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The Behavior of Ammonium Exchange (Q/I) in Soil, Nitrogen and Carbon Uptake, and Mung Beans (*Vigna radiata L.*) Yields as Affected by Tillage and Fertilization at the Sixth Planting Period in Ultisol Soil

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ABSTRACT

Ultisol soil has a low organic matter content, CEC, and pH, causing an insufficient buffering capacity for N nutrients, especially NH_4^+. The objective of this study was to determine the effect of tillage and fertilization on the quantity and intensity (Q/I) of Ammonium ($CR_{NH_4^0}$, $PBC_{NH_4^+}$, ΔNH_4^0, K_G) in the soil, plant N and C uptake, and mung bean yields at the sixth growing season in ultisols. This study was arranged in a 2 × 2 factorial in a Randomized Block Design (RBD). The first factor was the tillage system (T), namely minimum tillage (T0) and intensive tillage (T1). The second factor was the fertilization (P), namely without fertilizer application (P0), and with fertilizer application (NPK 200 kg ha^{-1} + 1 Mg ha^{-1} chicken manure) (P1). Each treatment was replicated four times. The results showed that the application of NPK fertilizer significantly affected the mung bean yield, mung bean plant Nitrogen and Carbon uptake at harvest time. While, the intensive tillage had a very significant effect on increasing the N uptake compared to the minimum tillage. Minimum tillage and fertilization increased Q/I parameters ($PBC_{NH_4^+}$, K_G, $CR_{NH_4^0}$, and ΔNH_4^0). The parameter of Q/I ($CR_{NH_4^0}$) was significantly correlated with mung bean plant N and C uptake. $PBC_{NH_4^+}$ and K_G were significantly correlated with mung bean yields.

Keywords: Ammonium exchange (Q/I), intensive tillage, minimum tillage, mung beans, ultisols

INTRODUCTION

Mung bean (*Vigna radiata* L.) is one of the agricultural commodities with excellent development prospects in Indonesia. Mung beans are the third most crucial legume commodity after soybeans and peanuts (Widjajaseputra *et al*. 2019). The main problems of mung bean cultivation in Indonesia are low productivity and limited cultivation area. This problem can be overcome by optimizing marginal land such as Ultisol soil for mung bean cultivation activities.

Ultisols are a significant group of marginal soils extensively found in the upland area of Indonesia (Prasetyo *et al*. 2021). The total area of Ultisol in Indonesia is up to 45.8 million ha, or about 25% of the total land area of Indonesia (Subagyo *et al.* 2004). Ultisol soil is less fertile soil (Offiong *et al*. 2021) but can still respond well if properly managed (Utomo *et al*. 2016). Ultisol soils have several problems, including low pH, N, P, K, Mg, and Ca content (Hale *et al*. 2020), low cation exchange capacity (CEC) (Alves *et al*. 2021; Pan *et al*. 2021) and high levels of aluminum (Al) which can cause poisoning in plants and inhibit the growth of roots and soil microbes (Mulyani *et al*. 2010; Zhao *et al*. 2020).

Ultisol soils have a very low organic matter content, CEC, and low pH (Peng *et al*. 2011; Septiyana *et al*. 2021), causing a very low N nutrient buffer, especially NH_4^+. The availability of N in acid soils is dominated in the form of NH_4^+ compared to in the form of nitrate (NO_3^-), so it is necessary to improve the buffering capacity of NH_4^+ (Lumbanraja *et al*. 2019). The buffering capacity of ammonium can be increased by using organic and inorganic fertilizer management technology and soil management (Prasetyo and Suriadikarta 2006).

One type of fertilizer commonly used in addition to N nutrients is urea. Urea in the soil is mainly converted to NH_4^+, which is adsorbed in the soil colloid, but NH_4^+ in the soil solution can be oxidized to NO_3^- (Lumbanraja *et al*. 2019). Several studies on the relationship between the quantity/intensity of NH_4^+ in various soil types have been carried out, especially on dry land (Lumbanraja *et al*. 2019; Wang and Alva 2000). Applying organic matter can increase the availability of ammonium and nitrate so that more nitrogen will be available in the soil (Munawar 2011). Isnaini's research (2005) showed that the no-tillage combined with fertilization affected the $N\text{-}NH_4^+$ content and K^+ uptake. Lumbanraja *et al*. (2020) stated that minimum tillage treatment has higher PBC_K (potential buffering capacity for K^+) than conventional tillage. It is suspected that minimum tillage has higher organic matter compared to conventional tillage and organic matter can increase the soil CEC values. The minimum tillage system that was given fertilization improved the soil's chemical properties (N, P, K, pH, Organic-C, and CEC). The CEC value is directly proportional to the PBC_K value; the higher the soil CEC value, the PBC_K will also increase (Lumbanraja 2017).

The relationship (Q/I) was used in several studies to evaluate the availability of K^+ and NH_4^+ (Singh *et al.* 2019). The previous research (in the third planting period) has conducted a Q/I K^+ analysis. Hence in this study, an analysis of the Q/I NH_4^+ relationship was conducted to determine the effect of tillage and fertilization on the behavior of Ammonium in soil, mung bean plant N and C uptake, and mung bean yields in Gedong Meneng ultisols at the sixth planting period.

MATERIALS AND METHODS

History of Research Area and Reseach Site

Series of experiment were done in the experimental field since December 2016. The research in the first planting season from December 2016 to February 2017 used maize as an indicator plant. The second planting season in April-June 2017 used mung bean, the third planting season in February-June 2018 used maize, the fourth planting season in September-December 2018 used mung bean, the fifth planting season in October 2019-January 2020 used maize, and the sixth planting season in September 2020-May 2021 used mung bean. The field experiment was done in the Integrated Agricultural Experimental Stations (5°22'10"S 105°14'38"E), the University of Lampung, from. For the sixth planting season, a laboratory experiment on Quantity – Intensity (Q/I) Ammonium was conducted in the Laboratory of Soil Science, the University of Lampung.

Experimental Design

A 2×2 factorial in Randomized Block Design (RBD) was applied. The first factor was the tillage system (T), namely minimum tillage (T0) and intensive tillage (T1). The second factor was the fertilization (P), namely without fertilizer application (P0), and with fertilizer application (NPK 200 kg ha^{-1} + 1 Mg ha^{-1} chicken manure) (P1). The combination traetments were Minimum Tillage and No Fertilization (T0P0), Minimum Tillage and Fertilizer Application (T0P1), Intensive Tillage and No Fertilizer (T1P0), and Intensive Tillage and Fertilizer Application (T1P1). Each treatment was replicated four times. So, the experiment had 16 experimental plots.

