SINET: Ethiop. J. Sci., 36(2):109–118, 2013
 ISSN: 0379–2897

EFFECTS OF MOISTURE LEVEL AND POTASSIUM ON NH_4^+ NITRIFICATION AND THEIR INFLUENCE ON GROWTH PARAMETERS AND NUTRIENT UPTAKE OF BREAD WHEAT (*TRITICUM AESTIVUM. L*) GROWN ON TYPIC HAPLUDERT OF CENTRAL HIGHLANDS OF ETHIOPIA

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ABSTRACT: To understand the impact of moisture level and potassium on NH_4^+ nitrification a greenhouse and laboratory studies were conducted using surface soil of Typic Hapludert (0–30 cm) of Ginchi, central Ethiopia. The treatments were two levels of moisture and three levels of fertilizer (six combinations replicated three times). The Typic Hapludert, which is dominated by smectite and contains relatively high illite, has 6.44% total potassium, high K-fixing (minimum of 4.89 and maximum of 69.88 mg/100 g soil) and buffering (45.05 mmol/) capacities and low potassium availability (2.26 cmol (+) kg soil). The soil contains significant amounts of potassium in the form of micaceous K. Eighty percent of the applied $(NH_4)_2SO_4$ was nitrified and caused sharp increase of NO_3 under both moisture statuses between the 2nd and 5th weeks. Maintaining moisture at constant level could only delay nitrification, but could not stop nitrification process completely. Under all treatments the oxidation of $(NH_4)_2SO_4$ into NO_3^- ions took place in a very short period. In treatments T_1 (without N and K fertilizers), T_3 (83 mg nitrogen) and T_5 (83 mg nitrogen, 37.5 mg K), which were watered every other day, 86-88% of $(NH_4)_2SO_4$ was converted to NO_3^-within 15 days where as in T_2 (without N and K fertilizers), T4 (83 mg nitrogen) and T_6 (83 mg nitrogen, 37.5 mg K), which were moist to 60% water holding capacity of the soil every day, 34-44% of the applied $(NH_4)_2SO_4$ oxidized to NO_3^- within 22 days. High moisture status has discouraged K assimilation without affecting nitrogen uptake significantly. However, Mg^{2+} uptake was not affected under both water treatments. Application of potassium was found to shorten the time required for flowering.

Keywords/phases: K-fixing and buffering, micaceous K, nitrification and $(NH_4)_2SO_4$, smectite, Typic Hapludert

INTRODUCTION

Nitrogen availability often limits plant productivity in terrestrial ecosystems (Chapin, 1980). Several genera of autorophic bacteria are able to oxidize ammonium to nitrite, including Nitrosomonas, Nitrosolobus, and Nitrospira, while Nitrobacter appears to be the dominant in terrestrial ecosystems. Nitrosomonas exist in almost every ecosystem and live in the soil under aerobic condition. Aerobic condition facilitates the nitrification process. Thus, where oxygen is limited, such as a puddle in a field, NH_4^+ will accumulate in the soil (Haynes *et al.*, 1986). Maintenance of ammonium (NH_4^+) and potassium (K^+) ions in the soil is critical to plant development. However, the uptake of NH_4^+ and its amount vary widely with environmental conditions. One of the chief factors influencing NH_4^+- K^+ relations is the moisture status of the soil (Engels and Marschner, 1993; Peuke and Jeschke, 1993; Wang *et al.*, 1996; Gerenda´s *et al.*, 1997; Santa-Marı´a *et al.*, 2000; Ban˜uelos *et al.*, 2002; Kronzucker *et al.*, 2003). However, inhibition of NH_4^+ nitrification and making availability of nitrogen in form of cation is one of the challenges of the modern agriculture

In rain fed agricultural system of Ethiopia, farmers plant at the onset of rains after a long period of drought. At this time cracks in Vertisols are open and at initial stage applied N fertilizers are susceptible to movement down the soil profile in bypass flow often beyond plant rooting depth. Fertilizer N loss in bypass flow is predisposed by soil's hydrological processes (Booltink and Bouma, 1993), N species (Sigunga *et al.*, 2008), and concentration of favoured flow paths in the soil (Renck and Lehmann, 2004). In

Ethiopia nitrogen is applied in form of urea and/or di-ammonium phosphate (DAP) fertilizers. Both these forms of fertilizers are exposed for loss on the central highlands of Ethiopia. Urea is easily water soluble and removed from the site of application through water runoff whereas ammonium will be adsorbed on the surface of soil colloid or converted to NO_3^- due to nitrification.

