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Full Length Research Paper

Effectiveness of liquid organic-nitrogen fertilizer in enhancing nutrients uptake and use efficiency in corn (*Zea mays*)

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The ever increasing price of nitrogenous (N) fertilizers coupled with the deleterious effects of imbalanced N fertilizers on the environment necessitates the enhancement of N use efficiency of plants. The objectives of this study were to: (1) Evaluate the uptake of selected nutrients due to application of liquid organic-N fertilizers and (2) determine the efficiency of the formulated fertilizers in *Zea mays* cultivation in an acid soil. Liquid organic-N fertilizers with different sources of humic molecules were evaluated. The treatments were applied at 10 and 20 days after sowing (DAS) of corn. Plant and soil samples were collected at 54 DAS (tasseling stage) and analyzed for N, P, K, Ca, Mg and Na. The use of liquid organic-N fertilizer increased N content in leaf, stem and roots. The fertilizer with Fulvic acids (FA) increased N uptake and use efficiency. It also improved exchangeable Ca and Mg in soil solution. No significant difference was observered for soil exchangeable K. It can be concluded that the use of organic substances could enhance N uptake and N use efficiency of corn.

Key words: Humic acids, fulvic acids, liquid fertilizers, nitrogen use efficiency, nutrient uptake, corn.

INTRODUCTION

Unbalanced and prolonged use of inorganic fertilizers such as ammonium sulphate causes soil fertility decline because they significantly reduce soil pH which in turn reduces crop productivity. Excessive use of inorganic fertilizers has also created a number of environmental problems with the most serious one being the contributions of phosphate and nitrogen compounds in water and the atmosphere. For instance, nitrate and phosphorus eutrophication has been linked to unbalanced use of inorganic fertilizers. It is also reported that between 1 to 60% N of nutrient based fertilizers such as urea is lost through ammonia volatilization (Prasertsak et al., 2001; Cai et al., 2002).

Organic substances such as humic substances are made up of humin, humic and fulvic acids (Tan, 2003). These organic compounds have the capability of increasing N, P, K, Ca, Mg and Na availability in soils by producing soil organic carbon (SOC), forming organophosphate complexes, increasing cation exchange capacity (CEC), act as anion replacement of $H_2PO_4^-$ as well as coating materials for Fe/Al oxides (Tan, 2003). The sole use of organic fertilizers is not economically viable but the continued use of inorganic fertilizers in the light of the ever increasing cost of inorganic fertilizers with their undesirable effect on the environment need careful consideration (Heffer and Prud'homme, 2008). The use of inorganic fertilizers alone is being replaced with mixture of inorganic and organic fertilizers, where better crop yield could be obtained without compromising the quality of the environment (Leite et al., 2007). Nitrogen use efficiency from an inorganic fertilizer

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Abbreviations: DAS, Days after sowing; **SOC,** soil organic carbon; **CEC,** cation exchange capacity; **HA,** humic acid; **FA,** fulvic acids.

has been reported to be low for corn (Cassman et al., 2002). Thus, mixture of inorganic and organic fertilizers seems to be the most appropriate approach for the current needs. As an example, the use of 4 t ha^{-1} of farmyard manure reduced inorganic N consumption from 120 to 60 kg N ha^{-1} (Shah and Ahmad, 2006).

Liquid form of fertilizers is more uniform in mixture of nutrients. This enhances nutrients availability due to the presence of water. Since there is a high relationship between water content and nutrients availability, the use of liquid organic fertilizers may be an efficient way of enhancing nutrient uptake. Previous data showed that, uptake of P by corn increased more rapidly than the rate of corn growth when additional water was applied to mobilize the nutrients from one place to another (Mackay and Barber, 1985). This observation was also true for K. However, too much water reduces its absorption due to lack of oxygen in the soil body. This is because, plants normally absorb K, N, and P against a concentration gradient that requires their roots to expend considerable energy due to oxidation of sugars transported from the tops of the plants to the roots (Troeh and Thompson, 2005). The objectives of this study were to: (1) Evaluate the uptake of nutrients due to application of liquid organic-N fertilizers and (2) determine the efficiency of the formulated fertilizers.