The size of each plot size was 2.5 m × 2.5 m with 0.7 m spacing between plots. The minimum tillage plots were processed only as necessary by clearing weeds and returning them to the experimental plots. While, in the intensive tillage plots, the soil was tilled entirely to a depth of 15-20 cm, and weeds in the plots were removed. Planting was done by inserting 4 mung bean seeds in each hole of the Vima-2 variety with a spacing of 60 cm × 15 cm. After 7 days after planting (DAP), thinning was done, leaving two plants per hole. Manure was applied during the planting process; while, NPK compound fertilizer was applied at 7 DAP by spreading over an array with a distance of ± 10 cm from the plant. During mung bean cultivation, plant maintenance includeed watering, weeding, and hoarding. Harvesting was done gradually when the pods had brown or black color at the age of 60-70 DAP. Soil samples were taken twice which were before planting and after harvesting. Each plot was taken 3 points randomly using a Belgian drill, then composited based on the treatment. Meanwhile, five samples from each plot were taken, then the stover, pods, and seeds were separated to calculate the dry weight of the plant.

The main variables in this study were the Quantity-Intensity (Q/I) Ammonium experiment, wet and dry weight of plants. Harvested plants samples that had been separated from stover, pods, and seeds in each plot were weighed to obtain wet weight and then oven-baked (60 ^oC for three days) to obtain dry weight. The mung bean plant N uptake was analysed using the Kjeldahl method, and C uptake using the Walkey and Black method. While the supporting variables of this study were soil total N (Kjeldahl method), soil available P (Bray-1 method), soil organic C (Walkey and Black method), soil pH (actual and potential), soil CEC (NH_4OAc 1N pH 7) (Sparks 1996).

The Experiment of Quantity – Intensity (Q/I) Ammonium in Laboratory

The concept of Q/I describes the relationship between the ion concentration in the soil colloid and the equilibrium concentration in the soil solution. According to Forghani and Sabouri (2020), evaluating the relationship of nutrient supply characteristics to the soil can be described using the Q/I method. The analysis of NH_4^+ by the Q/I method was in accordance with the procedure used by Beckett (1964). A four gram of soil samples was placed into each series (6 centrifuge tubes) then added 40 ml of NH_4Cl with a concentration of 0; 0.2; 0.5; 1.0; 2.0; and 3.0 mmol L^{-1}, which has already contained 0.005 M $CaCl_2$. Then, the soil was shaken for 2 hours and centrifuged for 15 minutes at 3000 rpm. After being centrifuged, the solution was filtered to separate the clear solution from the soil. The clear soil solution was distilled with a 40% NaOH solution to measure NH_4^+, which was accommodated in a mixture of boric acid and Conway indicator, as well as Ca and Mg, using an Atomic Absorption Spectrophotometer (AAS) (Wang *et al.* 2004). Each treatment was repeated three times.

Cation exchange will occur in the soil that has been given a series of solutions based on the Q/I method. The concept of PBC can be illustrated by a simple exchange reaction between Ca^{2+} and NH_4^+. The exchange reaction can be written as follows (Ninh *et al.* 2009):

$$\text{(soil) Ca½} + NH_4^+ \longleftrightarrow \text{(soil) } NH_4 + ½\, Ca^{2+} \text{....(1)}$$

Beckett's (1964) approach was used to study the Q/I NH4+ relationship in soils. From the Q/I NH_4^+ method, a curve (Figure 1) is obtained, which can provide clues to determine the ability and adequate quantity of ammonium supply into the solution in the soil, which can then be available to plants. From the ideal curve of Q/I, NH_4^+ gives input the amount of NH_4^+ absorbed or released from the soil (ΔNH_4^+, cmol kg^{-1}) and the concentration ratio of NH_4^+ ($CRNH_4^+$, (mol L^{-1})^{½}). T the reactions of $\Delta NH4^+$ and $CR_{NH_4^+}$ are described by equations (2 and 3):

$$\Delta NH_4^+ = CR_{NH_4^{+i}} - C_{NH_4^{+f}} \text{.............................(2)}$$

Changes in the value of exchangeable NH_4^+ (ΔNH_4^+) are the difference between the concentrations of NH_4^+ before (i) and after (*f*) equilibrium with soil colloids, which can be seen in equation (2). The intensity factor of NH_4^+ ($CR_{NH_4}^+$) is the result of the calculation of the concentrations of NH_4^+ ($C_{NH_4^+}$), Ca (C_{Ca}), and Mg (C_{Mg}) in the soil solution (equation 3). The buffering capacity of NH_4^+ ($PBC_{NH_4^+}$, Cmol kg^{-1} (mol L^{-1})$^{-1/2}$) is the slope of the linear line of the Q/I curve. Non-specific NH_4^+ (ΔNH_4^0, cmol kg^{-1}) was obtained from the linear line of the Q/I curve when $AR_{NH_4^+} = 0$ and the