Plant removes about 30 to 50% of the applied nitrogen fertilizer whereas the remaining is exposed for elluviation and used by soil micro-organisms (Tripathy and Singh, 2003; Russel and Fillery, 1996; Mengel, 1980). To maximize the use of nitrogen fertilizer there is high demand to minimize elluviation of nitrate or fixation of NH_4^+ and where there is high nitrogen loses, nitrogen application must be increased by 10% and out of which almost 15 to 30% will be lost by nitrification (Scheeffer and Schachtschabel, 1979). The ability of the soil to release K varies according to the mineralogy of the soil. Micas, in particular, may release significant amounts of K. When the concentrations of soil solution K and/or exchangeable K become small due to leaching minerals must release K (McLean and Watson, 1985; Hinsinger and Jaillard, 1993). Fixation of NH_4^+ and K^+ ions by clay minerals has been attributed to their close fit within the inter layer of the clay minerals low hydration energy of the ions is now to be the major factor in fixation of both cations (Shainberg and Kemper, 1966; Kittrich, 1966).

Nintey percent of all nitrogen fertilizers are in form of NH_4^+ ions or contain NH_4^+ ions and in biologically active soils these fertilizers pass through the process of nitrification and transform into NO_3 and NO_2 and elluviate in very short period (Newnman and Watson, 1977). Thus, in the tropical regions, which are characterized by high precipitation, it becomes important to maintain the proportion of various mineralizable N-forms in the soil.

Researches were conducted to prevent or slow down the nitrification process so that plants could take nitrogen in form of NH_4^+ ions rather than in nitrate form. According to Mengel and Rahmatullah (1998), plants take nitrates that are compounds of Ca^{2+} and Mg^{2+} than K^+ and the uptake of nitrogen in form of NH_4^+ lowers the cation composition and amount in the plant tissue. K^+ and NH_4^+ have similar behaviours such as ion diameter and hydration energy (Pannikow and Minejew, 1980; Follet *et al.*, 1981) and an increase in one of these cations affect the uptake and availability of the other. The existence of high quantity of K^+ in soil influences NH_4^+ uptake and ion exchange vies versa (Cao *et al.*, 1993). Treatments that focused on stopping nitrification would affect the ion exchange and availability of both NH_4^+ and K^+ particularly in soil dominated by 2:1 type of clay minerals. Thus, the objective of this study was to investigate the impact of moisture level and potassium on the process of NH_4^+ nitrification in the Ethiopian Vertisols.

MATERIALS AND METHODS

Field study

Reconnaissance soil survey was conducted in Vertisols areas of the central highlands of Ethiopia to identify a representative site and collect sample for green house and laboratory studies. The Vertisols at Ginchi was found to be typical representative and profile was opened at the southern part of Ginchi town closer to the Ginchi agricultural research sub-centre of Holetta research centre (09° 02′ N and 38° 05′ E, 2250 masl).

Laboratory studies

Soil samples were taken to a depth of 30 cm (Ap) from Vertisols profile at Ginchi, air-dried and grinded to pass through 2 mm sieve for the following analysis: particle size distribution (Bouyoucos, 1962); pH (Schofield and Tayer, 1955); organic carbon (Black, 1965); total nitrogen (Kunze *et al.*, 1964); exchangeable cations and cation exchange capacity (Davidescu and Davidescu, 1982); cation saturation and water soluble phosphate (Richards, 1954); total potassium (Bonfils, 1967); available potassium and potassium fixation (Schachtschable, 1961). The analyses were conducted in soil laboratory of the Institute for Soil Science and Soil Conservation of Justus Liebig University (JLU)-Giessen, Germany.

Green house study

The soil sample collected from the upper 30 cm was air-dried and grinded to pass through 2 mm sieve and 250 g of the soil mixed with 250 g acid washed sand and kept in plastic pots in the greenhouse of the Institute for Soil Science and Soil Conservation of JLU-Giessen. Each treatment was replicated three times. The treatments were two levels of moisture, which were determined based on water holding capacity of the soil at field capacity and permanent welting points (61.5 and 43.8%, respectively), and two levels of potassium (0 and 37.5 mg K/pot) and nitrogen (0 and 83 mg N/pot) fertilizers. The treatment combinations were: 1) Without N and K fertilizers and watered every other day (T_1); 2) without N and K fertilizers and soil moist to 60% water holding capacity every day (T_2); 3) 83 mg nitrogen and sample watered every other day (T_3) and 4) 83 mg nitrogen and sample kept at 60% of water holding capacity every day (T_4); 5) 83 mg nitrogen, 37.5 mg K and sample watered every other day (T_5); and 6) 83 mg nitrogen, 37.5 mg K and soil moist to 60% water holding capacity every day (T_6). Nitrogen was applied in form of $(NH_4)_2SO_4$ and potassium in form of KCl. Bread wheat (*Triticum aestivum. L*) was used as test crop. The weights of the soil and sand mixed pots were determined at field capacity and permanent welting points, respectively, and kept constant during watering. Starting the four-leave stage up to heading the stock diameter and high of the plant were measured every week using caliper and meter-tape, respectively, and plant was harvested at the end of the seventh week. Soil sample was taken from each treatment every week to determine the amount of NO_3 and NH_4^+.