MATERIALS AND METHODS

Saprists (peat) was taken from Kuala Tatau, Sarawak, Malaysia at 0 to 25 cm depth. This area is located on 3°05'12'N 112°47'05E with annual rainfall, relative humidity and temperature of 3586 mm, 67% and 28°C, respectively. The soil was air dried and sieved to pass through 2 mm sieve before it was oven dried at 60°C for 24 h to remove water. It was then stored in an air tight container for further analysis. It must be noted that, the purpose of using peat soil in this study was to isolate humic acids (for production of liquid-organic fertilizer) from it as it contains substantial amount of these acids. The mineral used in this study served as the growth medium of the test crop. The mineral soil *(Typic paleudults)* used was also sampled at 0 to 25 cm depth from an undisturbed area at Universiti Putra Malaysia, Bintulu Campus, Sarawak. This area is located on 3°12'N 113°02'E with annual rainfall, relative humidity and temperature of 4928 mm, 83% and 27°C, respectively. The mineral soil was also air dried at room temperature and sieved to pass through 2 mm sieve before analysis. It was analyzed for pH (water and KCl) (Peech, 1965), cation exchange capacity exchangeable cations (K, Ca and Mg) (Knudsen et al., 1982; Lanyon and Heald, 1982), total N (Bremner, 1965), total organic carbon, organic matter (Cheftetz et al., 1996) and bulk density (Blake and Hartge, 1986).

Prior to fertilizer formulation, humic acid (HA) from *Saprists* (containing about 10% HA) was isolated using the modified method of Susilawati et al. (2007). The isolation of the HA produces HA, fulvic acids (FA) or even mixture of humic and fulvic acids (before acidification). These fractions were used to prepare liquid fertilizers by adding 50 ml or as needed (to bring the volume up to 50 ml in liquid FA or mixture of HA and FA) of distilled water. Granular urea (46% N) was used as a source of N in this study. A ratio of 4:50 (N: solution) was used for all of the fertilizer preparation.

A 7.5 kg of the air dried mineral soil only (based on the bulk density of the soil) was weighed into plastic pots measuring 27 cm x 18 cm. Eight treatments were prepared for evaluation in this study. They were: (a) Liquid urea (T1), (b) solid urea (T2), (c) urea + liquid HA (T3), (d) urea + liquid FA (T4), (e) urea + liquid mixture of acidified HA + FA (T5), (f) urea + liquid mixture of un-acidified HA + FA (T6), (g) liquid ammonium sulphate [$(NH_4)_2SO_4$] (T7) and (h) control (no fertilizer) (T0). The experiment was conducted in a randomized complete block design (RCBD) with three replications.

With the exception of control, the same rate of N, P and K based on nutrients requirement of the test crop that is, corn (330.4 kg ha^{-1} urea; 121.6 kg ha^{-1} TSP; 107.2 kg ha^{-1} MOP) was used. The fertilizers were applied 10 and 28 days after sowing (DAS) with same rate. The treatments were surface applied. The plants were monitored until 54 DAS, which is, tasselling stage (maximum growth stage achieved before going to productive stage) before harvest. The plants were watered daily. At 54 DAS, the soil in the pots was sampled and analyzed for pH (Peech, 1965), exchangeable NH_4^+ and available NO_3^- (Keeney and Nelson, 1982).

At 54 DAS, the plants were also harvested and partitioned into leaves, stem and roots. These parts were washed with running tap water followed by distilled water to remove any contamination or dust particles. The plant parts were oven dried at 60°C to constant weight and weighed using a digital balance. Micro-Kjeldahl method (Bremner, 1965) was used to analyze total N in plant samples, whilst the dry ash method was used to analyze K, Ca and Mg. Nutrient use efficiency was calculated based on the following formula (Pomares-Gracia and Pratt, 1987):

$$\% \text{ Fertilizer nutrient recovery} = \frac{(TNF) - (TNU)}{R} \times 100$$

Where, TNF = Total plant nutrient uptake from fertilized soil, TNU = total plant nutrients uptake from unfertilized soil, and R = rate of fertilizer nutrients applied.

Analysis of variance was used to test treatment effect, while means of treatments were compared using Duncan's new multiple range test (DNMRT). Statistical analysis system version 9.1 was used for the statistical analysis.