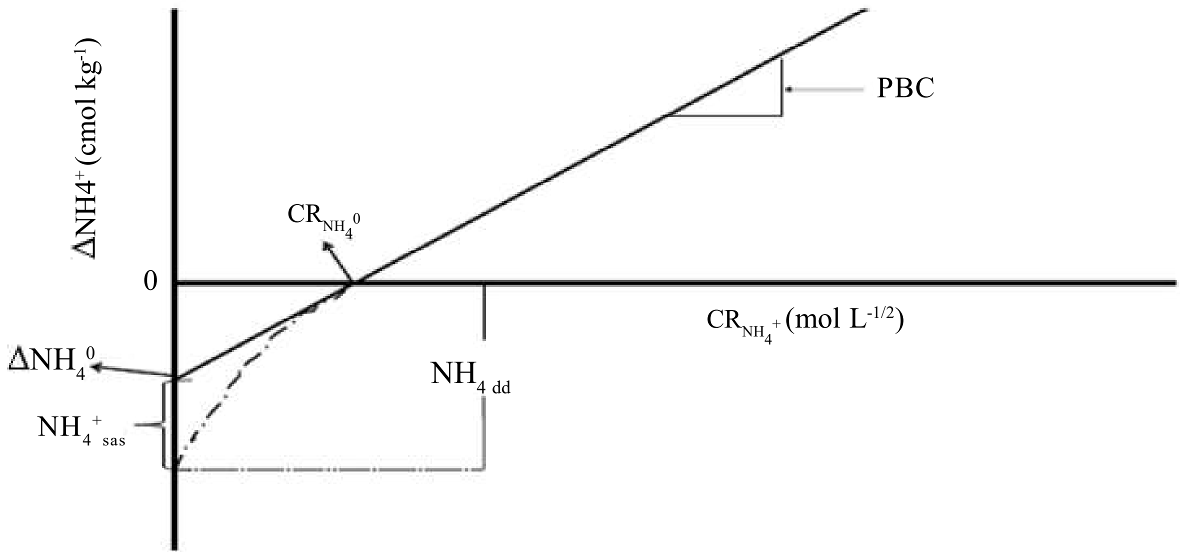

Figure 1. Ideal Curve of Q/I NH_4^+. NH_4^+ : Amount of NH_4^+ absorbed or released NH_4^+ from soil (vertical); $CR_{NH_4^+}$ = Ammonium ratio concentration (horizontal); $CR_{NH_4 0}$ = Equilibrium concentration ratio ammonium; PBC_{NH4}^+ = Buffer Capacity of NH_4^+ (slope); ΔNH_4^0 = Non-specific position of NH_4^+; NH_4dd : exchangeable NH_4^+ extracted with 1M KCl; $NH_4^+{}_{sas}$ = The specific position of NH_4^+ (NH_4dd - ΔNH_4^0) (Lumbanraja *et al.* 2019).

specific adsorbtion site of NH_4^+ (NH_4-$_{sas}$, cmol kg^{-1}) (Wang and Alva 2000). The ΔNH_4^+ and $CRNH_4^+$ calculated values were used to plot a Q/I curve; NH_4^+ is the y-axis, $CR_{NH_4}{}^+$ is the x-axis, and $PBC_{NH_4^+}$ is the slope of the regression line (Becket 1964).

$$CR_{NH_4}{}^+ = (NH_4^+)/[(Ca) + (Mg)]^{1/2} \quad (3)$$

Potential Buffering Capacity ($PBC_{NH4}{}^+$) is one of the parameters derived from the Q/I NH_4^+ relationship. The $PBC_{NH_4^+}$ value is the slope (gradient) of the Q/I linear curve, where a steeper curve indicates a higher potential buffering capacity than a gentler curve. This value describes the ability of the soil to maintain the quantity of NH_4^+ in the soil adsorption complex. The Gapon coefficient (K_G) = 2($PBC_{NH_4^+}$)/CEC is the selectivity coefficient for NH_4^+, which is the soil adsorption constant for NH_4^+. The higher the K_G value, the relatively more soil colloids adsorb NH_4^+ compared to Ca^{2+} and Mg^{2+} cations.

The Gapon coefficient value (K_G) is used to determine the preference for cation adsorption which is proportional to the total cations present in the soil colloid (Tan 1982). K_G is calculated using the equation Evangelou and Philips (1987) with formula (7):

$$PBC_{NH_4^+} = \tfrac{1}{2} K_G CEC \text{ so } K_G = \frac{2PBC_{NH_4^+}}{CEC} \quad (4)$$

Data Analysis

Statistics were conducted with Microsoft Excel 2019. The student-t-test (5% level) determines the difference between the amount of released soil NH_4^+ in each treatment and each labile NH_4^+ in the treatment analyzed using the Q/I method. A correlation test was conducted to determine the relationship between the parameters Q/I ($CR_{NH_4}{}^0$, ΔNH_4^0, $PBC_{NH_4^+}$), NH_{4dd} with soil available N, N and C uptake of mung bean plant due to tillage and fertilization. Analysis of variance was performed to analyse the data of vegetative and generative components of the mung bean. In addition, the Least Significant Difference (LSD) test was further performed to see the differences among the mean.

RESULTS AND DISCUSSION

Soil Chemical Properties Before and After Planting

The results of the soil chemical analysis pre-planting and post-planting can be seen in Table 1. The pH value of the Gedung Meneng Ultisol soil is in the slightly acidic criteria, and the soil nutrients content of total N is low to moderate, available P is moderate to very high, organic C and CEC values are low. The low soil pH was due to the leaching of primarily bases nutrients, so the soil reacts with acid. The soil total N and available P tend to decrease after harvest, presumably because mung bean plants have absorbed the soil N and P. The low soil organic matter content is generally due to the rapid decomposition process, and some of it is carried away by erosion (Prasetyo and Suriadikarta 2006), besides the decrease in carbon content is due to the weathering process of organic matter by microorganisms, releasing CO_2 into the air,

Table 1. Soil chemical properties before and after planting mung bean.

Chemical properties		Treatments			
		T0P0	T0P1	T1P0	T1P1
pH H_2O	Before	5.65^{SA}	6.09^{SA}	6.19^{SA}	6.50^{SA}
	After	6.23^{SA}	6.36^{SA}	5.95^{SA}	6.18^{SA}
pH KCl	Before	5.19^{A}	5.44^{A}	5.55^{A}	5.59^{A}
	After	5.23^{A}	5.41^{A}	4.91^{A}	5.29^{A}
Total N (%)	Before	0.20^{L}	0.27^{M}	0.22^{M}	0.23^{M}
	After	0.18^{L}	0.19^{L}	0.16^{L}	0.15^{L}
Available P (mg P_2O_5 kg^{-1})	Before	28.80^{H}	39.43^{VH}	25.69^{H}	48.46^{VH}
	After	16.01^{M}	37.09^{VH}	15.76^{M}	38.83^{VH}
Organic C (%)	Before	1.71^{L}	1.85^{L}	1.77^{L}	1.60^{L}
	After	1.33^{L}	1.75^{L}	1.61^{L}	1.55^{L}
CEC (cmol kg^{-1})	Before	5.3^{L}	5.3^{VL}	6.1^{L}	5.9^{L}
	After	5.4^{L}	5.7^{L}	4.3^{VL}	5.6^{L}

T0= (Minimum Tillage), T1= Intensive Tillage, P0= No Fertilizer, P1= Fertilizer. The numbers followed by the same letters indicate the criteria of soil chemical properties, namely VH= Very High; H= High; M=Moderate; L=Low; VL=Very Low; A= Acid; SA= Slightly Acid.

accompanied by energy production (Oktavia 2006). Because Ultisol soils have low organic matter, the CEC value is also low, according to the results obtained, the CEC values before and after harvest fall into the very low to low criteria. According to Syahputra *et al*. (2015), organic matter is a humus that acts as a soil colloid, so the more organic matter, the greater the CEC of the soil.