RESULT AND DISCUSSION

Physical, chemical and mineralogical properties of the soil

Physical, mineralogical and chemical characteristics of representative Vertisols of Ethiopia, including the Vertisols at Ginchi were studied and reported (Eylachew Zewdie, 2001). The Vertisols of the current study was developed on less than 2% slope from continuous in-situ weathering of basalt and has similar characteristic with other Vertisols of the central highlands of Ethiopia. Mitiku Haile (1987) and Ahmed (1983) have reported similar results.

The summary of the morphological properties of the Vertisols of Ginchi, which is classified as Typic Hapludert, is given in Table 1. The soil has large sized parallelepiped structural aggregates, clearly observable silkensides and deep cracks. The depths of the cracks extend from the surface to more than 50 cm downward with widths ranging between 5 and 10 cm. There was a massive upward movement of parallelepipeds, but except showing tonguing future, it was able to develop gilgai micro-relief due to the intensive cultivation. However, the upward movement has mixed certain portion of subsurface soil (B_w) with the surface soil (A). Due to strong and dense structural aggregates in subsurface horizon (B_w) fine roots were growing on ped faces. Eylachew Zewdie (2001) has reported similar results on root distribution and associated it with high bulk density or mismanagement of the soil.

The chemical properties of the surface soil (Ap) of Typic Hapludert is given in Table 2. The soil has slightly acidic reaction in the surface. But, Eylachew Zewdie (2001) has indicated that this acidic reaction changes to alkaline in the subsurface soil as a result of high accumulation of calcium carbonate and continuous release of base cations from the parent material. The soil has a low available phosphorous as well as nitrogen. The percent base saturation was high and calcium took the major portion. From this it is possible to deduct that Ca^{++} could precipitate phosphate ions into non-water soluble Ca-compounds. Eylachew Zewdie (1987) and Eylachew Zewdie and Moll (1989) found out that phosphorous availability could be reduced up to 75% in Ethiopian Vertisols.

Eylachew Zewdie (2001) studied mineral composition of Vertisols in the same area and determined approximate quantitative contents of the clay minerals (Table 3) and his result clearly indicated that the surface soil (0–20cm; Ap) is dominated by smectite, but the subsurface horizons (AB, Bw_1, Bw_2 and BC_k) contained other clay minerals beside smectite. The existence of illite in the sub-surface horizons could be one of the reasons for the stability of the physical properties of Typic Hapludert in Ginchi. The surface soil (0–30 cm; Ap) of the profile used for this study has both smectite and illite (74 and 26%, respectively). The existence of illite in the surface soil could be due to churning, which was justified by the existence of $CaCO_3$ nodules in the surface soil and tonguing future in the profile.

Table 1. Summary of important morphological properties of Vertisols at Ginchi.

Horizon	Depth (cm)	Munsell Colour *	Clay %	Structure	Consist wet	Lower boundary	Remarks
Ap	0 - 30	10YR 3/1	47	Massive	vst/pl	d/w	Mats of fine roots
BA	30 - 48	10YR 3/1	68	Sub-angular blocky	vst/pl	d/w	Fine roots b/t peds
Bw_1	48 - 90	10YR 3/1	72	blocky	vst/pl	c/w	Fine roots b/t peds
Bw_2k	90-117	10YR 3/1	68	Sub-angular blocky	vst/pl	c/w	Few $CaCO_3$ nodules
BCk	117-148	10YR 3/1	56	blocky	sst/pl	c/w	Many $CaCO_3$ nodules
C	148+	10YR 4/4	42	granular	sst/pl	n/o	Few Mn-Fe nodules

*** = moist value; d/w = diffuse and wavy: c/w = clear and wavy: n/o = not observed; sst/pl = slightly sticky/ plastic; vst/pl = very sticky/plastic. (Source: Eylachew Zewdie (2001)).**

Table 2. Approximate mineral contents in the clay fraction (%) of Vertisols profile at Ginchi.

Horizon	Smectite	Vermiculite	Chlorite	Mixed-layer	Illite	Kaolinite
Ap	94	-	-	-	-	6
AB	59	-	-	-	10	-
Bw_1	14	23	41	8	12	2
Bw_2	65	-	-	6	29	-
BCk	-	-	-	-	100	-

Source: - Eylachew Zewdie (2001).