RESULTS

The pH of the mineral soil were 4.29 (pHwater) and 3.57 (pHKCl). The bulk density, total N, total organic carbon and organic matter were 1.548 g cm-3, 0.34, 3.35 and 5.78%, respectively. The cation exchange capacity of the mineral soil was 24.5 cmol (+) kg^{-1} soil and the concentrations of K, Ca and Mg were 0.18, 2.26 and 2.98 cmol (+) kg^{-1}, respectively.

The dry matter yield of the test crop (leaves, stem and roots) at 54 DAS is presented in Table 1. Regardless of the plant part, there was no significant difference between liquid urea (T1) and urea + liquid mixture of acidified HA + FA (T5) and (f) urea + liquid mixture of un-acidified HA + FA (T6). However, the dry matter production of liquid urea (T1) and urea + liquid mixture of acidified HA + FA (T5) and (f) urea + liquid mixture of un-acidified HA + FA (T6) were superior to those of no fertilizer (T0) and liquid ammonium

Table 1. Dry weight of leaves, stems and roots at 54 DAS.

Treatment	Dry matter production (g)		
	Leaf	Stem	Root
T0	05.77^{c}	04.22^{b}	02.93^{b}
T1	43.98^{a}	55.15^{a}	24.62^{a}
T2	43.13^{a}	55.47^{a}	27.07^{a}
T3	36.10^{a}	53.28^{a}	18.20^{a}
T4	44.01^{a}	47.37^{a}	19.03^{a}
T5	38.06^{a}	46.78^{a}	22.11^{a}
T6	43.37^{a}	54.23^{a}	19.88^{a}
T7	18.06^{b}	10.97^{b}	5.53^{b}

Different letters indicate significant difference between means using Duncan's new multiple range test (DNMRT) at p = 0.05.

Table 2. Nitrogen (N), phosphorus (P) and potassium (K) contents of plant parts at 54 DAS.

Treatment	Leaf	Stem	Root
Concentration of N (%)			
T0	0.650^{d}	0.567^{e}	0.733^{c}
T1	1.950^{bc}	1.900^{bc}	1.783^{b}
T2	2.000^{bc}	1.650^{bcd}	1.617^{b}
T3	2.400^{ab}	1.567^{cd}	1.483^{b}
T4	2.583^{a}	2.300^{a}	2.183^{a}
T5	2.667^{a}	1.817^{bcd}	1.683^{b}
T6	2.417^{ab}	1.467^{d}	1.633^{b}
T7	1.800^{c}	1.950^{b}	1.783^{b}
Concentration of P (%)			
T0	0.103^{c}	0.080^{b}	0.063^{d}
T1	0.193^{a}	0.160^{a}	0.083^{c}
T2	0.193^{a}	0.150^{a}	0.110^{ab}
T3	0.197^{a}	0.163^{a}	0.087^{c}
T4	0.193^{a}	0.173^{a}	0.123^{a}
T5	0.203^{a}	0.177^{a}	0.100^{bc}
T6	0.183^{a}	0.153^{a}	0.100^{bc}
T7	0.143^{b}	0.183^{a}	0.120^{a}
Concentration of K (%)			
T0	2.193^{a}	1.653^{a}	1.700^{a}
T1	1.640^{b}	1.077^{cd}	0.647^{d}
T2	1.613^{b}	1.170^{bc}	0.700^{d}
T3	1.713^{b}	1.187^{bc}	0.750^{d}
T4	1.693^{b}	1.277^{b}	0.930^{bc}
T5	1.477^{b}	1.123^{bcd}	0.800^{cd}
T6	1.723^{b}	1.007^{cd}	0.790^{cd}
T7	1.630^{b}	0.937^{d}	0.990^{b}

Different letters indicate significant difference between means using Duncan's new multiple range test (DNMRT) at p = 0.05.

sulphate ($(NH_4)_2SO_4$) (T7).

For leaves, T4 and T5 showed the highest concentration of N compared with other treatments (Table 2). It was followed by T3 and T6. However, T3 and T6 did not show any statistical difference when compared with T1 and T2. For roots and stem, the highest N concentration was recorded for T4. In the case of stem, T6 recorded the lowest N concentration compared with the organically based-N fertilizers. The concentrations of N for the liquid organic-N fertilizers in stem and roots were generally higher when compared with T0 or similar when compared with T1 and T2 or lower when compared with T7 (stem) (Table 2).