Mung Bean Yields and the Amount of Nitrogen and Carbon Uptake by Mung Bean Plants

The results of the analysis of variance showed that the application of NPK compound fertilizer and manure had a significant effect on harvested dry weight, oven dry seed, and 100-seed weight (g), but tillage treatment had no significant effect. Based on the BNT test (Table 2), the fertilizer application gave significantly higher harvested dry seed, oven dry seed and 100-seed weight than without fertilization application**.**

The addition of nutrients through the fertilization can affect the plants nutrients supply, increasing the growth process and yields of mung bean plants. In addition, during the cultivation process, the provision of water is always maintained by watering the plants twice a day in the morning and evening that it can help the process of plant nutrients absorption. Hastuti *et al*. (2018) stated that the availability of sufficient water during generative growth can increase seed weight because seed weight is strongly influenced by the amount of water available in the soil.

The analysis of variance showed that tillage and fertilization treatments had a very significant effect on plant N uptake in stover and total, while only fertilization had a significant effect on plant N uptake in pods and seeds. Based on the results of the LSD test (Table 3), intensive tillage has a higher plant N uptake in the stover and total than minimum tillage; then fertilizer application has a higher plant N uptake in the stover, pods, seeds, and totals than without fertilizer application. It is suspected that adding fertilizer will increase the availability of nutrients in the soil so that the uptake of nitrogen by plants with the addition of fertilizer will increase (Wang *et al.* 2019). NPK fertilizer is a source of essential macronutrients that can meet plant nutrient needs. Alavan *et al*. (2015) stated that applying inorganic fertilizers into the soil can quickly increase plant nutrient availability. Application of chicken manure was able to increase soil N-total and N uptake on Ultisol (Harahap *et al.* 2022). Nyiraneza and Snapp (2007) found that the chicken manure application can increase tomato yields and the efficiency of plant N uptake by up to 20% in field experiments. In addition, intensive tillage will improve soil structure so that root growth is good, and couple with sufficient nitrogen availability, roots will absorb nitrogen properly (Kaya 2018).

Based on the analysis of variance, tillage had no significant effect on plant C uptake of pods, while fertilization significantly increased plant C uptake of mung beans. Table 4 shows that tillage had no significant effect on plant C uptake of stover, seeds, and total. While, the LSD' test results showed that fertilization had a higher plant C uptake of stover, seeds, and total than without fertilizer. Applying fertilizer will increase the activity of microorganisms because it is a source of energy for microorganisms. According to Akbar *et al*. (2016), the nitrogen content in NPK fertilizer is an energy source that can increase the soil microorganisms activity so that the decomposition of organic matter and mineralization of nutrients can run quickly and so plants can absorb nutrients. The high plant C uptake

Table 2. Effect of tillage and fertilization on mung bean yields.

Treatments	Seed Weight of Mung Bean		
	Harvested Dry Seed (Mg ha^{-1})	Oven Dry Seed (Mg ha^{-1})	100-seed weight (g)
T0	1.82	1.49	6.23
T1	1.81	1.42	5.49
F-Test	ns	ns	ns
P0	1.52^{b}	1.30^{b}	4.13^{b}
P1	2.11^{a}	1.61^{a}	7.60^{a}
F-test	*	*	**
LSD 5%	0.58	0.31	0.33

T0= (Minimum Tillage), T1= Intensive Tillage, P0= No Fertilizer, P1= Fertilizer (200 kg ha^{-1} NPK + 1.000 kg ha^{-1} manure). The numbers followed by the same letters in the same column are not significantly based on the LSD test at a 5% significance level. ** = significant at $p < 0.01$, * = significant on $p < 0.05$, ns = not significant.

Table 3. Effect of tillage and fertilization on N uptake by mung bean plant.

Treatments	N uptake (kg ha^{-1})			
	Stover	Pod	Seed	Total
T0	5.32^b	0.84	12.24	18.40^b
T1	11.65^a	0.95	12.63	25.22^a
F-Test	**	tn	tn	**
LSD 5%	1.97			4.53
P0	5.62^b	0.77^b	10.42^b	16.81^b
P1	11.34^a	1.03^a	14.44^a	26.81^a
F-Test	**	*	**	**
LSD 5%	1.97	0.24	1.18	4.53

T0= (Minimum Tillage), T1= Intensive Tillage, P0= No Fertilizer, P1= Fertilizer (200 kg ha^{-1} NPK + 1.000 kg ha^{-1} manure). The numbers followed by the same letters in the same column are not significantly based on the LSD test at a 5% significance level. ** = significant at $p < 0.01$, * = significant on $p < 0.05$, ns = not significant.

was in line with the high plant dry weight (Deliyana *et al.* 2016). According to the study results, fertilization treatment had a higher plant dry weight than without fertilization.

Quantity-Intensity (Q/I) Ammonium

The linear curve of Q/I NH_4^+ (Figure 2) shows the relationship between the Quantity and Intensity of NH_4^+ in the soil solution, namely between $CR_{NH_4^+}$ (intensity factor) and ΔNH_4^+ (quantity factor), while (Table 5) shows the value of the Q/I parameter.

Figure 2 shows that $CR_{NH_4^+}$, on the X axis, is the ratio of ammonium concentration to Ca^{2+} in the soil solution, and ΔNH_4^+ on the Y axis is ammonium adsorbed by soil colloids. The value of $CR_{NH_4^+}$ depends on the concentration of NH_4^+ and Ca^{2+} in the soil solution. The curves in Figure 2 are above the X-axis in each treatment, which means that all treatments experience NH_4^+ adsorption. The value of the Quantity-Intensity (Q/I) Ammonium parameter for each treatment can be seen in Table 5. Meanwhile, the differences in the parameters for each treatment is shown in Table 6.

Potential Buffering Capacity of Ammonium ($PBC_{NH_4^+}$) and Gapon Coefficient (K_G)

Table 5 shows that the T0P1 treatment had the highest $PBC_{NH_4^+}$ value compared to the other treatments but did not differ much from the T1P1 treatment. The addition of organic and inorganic fertilizers can increase NH_4^+ uptake. It is suspected that the soil colloid is not saturated with NH_4^+ so the addition of NPK fertilizer will be adsorbed to the soil colloid and will be released into the soil solution if the NH_4^+ concentration in the soil solution is reduced due to being absorbed by plants or leached so that NH_4^+ will be available again (Lumbanraja *et al.* 2019). Adding organic fertilizer

Table 4. Effect of tillage and fertilization on C uptake by mung bean plant.

Treatments	C uptake (kg ha^{-1})		
	Stover	Seed	Total
T0	616.48	795.95	1616.4
T1	769.50	753.23	1891.1
Uji F	tn	tn	tn
P0	582.09^b	639.86^b	1521.2^b
P1	803.90^a	909.32^a	1986.3^a
F-Test	*	*	*
LSD 5%	158.09	166.50	383.92

T0= (Minimum Tillage), T1= Intensive Tillage, P0= No Fertilizer, P1= Fertilizer (200 kg ha^{-1} NPK + 1.000 kg ha^{-1} manure). The numbers followed by the same letters in the same column are not significantly based on the LSD test at a 5% significance level. ** = significant at $p < 0.01$, * = significant on $p < 0.05$, ns = not significant.

