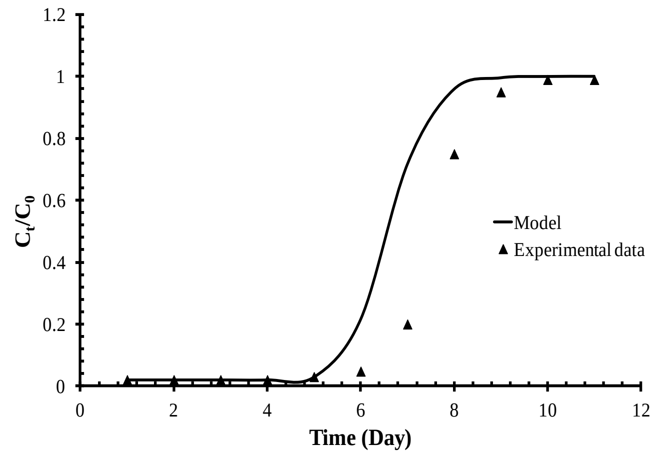


(c)

Fig. 3. Linear plot of Thomas model with experimental data. (a) *Bungor* soil (b) *Bungor* soil with DPL and (c) *Bungor* soil with *R. palustris* adhered on DPL

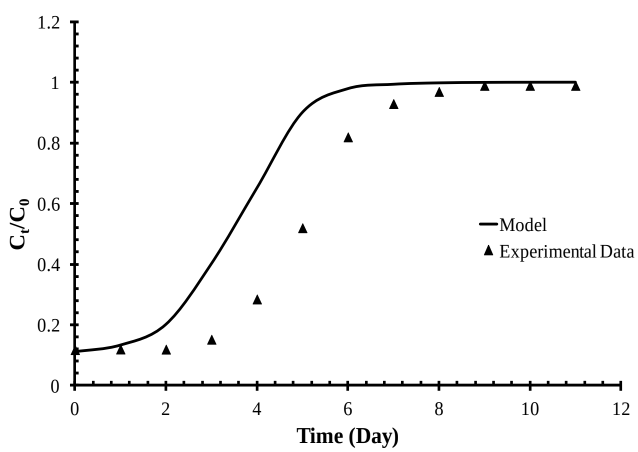


(b)



(c)

Fig. 4. Curve Fitting of Thomas model with experimental data. (a) *Bungor* soil (b) *Bungor* soil with DPL and (c) *Bungor* soil with *R. palustris* adhered on DPL. (SD $\pm$ 0.05 for experimental data)



(a)

TABLE II

THOMAS MODEL PARAMETERS USING LINEAR REGRESSION ANALYSIS FOR NA+ ADSORPTION UNDER DIFFERENT SOIL PREPARATION

	EC (μS)	$q_{e.max}$ (mg/g)	K_{th} (mL.min.mg)	$q_{e.max}$ (exp) (mg/g)
Soil	60.0	0.2311	0.210	0.1241
Soil + DPL	100.0	0.2113	0.290	0.0535
Soil + DPL + *R. palustris*	259.0	0.1985	0.407	0.0878

All curves in the Figure 4 (a), (b) and (c) showed an S-shaped breakthrough profile with a good agreement between the experimental data with the Thomas Model adsorption profile. To evaluate the overall performance, the column breakthrough time, t_b is determined at time when the fraction of Na^+ concentration in the effluent reached 5%. Whereas the exhaustion time, te is defined as the time which C/Co is equal to 95% of the influent concentration. For the calculation for the total quantity of Na^+ adsorbed in the soils, qe, the total area above the breakthrough curve was multiplied by the flow rate. The breakthrough time in *Bungor* soils is the highest with *R. palustris* adhered on DPL, which $t_b = 6$ days, followed by *Bungor* soil with DPL (day 5) and has the lowest in *Bungor* soil at day 3. Similarly, soils (c) poses the longest exhaustion time, t_e of 10 days compared than other soils. This evidenced that with the attachment of bacteria to the soils, the breakthrough curve time for Na^+ adsorption could be prolonged. This could be related to the rise of soil electrical conductivity (EC) after applied the *R. palustris* in the soils (refer Table 2). The rise of EC in soils related to the increase of contact period of the sorbate with the sorbent in the column [8]. Also, it is observed that the steepness (dc/dt) of breakthrough curve for Na^+ sorption in soils is inceasing from plain soils (a) to the soils with attachment of DPL (b) and even higher with the soils attached with bacteria on DPL. As mentioned by Singh et al., the steepness of curve is indicator of the efficiency of column (soils compaction) to reach saturation; the steeper is the curve, the better will be the performance [9].

Despite the good agreement in breakthrough curve, the estimated equilibrium sorption, q_e, of Thomas model was one fold higher than experimental value. The Thomas kinetic coefficient, K_{th} become higher with the increased of EC in soil. The value of q_e and K_{th} were obtained for the soils with *R. palustris* bacterium adhered on DPL (refer Table II). According to Table II, the calculated $q_{e,max}$ from Thomas model is greater than experimental $q_{e,max}$. It is also seen in Table II that as Co and adsorbent weight increased, the value of $q_{e,max}$ and K_{th} increased and decreased, respectively. This is because the driving force for adsorption is the difference in concentration between the lead on the adsorbent and in the solution. As flow rate increased, the value of *qe,max* decreased. This is because of unavailability of reaction sites, but the value of K_{th} increased.

IV. Conclusion

The Thomas model was well applied to predict the breakthrough curves and determine the characteristics parameters of the adsorption of column. This result shows that *R. palustris* bacterium potentially play a role in an increase of nutrient uptake in soils. The same understanding of bacteria and soil particles as reported by [10] and the magnitude of the negative charge on the soil organic matter which effect the adsorption of cation also reported by [11].

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