With the exception of T7 and T0, the concentration of P in leaves was not different for all the treatments (Table 2). Similar result was recorded for stem. For roots, T4 recorded highest P concentration. However, it was not different when compared with those of T2 and T7. With the exception of T7, the concentration of K in leaves, stem and roots were not statistically different (Table 2). All the treatments significantly reduced K concentration in leaves, stem and roots. The liquid organic-N fertilizers formulated in this study did not increase the concentrations of Ca, Mg and Na in plant tissue (Tables 3 to 5).

The uptake of N in leaves was superior for T4 treatment (Table 6). However, it was not statistically different when compared with T5 and T6. These three treatments were effective in enhancing N uptake in leaves. The other liquid organic-N fertilizers did not show any significant difference in N uptake compared to T1 and T2. However, T3, T4, T5 and T6 gave higher N uptake when compared with T0 and T7. In the case of stem, the uptake of N was highest for T4 (Table 6). However, the result was not significantly different when compared with T1. Other liquid organic-N fertilizer treatments recorded lower N uptake when compared with T1 and T2. For roots, lower N uptake was recorded when the soil was treated with T3 and T6. These two treatments recorded lower N uptake when compared with T1, T2 and T5. In general, the uptake of N due to T1, T2, T3, T4, T5 and T6 were higher when

Table 3. Calcium (Ca), magnesium (Mg) and sodium (Na) contents in leaves of corn at 54 DAS.

Treatment	Concentration (%)		
	Ca	Mg	Na
T0	0.170[b]	0.133[c]	0.040[a]
T1	0.337[a]	0.187[b]	0.040[a]
T2	0.380[a]	0.253[a]	0.047[a]
T3	0.347[a]	0.217[ab]	0.040[a]
T4	0.267[ab]	0.180[b]	0.043[a]
T5	0.330[a]	0.207[b]	0.043[a]
T6	0.317[a]	0.200[b]	0.040[a]
T7	0.297[a]	0.213[ab]	0.043[a]

Different letter indicate significant difference between means using Duncan's new multiple range test (DNMRT) at p = 0.05.

Table 4. Calcium (Ca), magnesium (Mg) and sodium (Na) contents in stem of corn at 54 DAS.

Treatment	Concentration (%)		
	Ca	Mg	Na
T0	0.097[b]	0.150[d]	0.043[ab]
T1	0.167[a]	0.197[c]	0.040[ab]
T2	0.190[a]	0.230[a]	0.040[ab]
T3	0.163[a]	0.203[abc]	0.043[ab]
T4	0.177[a]	0.227[ab]	0.040[ab]
T5	0.150[a]	0.200[bc]	0.043[ab]
T6	0.170[a]	0.197[c]	0.037[b]
T7	0.100[b]	0.143[d]	0.047[a]

Different letters indicate significant difference between means using Duncan's new multiple range test (DNMRT) at p = 0.05.

Table 5. Calcium (Ca), magnesium (Mg) and sodium (Na) contents in roots of corn at 54 DAS.

Treatment	Concentration (%)		
	Ca	Mg	Na
T0	0.020[d]	0.103[c]	0.067[e]
T1	0.057[a]	0.130[b]	0.147[b]
T2	0.057[a]	0.137[b]	0.110[d]
T3	0.040[c]	0.133[b]	0.130[c]
T4	0.043[bc]	0.177[a]	0.180[a]
T5	0.043[bc]	0.140[b]	0.157[b]
T6	0.053[ab]	0.137[b]	0.130[c]
T7	0.033[c]	0.123[b]	0.127[c]

Different letters indicate significant difference between means using Duncan's new multiple range test (DNMRT) at p = 0.05.

Table 6. Nitrogen uptake in different plant parts at 54 DAS.

Treatment	N uptake (mg plant^{-1})		
	Leaf	Stem	Root
T0	12.67[d]	7.67[e]	7.33[e]
T1	286.00[b]	349.00[ab]	146.33[a]
T2	287.33[b]	305.33[bc]	145.67[a]
T3	289.00[b]	278.33[c]	90.00[c]
T4	378.67[a]	363.00[a]	138.67[a]
T5	338.00[ab]	283.00[c]	124.00[ab]
T6	349.33[ab]	265.00[c]	108.00[bc]
T7	108.00[c]	71.33[d]	32.67[d]

Different letters indicate significant difference between means using Duncan's new multiple range test (DNMRT) at p = 0.05.

compared with T0. T4 was the most effective treatment in enhancing N uptake in leaves, stem and roots.