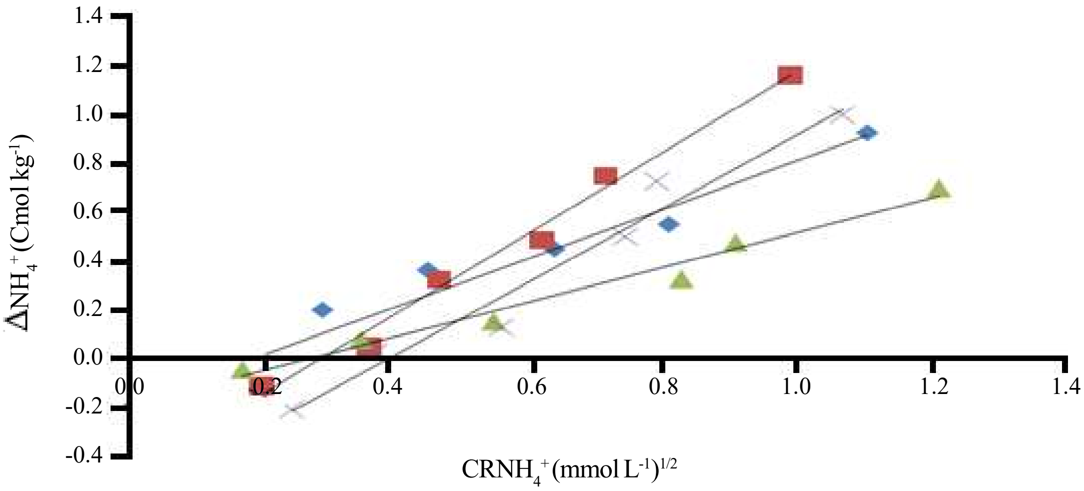

Figure 2. Ammonium Quantity-Intensity (Q/I) Curve in Ultisol Soil. T0= (Minimum Tillage), T1= Intensive Tillage, P0= No Fertilizer, P1= Fertilizer (200 kg ha^{-1} NPK + 1.000 kg ha^{-1} manure). CR $_{NH4}{}^{+}$: Concentration ratio; ÄNH_4^+: The amount of NH_4^+ absorbed or released in the soil. ◆ : T0P0= 0.99x - 0.185; ■ = T0P1= 1.655x - 0.476; ▲: T1P0= 0.709x - 0.193; ✕ TIP1= 1.504x - 0.583.

in the form of manure and plant litter used as organic mulch can trigger an increase the value of $PBC_{NH_4}{}^+$. It can be seen that the T0P1 treatment can increase the CEC value (Table 1) because the PBC value is directly proportional to the CEC value. The increase in CEC value is influenced by the decomposition process of organic matter, which produces humic compounds that contribute to the increase of CEC in soil colloids. This increase is also caused by an increase in the negative charge of soil colloids. The negative charge comes from the carboxyl (COOH) and hydroxyl (OH) groups present in organic compounds (Siregar 2017). The $PBC_{NH_4}{}^+$ value in the treatment without fertilization showed the lowest value, this means that the Ultisol Gedung Meneng soil needs to be fertilized. Based on the student-t-test (Table 6), the value of $PBC_{NH_4^+}$ treatment T0P0 vs T0P1, T0P0 vs T1P1, T0P1 vs. T1P0, and T1P0 vs T1P1 showed a very significant difference. The addition of fertilizer can increase $PBC_{NH_4^+}$ or NH_4^+ buffering capacity in the soil.

The PBC value is directly proportional to the K_G value (NH_4^+ adsorption capacity), so if the NH_4^+ PBC value is high, the K_G value will also be high. Following the results, the K_G value in the T0P1 treatment had the highest K_G value, and then the T1P0 treatment had the lowest K_G value (Table 5). The high K_G value in the soil indicates that the NH_4^+ given through the application of fertilizer will survive leaching, especially in soils with high rainfall (Lumbanraja *et al*. 2019) or in other words the soil ability to adsorb NH_4^+ is high. The higher the K_G value, the more soil colloids adsorb NH_4^+ compared to Ca^{2+} and Mg^{2+} cations.

Value of NH_4^+ Concentration at Equilibrium ($CR_{NH}{}^0$)

The soil NH_4^+ exchange behavior can describe the relationship between ΔNH_4^0 and $CR_{NH_4}{}^0$. The intensity value at equilibrium ($CR_{NH_4^+}$) is a value that describes the intensity of NH_4^+ in equilibrium, or the value reflects the availability of NH_4^+ for

Table 5. Effect of tillage and fertilization on the Quantity-Intensity Q/I parameter.

Treatments	$PBC_{NH4}{}^+$	$CR_{NH4}{}^0$	K_G	$\Delta NH_4{}^0$
	cmol kg^{-1} (mol $L^{-1})^{-½}$	(mol $L^{-1})^{½}$	(mol $L^{-1})^{-½}$	cmol kg^{-1}
T0P0	0.999	0.221	0.344	0.185
T0P1	1.655	0.288	0.591	0.476
T1P0	0.709	0.272	0.330	0.193
T1P1	1.504	0.388	0.590	0.583

T0= (Minimum Tillage), T1= Intensive Tillage, P0= No Fertilizer, P1= Fertilizer (200 kg ha^{-1} NPK + 1.000 kg ha^{-1} manure). $PBC_{NH_4^+}$: Potential Buffering Capacity of NH_4^+, $CR_{NH_4}{}^0$: NH_4 ratio at equilibrium, K_G: Gapon Coefficient and ΔNH_4^0: Non-specific position of ammonium.

Table 6. The student-t-test on the potential buffering capacity of $NH4^+$ (PBC_{NH4}^{+}), the non-specific position of ammonium (ΔNH_4^0), and the NH_4 ratio at equilibrium (CR_{NH4}^{0}).

Treatments	t-calculated			t-table	
	PBC_{NH4}^{+}	ΔNH_4^0	CR_{NH4}^{0}	0.05	0.01
T0P0 VS T0P1	13.452**	16.607**	16.888**	4.303	9.925
T0P0 VS T1P0	-54.136ns	2.000ns	-9.344ns		
T0P0 VS T1P1	48.031**	53.213**	34.722**		
T0P1 VC T1P0	18.305**	15.614**	1.371ns		
T0P1 VS T1P1	-3.291ns	-6.060ns	89.163**		
T1P0 VS T1P1	71.747**	50.859**	14.806**		

T0= (Minimum Tillage), T1= Intensive Tillage, P0= No Fertilizer, P1= Fertilizer (200 kg ha^{-1} NPK + 1.000 kg ha^{-1} manure). The student-t-test is performed to compare the differences between PBC_{NH4}^{+}, "NH_4^0, and CR_{NH4}^{0} in each treatment. ** = significant at $p < 0.01$, * = significant on $p < 0.05$, ns = not significant.

plants. The treatment of T1P1 had the highest $CR_{NH_4}^{0}$ value than the other treatments. The NPK fertilizer was given as an N source so that the availability of NH_4^+ increased in the soil and made it available to plants. Furthermore, adding manure can increase NH_4^+ in the soil solution because it contains many soluble NH_4^+ salts (Ramdoni and Lumbanraja 2021). Putra and Jalil (2018) stated that nitrogen availability is directly influenced by organic matter, so adding organic matter can increase the available N in the soil. Supported by Permana *et al.* (2017), tillage carried out manually by hoeing to a depth of 20-30 cm will improve soil aeration, loosen the soil, and stimulate the decomposition process by bacteria. Based on the student-t-test (Table 6), the value of $CR_{NH_4}^{0}$ treatment T0P0 vs. T0P1, T0P0 vs. T1P1, T0P1 vs. T1P1, and T1P0 vs. T1P1 show a very significant difference. Fertilization can increase the availability of soil NH_4^+ for plants.

Non-Specific Position of Ammonium (ΔNH_4^0)

The higher the value of ΔNH_4^0, the higher the NH_4^+ in the soil colloid. In the results, the T1P1 treatment had the highest ΔNH_4^0 value; then, the second highest was T0P1 treatment (Table 5). The application of NPK fertilizer and manure can increase NH_4^+ in soil colloids. Isnaini (2001) found that the content of N-NH_4^+ increases with addition of N and K fertilizer. Furthermore, NH_4^+ will be adsorbed a lot by the organic fraction of organic matter from given manure. Syaiful and Untung (2013) stated that the negative charge originating from functional groups of organic compounds could increase the chances of absorbing positive charges such as NH_4^+ in soil colloids.

The student-t-test was done to find the difference between the slope ($PBC_{NH_4}^{+}$), intercept (ΔNH_4^0), and CR_{NH}^{0} in each treatment. The resuts of student-t' test (Table 6) show that the parameters $PBC_{NH_4}^{+}$, ΔNH_4^0, and CR_{NH4}^{0} are very significantly different in the treatment of T0P0 vs. T0P1, T0P0 vs. T1P1, and T1P0 vs. T1P1. The minimum and intensive tillage with fertilization has higher NH_4^+ buffering capacity and increases the availability of N-NH_4^+ for plants than without fertilization. In addition, the given fertilization can increase NH_4^+ in soil colloids which the organic fraction will then adsorb through the applied manure and plant litter used as organic mulch (Isnaini 2001). Student-t test in treating T0P0 vs. T1P0 for each Q/I parameter showed no significant difference. The minimum and intensive tillage without fertilization did not increase $PBC_{NH_4}^{+}$, ΔNH_4^0, and $CR_{NH_4}^{0}$. At Table 5, T0P0 and T1P0 treatments had the lowest Q/I parameter values compared to other treatments. Based on the student-t' test, T0P1 vs. T1P0 showed a significant difference in the parameters $PBC_{NH_4}^{+}$ and ΔNH_4^0 except for the $CR_{NH_4}^{0}$ parameter. The treatment does not significantly increase ammonium in the soil solution.

Correlation Between Soil and Plant Analysis Parameters and Q/I Parameter

The results of correlation test are in Table 7, it is shown that CR_{NH4}^{0} is significantly correlated with plant N and P uptake. CR_{NH4}^{0} is NH_4^+ in a balance state, or the value reflects the availability of NH_4^+ for plants, so the more NH_4^+ in the soil, the N uptake by plants will also increase. Kaya (2018) stated that the increase in plant N uptake correlated to soil N availability.

Table 7. Correlation test between ΔNH_4^0, PBC_{NH4}^+, NH_4dd, KTK, CR_{NH4}^0, K_G, N and C uptake by mung bean plant.

No	Correlations	Linear Equation	r
1	ΔNH_4^0 Vs. transported N	y = 4.729x + 9.987	0.82^{ns}
2	PBC_{NH4}^+ Vs. transported N	y = 9.815x + 9.868	0.62^{ns}
3	NH_4dd Vs. transported N	y = 1.634x + 21.21	0.02^{ns}
4	K_G Vs. N transported N	y = 38.46x + 3.973	0.80^{ns}
5	CR_{NH4}^0 Vs. transported N	y = 96.49x – 6.388	0.96^{*}
6	KTK Vs. transported N	y = -3.158x + 38.23	0.30^{ns}
7	ΔNH_4^0 Vs. harvested C	y = 202.8x + 1246	0.83^{ns}
8	PBC_{NH4}^+ Vs. harvested C	y = 504.9x + 1139	0.66^{ns}
9	NH_4dd Vs. harvested C	y = 605.8x + 1531	0.12^{ns}
10	K_G Vs. harvested C	y = 1822.x + 908.4	0.79^{ns}
11	CR_{NH4}^0 Vs. harvested C	y = 4719.x + 374.5	0.97^{**}
12	KTK Vs. harvested C	y = -15.26x + 1833	0.003^{ns}
13	ΔNH_4^0 Vs. production	y = 0.031x + 1.378	0.84^{ns}
14	PBC_{NH4}^+ Vs. production	y = 0.425x + 0.938	1.00^{**}
15	NH_4dd Vs. production	y = 2.094x + 0.685	0.77^{ns}
16	K_G Vs. production	y = 1.245x + 0.878	$0.97z^{**}$
17	CR_{NH4}^0 Vs. production	y = 1.596x + 0.989	0.59^{ns}
18	KTK Vs. production	y = 0.140x + 0.726	0.84^{ns}

r = correlation coefficient; ** = highly significant at 1% level; * = significant at 5% level; ns = not significant

Table 7 shows that PBC_{NH4}^+ and K_G are significantly correlated with mung bean yields. The value of PBC_{NH4}^+ is directly proportional to the K_G value, where PBC_{NH4}^+ is the ability of the soil to retain NH_4^+ in the soil solution so that plants can absorb it and the high K_G indicates that NH_4^+ will survive from leaching. So that, the more N and other nutrients are available, the more that can be absorbed by plants. Plant nutrients must be available to meet all plant needs (Supramudho *et al.* 2012) so that the provision of nutrients to the soil through the fertilization process can affect the supply of nutrients to plants to increase the growth process and yields of mung bean plants.