The uptake of P in leaves and stem followed a similar trend of P concentration (Table 7). No significant difference was observed for all the treatments except for T7. For roots, the uptake of P was superior for T2. Other treatments gave no effect. The K uptake in leaves was high for T1, T2, T3, T4 and T6 (Table 8). All the five treatments showed higher K uptake when compared with T5. As compared to T0 and T7, the other treatments recorded higher K uptake. T3 and T5 showed lowest value in uptake of K in roots and stem, respectively. The uptake of K for T1, T2, T3, T4, T5 and T6 were not significantly different but they were higher when compared with T0 and T7.

With the exception of T0 and T7, the uptake of Ca in leaves was statistically similar to the other treatments (Table 9), whilst T2 showed the highest uptake of Mg. T5 reduced Ca and Mg uptake in stem (Table 10) and increased the uptake of Na in roots (Table 11). T3 reduced the uptake of Na and Ca in leaf (Table 9) and roots (Table 11), respectively. Similar result was observed for T6 (Na uptake in roots). The use of either urea or liquid organic-N fertilizers increased the uptake of Ca, Mg and Na in leaves, stem and roots (Tables 9 to

Table 7. Phosphorus uptake in different plant parts at 54 DAS.

Treatment	P uptake (mg plant^{-1})		
	Leaf	Stem	Root
T0	1.93^{c}	1.13^{c}	0.63^{e}
T1	28.70^{a}	29.67^{a}	6.83^{b}
T2	27.73^{a}	27.27^{a}	9.87^{a}
T3	23.60^{a}	29.00^{a}	5.10^{c}
T4	27.90^{a}	27.43^{a}	7.60^{b}
T5	25.87^{a}	27.60^{a}	7.17^{b}
T6	26.50^{a}	27.80^{a}	6.60^{b}
T7	8.50^{b}	6.73^{b}	2.20^{d}

Different letter indicate significant difference between means using Duncan's new multiple range test (DNMRT) at p = 0.05.

Table 8. Potassium uptake in different plant parts at 54 DAPS.

Treatment	K uptake (mg plant^{-1})		
	Leaf	Stem	Root
T0	42.00^{d}	23.33^{d}	16.67^{d}
T1	240.00^{a}	198.00^{abc}	53.33^{abc}
T2	231.67^{ab}	216.33^{a}	63.00^{a}
T3	206.33^{ab}	210.33^{a}	45.33^{c}
T4	248.33^{a}	202.00^{ab}	59.00^{ab}
T5	187.33^{b}	175.33^{c}	59.00^{ab}
T6	249.00^{a}	182.33^{bc}	51.67^{bc}
T7	98.00^{c}	34.00^{d}	18.33^{d}

Different letters indicate significant difference between means using Duncan's new multiple range test (DNMRT) at p = 0.05.

Table 9. Calcium (Ca), magnesium (Mg) and sodium (Na) uptake in leaves at 54 DAP.

Treatment	Uptake in leaf (mg plant^{-1})		
	Ca	Mg	Na
T0	3.23^{b}	2.50^{d}	0.70^{e}
T1	49.87^{a}	27.57^{b}	6.07^{abc}
T2	55.00^{a}	36.13^{a}	7.03^{a}
T3	42.00^{a}	26.07^{b}	4.83^{c}
T4	39.10^{a}	26.20^{b}	6.50^{ab}
T5	41.67^{a}	26.07^{b}	5.20^{bc}
T6	45.73^{a}	29.10^{b}	5.60^{abc}
T7	17.77^{b}	12.80^{c}	2.63^{d}

Different letters indicate significant difference between means using Duncan's new multiple range test (DNMRT) at p = 0.05.

Table 10. Calcium (Ca), magnesium (Mg) and sodium (Na) uptake in stem at 54 DAS.