CONCLUSIONS

The application of NPK fertilizer 200 kg ha^{-1} and manure 1000 kg ha^{-1} significantly affected the yields and plant N and P uptake of mung bean, while intensive tillage had a very significant effect in increasing the plant N uptake of mung bean compared to minimum tillage. Moreover, minimum tillage and fertilization (NPK 200 kg ha^{-1} and manure 1000 kg ha^{-1}) affected the increasing of Q/I parameters (PBC_{NH4}^+, K_G, $CR_{NH_4}^0$, and ΔNH_4^0). Subsequently, Q/I ($CR_{NH_4}^0$) was significantly correlated with plant N and C uptake of mung bean; while, $PBC_{NH_4}^+$ and K_G were significantly correlated with mung bean yields.

REFERENCES

Akbar FT, M Utomo and Sarno. 2016. Pengaruh sistem olah tanah dan pemupukan nitrogen jangka panjang terhadap efisiensi serapan nitrogen pada tanaman padi gogo (*Oryza Sativa* L.) tahun ke-27 di lahan Politeknik Negeri Lampung. *J Agrotek Tropika* 4: 75-80. (in Indonesian)

Alavan A, R Hayati and E Hayati. 2015. Pengaruh pemupukan terhadap pertumbuhan beberapa varietas padi gogo (*Oryza sativa L.*). *J Floratek* 10: 61-68. (in Indonesian)

Alves LA, TL Tiecher, JPM Flores, D Filippi, LC Gatiboni, C Bayer, OH de Castro Pias, AA Marquez, V Bordignon, RZ Goulart and T Tiecher. 2021. Soil chemical properties and crop response to gypsum and limestone on a coarse-textured Ultisol under no-till in the Brazilian Pampa biome. *Geoderma Regional 25*: p.e00372.

Beckett PHT. 1964. Studies on soil potassium II. The 'immediate' Q/I of labile potassium in the soil. *J Soil Sci* 15: 9-23.

Deliyana D, J Lumbanraja, Sunyoto and M Utomo. 2016. Pengaruh pengolahan tanah terhadap pertumbuhan, produksi dan serapan hara ubikayu (*Manihot Esculenta Crantz*) pada periode tanam ke-2 di Gedung Meneng Bandar Lampung. *J Agrotek Tropika* 4: 233-239.

Evangelou VP and RE Phillips. 1987. Sensitivity Analysis on the Comparison Between the Gapon and Vanselow Exchange Coefficients. *Soil Sci Soc Am J* 51: 1473-1479.

Forghani A and A Sabouri. 2020. Evaluating the Correlation of Soil Characteristics with Potassium Q/I Curve Parameters in Some Calcareous Soils of Lorestan Province. *J Water Soil* 34: 379-391.

Hale SE, NL Nurida, JM Jubaedah, S Erlend, S Ludovica, Samuel, J Stephen,T Sarasadat and C Gerard. 2020. The effect of biochar, lime, and ash on maize yield in a long-term field trial in a Ultisol in the humid tropics. *Sci Total Environ* 719: 137455.

Harahap FS, I Arman, N Harahap, FA Syawaluddin and RF Yana. 2022. Provision of chicken manure and urea fertilizer on the chemical characteristics of ultisol soil in Bilah Barat District. *Int J Sci Environ* 2: 98-103.

Hastuti DP, S Supriyono and S Hartati. 2018. Pertumbuhan dan hasil kacang hijau (*Vigna radiata*, L.) pada beberapa dosis pupuk organik dan kerapatan tanam. *J Sustain Agr* 33: 89-95.

Isnaini S. 2001. Dekomposisi bahan organik, nisbah q/i kalium, kandungan hara N dan K tanah serta serapannya oleh padi (*Oryza sativa L.*) akibat pengolahan tanah yang dipupuk kalium dan nitrogen pada tanah sawah. [Disertasi]. Universitas Padjadjaran, Jawa Barat. (in Indonesian).

Isnaini S. 2005. Kandungan amonium dan kalium tanah serapannya serta hasil padi pada akibat perbedaan pengolahan tanah yang dipupuk nitrogen dan kalium pada tanah sawah. *J Ilmu-ilmu Pertanian Indonesia* 7: 23-24. (in Indonesian).

Kaya E. 2018. Pengaruh kompos jerami dan pupuk NPK terhadap N-tersedia tanah, serapan-N, pertumbuhan, dan hasil padi sawah (*Oryza Sativa* L). *Agrologia* 2: 43-50. (inIndonesian)

Lumbanraja J, M Utomo and Fitriati. 1993. Karakteristik jerapan amonium tanah pada tiga perlakuan pengolahan tanah dan pemupukan nitrogen. *Prosiding Seminar Nasional IV: Budidaya Pertanian Olah Tanah Konservasi.* pp: 1-10. (in Indonesian).

Lumbanraja J, RH Amalia, R Hasibuan, W Agustina, CP Satgada, E Zulkarnain and TR Awang. 2019. Perilaku pertukaran amonium dan produksi tebu (*Saccharum officinarum* L.) yang dipupuk anorganik NPK dan organik pada pertanaman tebu di tanah ultisol Gedung Meneng. *J Trop Upland Res* 1: 1-18. (in Indonesian).

Lumbanraja J, H Norvpriansyah and M Utomo. 2020. Perilaku Pertukaran Kalium (K) dalam Tanah, K Terangkut serta Produksi Jagung (Zea mays L.) Akibat Olah Tanah dan Pemupukan di Tanah Ultisol Gedung Meneng pada Musim Tanam Ketiga. *J Trop Upland Res* 2: 1-15. (in Indonesian).

Lumbanraja J. 2017. *Kimia Tanah dan Air: Prinsip Dasar dan Lingkungan*. CV. Anugrah Utama Raharja. Lampung. 297 p. (in Indonesian).

Lumbanraja J and VP Evangelou. 1994. Adsorption-desorption of potassium and ammonium at low cation concentrations in three Kentucky sub soil. *Soil Science* 157: 269-278.

Mulyani A, A Rachman and A Dairah. 2010. Penyebaran lahan masam, potensi dan ketersediaannya untuk pengembangan pertanian. *Prosiding Simposium Nasional Pendayagunaan Tanah Masam.* Pusat Penelitian dan Pengembangan Tanah dan Agroklimat. Bogor. pp: 23-34. (in Indonesian).

Munawar A. 2011. *Kesuburuan Tanah dan Nutrisi Tanaman*. IPB Press. Bogor. 240 p. (in Indonesian).

Ninh HT, HTT Hoa, PQ Ha and JE Dufey. 2009. Potassium buffering capacity of sandy soils from Thua Thien Hue Province, Central Vietnam, as related to soil properties. *Communic Soil Sci Plant Analysis* 40: 3294-3307.

Nyiraneza J and S Snapp. 2007. Integrated Management of Inorganic and Organic Nitrogen and Efficiency in Potato Systems. *Soil Sci Soc Am J* 71: 1508-1515.

Offiong NAO, OK Fatunla, JP Essien, C Yang and J Dong. 2021. Soil washing of total petroleum and polycyclic aromatic hydrocarbons from crude oil-contaminated ultisol using aqueous extracts of waterleaf. *Environ Technol* 2021: 1961875. doi: https://doi.org/10.1080/09593330.2021.1961875.

Oktavia D. 2006. Perubahan karbon organik dan nitrogen total tanah akibat perlakuan pupuk organik pada budidaya sayuran organik. [Skripsi]. IPB. Bogor. (in Indonesian).

Peng XYLL, LL Ye, CH Wang, H Zhou and B Sun. 2011. Temperature-and duration-dependent rice straw-derived biochar: Characteristics and its effects on soil properties of a ultisol in southern China. *Soil Till Res* 112: 159-166.

Pan XY, RK Xu, JN Nkoh, HL Lu, H Hua and P Guan. 2021. Effects of straw decayed products of four crops on the amelioration of soil acidity and maize growth in two acidic Ultisols. *Environ Sci Pollut R* 28: 5092-5100.

Permana IBPW, IWD Atmaa and IW Narka. 2017. Pengaruh sistem pengolahan tanah dan penggunaan mulsa terhadap populasi mikroorganisme dan unsur hara pada daerah rhizosfer tanaman kedelai (*Glycine Max L.*). *J Agroekoteknologi Tropika* 1: 41-51. (in Indonesian).

Septiyana H, LR Widowati, AF Siregar and A Samsun. 2021. The use of soil ameliorants and fertilizers to increase the yields of rice and maize in ultisols Lampung, Indonesia. *IOP Conf Series: Earth and Environmental Science* 648: 012198.

Singh NK, GC Banik and A Ghosh. 2019. Spatial Variation of Potassium Quantity/Intensity Relationships and Buffering Capacity of Some Entisols of the Himalayan Floodplain. *J Indian Soc Soil Sci* 67: 321-328.

Sparks DL. 1996. Methods of soil analysis. Soil science society of Amerika Inc. United Stated of Amerika. 1309 p.

Supramudho GN, J Syamsiah and S Mujiono. 2012. Efisiensi serapan nitrogen dan hasil tanaman padi pada berbagai imbangan pupuk kandang puyuh dan pupuk anorganik di lahan sawah Palur, Sukoharjo, Jawa Tengah. *Bonorowo Wetlands* 2: 11-18. (in Indonesian).

Prasetyo BH, N Suharta, H Subagyo and H Hikmatullah. 2001. Chemical and mineralogical properties of Ultisols of Sasamba area, East Kalimantan. *Indonesian J Agricultural Science* 2: 37-47.

Prasetyo B and D Suriadikarta. 2006. Karakteristik, potensi, dan teknologi pengelolaan tanah ultisol untuk pengembangan pertanian lahan kering di Indonesia. *J Litbang Pertanian* 25: 39-47. (in Indonesian).

Putra I and M Jalil. 2018. Pengaruh bahan organik terhadap beberapa sifat kimia tanah pada lahan kering masam. *J Agrotek Lestari* 1: 27-34. (in Indonesian).

Ramdoni T and J Lumbanraja. 2021. Pengaruh besi (Fe) dan bahan organik terhadap perilaku pertukaran amonium pada tanah ultisol Natar. *J Tropical Upland Resources* 3: 22-35.

Siregar P. 2017. Pengaruh pemberian beberapa sumber bahan organik dan masa inkubasi terhadap beberapa aspek kimia kesuburan tanah ultisol. *J Online Agroekoteknologi* 5: 256-264. (in Indonesian).

Subagyo H, N Suharta and AB Siswanto. 2004. Tanah-tanah pertanaian di Indonesia. In: A Adimihardja, LI Amien, F Agus and D Djaenudin (eds.). *Sumberdaya Lahan Indonesia dan Pengelolaannya. Pusat Penelitian dan Pengembangan Tanah dan Agroklimat*. Bogor, pp. 21-66. (in Indonesian).

Sunarlim N, WH Adil, Sahwan and F Schuchardt. 1999. The effect of three different nitrogen sources on red pepper and tomato cropping pattern. In: C Ginting, A Gafur, FX Susilo, AK Salam, Erwanto, A. Karyanto, SD Utomo, M Kamal, J Lumbanraja and Z Abidin (eds.). *Proceeding International Seminar*: *Toward Sustainable Agriculture in Humid Tropics Facing the 21st Century*. UNILA, Bandar Lampung, Indonesia, pp. 322-321.

Syahputra E, Fauzi and Razali. 2015. Karakteristik sifat kimia sub grup tanah ultisol di beberapa wilayah Sumatera Utara. *J Agroekoteknologi* 4: 1796-1803. (in Indonesian).

Syaiful A and S Untung. 2013. *Kimia Tanah*. Institut Pertanian Bogor Press. Bogor. 212 p. (in Indonesian).

Tan KH. 1982. Principle of soil chemistry. Marce; Dekker Inc. New York. 112 p.

Utomo M, Sudarsono, B Rusman, T Sabrina, J Lumbanraja and Wawan. 2016. *Ilmu Tanah Dasar-dasar dan Pengelolaan*. Kencana. Jakarta. 434 p. (in Indonesian).

Wang FL and AK Alva. 2000. Ammonium adsorption and desorption in sandy soils. *Soil Sci Soc Am J* 64: 1669-1674.

Wang JJ, DL Harrell and PF Bell. 2004. Potassium buffering characteristics of three soils low in exchangeable potassium. *Soil Sci Soc Am J* 68: 654-661.

Widjajaseputra AI, TEW Widyastuti and CY Trisnawati. 2019. The potency of mung bean with different soaking times as a protein source for breastfeeding women in Indonesia. *Food Research* 3: 501-505.

Zhao WR, JY Li, J Jiang, HL Lu, ZN Hong, W Qian, RK Xu, KY Deng and P Guan. 2020. The mechanisms underlying the reduction in aluminum toxicity and improvements in the yield of sweet potato (*Ipomoea batatas* L.) after the organic and inorganic amendment of an acidic ultisol. *Agr Ecosyst Environ* 288: 106716.