Treatment	Uptake (mg plant^{-1})		
	Ca	Mg	Na
T0	1.37^{d}	2.17^{d}	0.63^{c}
T1	30.90^{ab}	35.80^{b}	7.37^{a}
T2	35.03^{a}	42.37^{a}	7.50^{a}
T3	29.07^{abc}	36.20^{b}	7.40^{a}
T4	28.10^{bc}	35.30^{b}	6.67^{a}
T5	23.30^{c}	30.83^{c}	6.76^{a}
T6	30.43^{ab}	35.30^{b}	6.63^{a}
T7	3.60^{d}	5.20^{d}	1.63^{b}

Different letters indicate significant difference between means using Duncan's new multiple range test (DNMRT) at p = 0.05.

11). In the case of leaves, T4, T5 and T6 significantly improved N use efficiency by 34, 19 and 23%, respectively (Table 12). T3 did not show any difference when compared with T1 and T2. Phosphorus and K uptake efficiency were not different for all the treatments. The use of HA (T3) or both (T5 and T6) reduced N use efficiency in stem. It was contrary to T4, which recorded the highest N use efficiency in stem. Phosphorus and K use efficiency in stem was similar to those of leaves. Different results were obtained for roots. T1, T2 and T4 recorded the highest N use efficiency. They were followed by T5 and T6.

DISCUSSION

The chemical properties of the soil outlined above are consistent with those reported by Paramananthan (2000). The low amount of humic molecules used (either HA or FA) could be one of the reasons for the insignificant results recorded for the dry matter production for HA and FA treatments. According to Tan and Nopamornbodi (1979), moderate amount of HA is needed to promote root and shoot growth and development in corn plants. It has been observed that addition of N to P fertilizer enhances P uptake in plants (Miller,

Table 11. Calcium (Ca), magnesium (Mg) and sodium (Na) uptake in roots at 54 DAS.

Treatment	Uptake (mg plant^{-1})		
	Ca	Mg	Na
T0	0.20^{d}	0.97^{f}	0.63^{e}
T1	4.70^{a}	10.70^{b}	11.73^{a}
T2	4.90^{a}	12.37^{a}	10.03^{b}
T3	2.40^{c}	8.20^{d}	7.93^{c}
T4	2.77^{bc}	11.17^{ab}	11.40^{a}
T5	3.20^{bc}	10.27^{bc}	11.57^{a}
T6	3.43^{b}	9.00^{cd}	8.67^{c}
T7	0.63^{d}	2.30^{e}	2.27^{d}

Different letters indicate significant difference between means using Duncan's new multiple range test (DNMRT) at p = 0.05.

Table 12. Nutrients (N, P and K) uptake efficiency in different plant parts at 54 DAS.

Plant part	Treatment	Nutrient efficiency (%)		
		N	P	K
Leaves	**T0**	**Nd**	**Nd**	**Nd**
	T1	7.18^{b}	4.18^{a}	14.79^{a}
	T2	7.22^{b}	4.03^{a}	14.18^{ab}
	T3	7.26^{b}	3.38^{a}	12.26^{ab}
	T4	9.63^{a}	4.05^{a}	15.39^{a}
	T5	8.56^{ab}	3.74^{a}	10.84^{b}
	T6	8.85^{ab}	3.84^{a}	15.45^{a}
	T7	2.51^{c}	1.02^{b}	4.19^{c}
Stem	**T0**	**Nd**	**Nd**	**Nd**
	T1	9.01^{b}	4.55^{a}	13.51^{ab}
	T2	7.85^{bc}	4.18^{a}	14.91^{a}
	T3	7.14^{c}	4.45^{a}	14.47^{a}
	T4	9.37^{a}	4.20^{a}	13.84^{ab}
	T5	7.27^{c}	4.23^{a}	11.85^{b}
	T6	6.80^{c}	4.26^{a}	12.34^{b}
	T7	1.69^{d}	0.96^{b}	1.32^{c}
Roots	**T0**	**Nd**	**Nd**	**Nd**
	T1	3.67^{a}	0.97^{b}	2.73^{abc}
	T2	3.66^{a}	1.45^{a}	3.47^{a}
	T3	2.18^{c}	0.71^{c}	2.16^{c}
	T4	3.46^{a}	1.09^{b}	3.17^{ab}
	T5	3.08^{ab}	1.03^{b}	3.15^{ab}
	T6	2.67^{bc}	0.94^{b}	2.64^{bc}
	T7	0.68^{d}	0.25^{d}	0.14^{d}

Different letters indicate significant difference between means using Duncan's new multiple range test (DNMRT) at p=0.05. * Nd, not determine.

1965). Thus, the uptake of P relates to N availability. The availability of N in the soil solution may have played an important role in the P uptake. Generally, T4 showed higher P uptake when compared with other liquid organic-N treatments. Thus, it can be concluded that, this treatment could probably have more N when compared with others.

High CEC could be a major reason for the increase in N concentration, uptake and efficiency for T4 (Table 2, 6 and 12). According to Schnitzer (1977), the total acidity of FA for tropical soil ranges from 820 to 1030 cmol kg^{-1}. This value is higher, when compared with HA (620 to 750 cmol kg^{-1}). Similar results have also been reported by Sim and Murtedza (2007) for peat soils of Sarawak (584 and 1366 cmol kg^{-1} as averages for total acidity of HA and FA, respectively). This high total acidity may have enabled FA to fix N and made it more available to the plant.

In general, T3 reduced N use efficiency. The less availability of N observed for this treatment was probably due to fixation of NH_3 by HA, during fertilizer formulation or in soil. HA has the ability to fix significant amount of NH_3 at high pH (>7). Based on a previous study, rapid increase of pH was noted for T3 (pH 1.89 (LHA) to pH 9.04 (LHA + urea)). At pH of 9.04, N could be in NH_3 form and could be fixed by HA. Thus, it was consistent that the HA can affect N contents in plants and its uptake (Visser, 1985). Even though Tan (2003) reported that the presence of HA could increase the uptake of N by plant significantly, it was the contrary in this study. The concentration of N and its uptake also partly explains this observation. This was because N uptake relates to N use efficiency (Moll et al., 1981).

This high availability of N because of T4 could also be supported by the results of cations (exchangeable Ca and Mg) in soil where higher contents of these cations were observed (Table 13). The high exchangeable Ca recorded for T4 (Table 13) suggests that, more NH_4^+ was fixed by the clay surfaces. The exchange of Ca was possible because NH_4^+ fits the hexagonal holes formed by oxygen atoms on exposed surface at the clay minerals better than Ca (Stevenson, 1994). In addition, high CEC of FA enables fixation of Ca, hence,

Table 13. Exchangeable cations in soil at 54 DAS.

Treatment	Exchangeable cations in soil (cmol kg1)		
	K	Ca	Mg
T0	0.105^{b}	0.189^{c}	1.744^{a}
T1	0.115^{b}	0.256^{a}	1.580^{bc}
T2	0.127^{b}	0.272^{a}	1.490^{c}
T3	0.108^{b}	0.209^{bc}	1.583^{b}
T4	0.102^{b}	0.258^{a}	1.627^{b}
T5	0.115^{b}	0.285^{a}	1.611^{bc}
T6	0.104^{b}	0.223^{b}	1.544^{bc}
T7	0.459^{a}	0.220^{b}	1.532^{bc}

Different letters indicate significant difference between means using Duncan's New Multiple. Range Test (DNMRT) at p = 0.05.

reduces its loss by leaching (Havlin et al., 1999). The soil data for exchangeable Ca (Table 13) and its uptake (Tables 9 to 11) support the stated observation (Table 12). On the contrary, T3 recorded lower exchangeable Ca and Mg when compared with T1, T2, T4 and T5. The main reasons were possibly low CEC of HA and NH_3 retention. As discussed earlier, these two factors could affect the availability of Ca^{++} and Mg^{++} in soil solution. Availability of high NH_4^+ immediately after application of T3 may have increased competition between NH_4^+ and Mg^{++} at soil and organic surfaces. This was followed by the release of Mg into soil solution and increased the tendency for the losses of Mg through leaching. It must be stressed that, high rates of NH_4^+ induces Mg^{2+} stress greatly (Havlin et al., 1999).

Conclusions

Organic substances could enhance plant nutrient uptake. In terms of N uptake, the prominent treatment was liquid FA, while HA was the contrary. The increase in CEC due to addition of FA may have increased N fertilizer use efficiency. Liquid organic-N did not affect dry matter production of corn. The concentration of other nutrients in the plant tissues and their uptake were also not affected much by the use of liquid organic-N fertilizer. However, in terms of N and K uptake and the use efficiency, liquid urea-FA is recommended.

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