Table 3. Physical and chemical properties of surface soil (Ap 0–30cm) of Typic Hapludert at Ginchi.

Parameter	Value	Parameter	Value
pH (H_2O)[1]	6.80	Mg^{++}_{Ex}	0.98 cmol (+) kg soil
pH (KCl)	6.30	Na^{+}_{Sa} [5]	7.3 %
Clay[2]	47 %	Ca^{++}_{Sa}	81.41 %
Silt	24 %	Mg^{++}_{Sa}	3.65 %
Sand	28 %	Na_t^{++}	0.13 %
OM[3]	3.60 %	Ca_t^{++}	0.10 %
CEC	26.82 cmol (+) kg soil	Mg_t^{++}	0.04 %
CEC	69.82 cmol (+) kg clay	P (H_2O soluble)	1.13 mg P/l
Na^{+}_{Ex} [4]	1.95 cmol (+) kg soil	NO_3	7.09 mg/100g soil
Ca^{++}_{Ex}	21.85 cmol (+) kg soil	NH_4^+	0.90 mg/100g soil

Ex= exchangeable; Sa = saturation.
[1] Schofield and Tayler (1955); [2] Bouyoucos (1962); [3] Black (1965); [4] Schactschable (1961) and [5] Richards (1954).

Potassium status

Based on the quantity of potassium, K-buffering capacity (Table 4) and cation exchange capacity of the clay [69.82 cmol (+) kg] it was possible to confirm that the soil is dominated by 2:1 type of clay mineral, smectite, and contain relatively good quantity of illite. Mengel (1981) indicated that such high K buffering capacity depends on the quantity of 2:1 type of clay minerals especially on Illite and Vermiculite. Eylachew Zewdie (2001) has also indicated that the Vertisols of the Central Highlands of Ethiopia is dominated by smectite and illite clay minerals. Illite is concentrated in the subsurface horizons. The total potassium (6.44%) has played an important role in the formation of Illite and/or Vermiculite in smectite dominated Hapluderts. The K equilibrium concentration of the soil solution (0.04 mmol/l) was too low. Potassium saturation and fixation, which were reflected by low and negative values, respectively, were found also to prove the low availability of the ion. The low availability of K+ ions (2.26 cmol (+) kg soil) was associated with the behaviour of the 2:1 type of clay mineral. This low availability was also the reflection of soil solution K/exchangeable K, which is a small part of total soil K in Typic Haupludert. Moreover, without the other parameters such as fixation, buffering, *etc.* exchangeable K has shown to be inadequate in assessing K the need of any plant. The high potassium fixation of the soil (-4.89 mg/100 g soil per hour)

Table 4. Potassium status of the surface soil (Ap; 0–30 cm) of Typic Hapludert at Ginchi.

Parameter	Value
K_{Ex}	2.26 cmol (+) kg soil
K_{Sa}	7.98 %
K_t	6.44 %
$K_{fixation}$ h^{-1} contact time	-4.89 mg/100 g soil
$K_{fixation}$ 2400 h contact time	-69.88 mg/100 g soil
K_{TPB} h^{-1} contact time	35.33 mg/100 g soil
K_{KCl}	34.31 mg/100 g soil
K-$_{HNO3}$	88.68 mg/100 g soil
$K_{constant}$	13.03 mg/100 g soil
Equilibrium concentration (eq. conc.)	0.04 mmol/l
Buffering range (eq. conc.)	45.05 mmol/l

Ex= exchangeable; Sa = saturation.

was also confirming that micaceous K was the dominant potassium in Haupluderts. However, the high K-buffering capacity of the soil (45.05 mmol/l) has indicated the good potassium-supplying potential of Typic Hapl-udert if the required amount of potassium fertilizer is applied to the soil.

Nitrogen status

The Typic Hapludert used for the study has relatively low mineral nitrogen (0.09 mg/100g soil), which was kept constant by the mineralization of organic matter. This was confirmed by the reduction of organic matter (3.6 to 0.5% within seven weeks). In un-fertilized pots, which were kept at various moisture levels, nitrification process was not taking place for about four weeks and, thus, soil NH_4 content has remained more or less constant, *i.e.* at 1 mg N/100g soil (Fig. 1). However, at the 5th week, a sudden NO_3 increment (12 mgNO_3/100g soil) was observed and this was associated with the increase in the activity of nitrifying bacteria as a result of the improvement of soil temperature (12–15°C). pots fertilized with 83 mg/pot (T_3 & T_4), which were kept at different moisture levels; the amount of NO_3 has significantly increased after 2nd week (17mgN/100 g soils) and between 2nd and 5th weeks 80% of the applied NH_4 ion was nitrified.

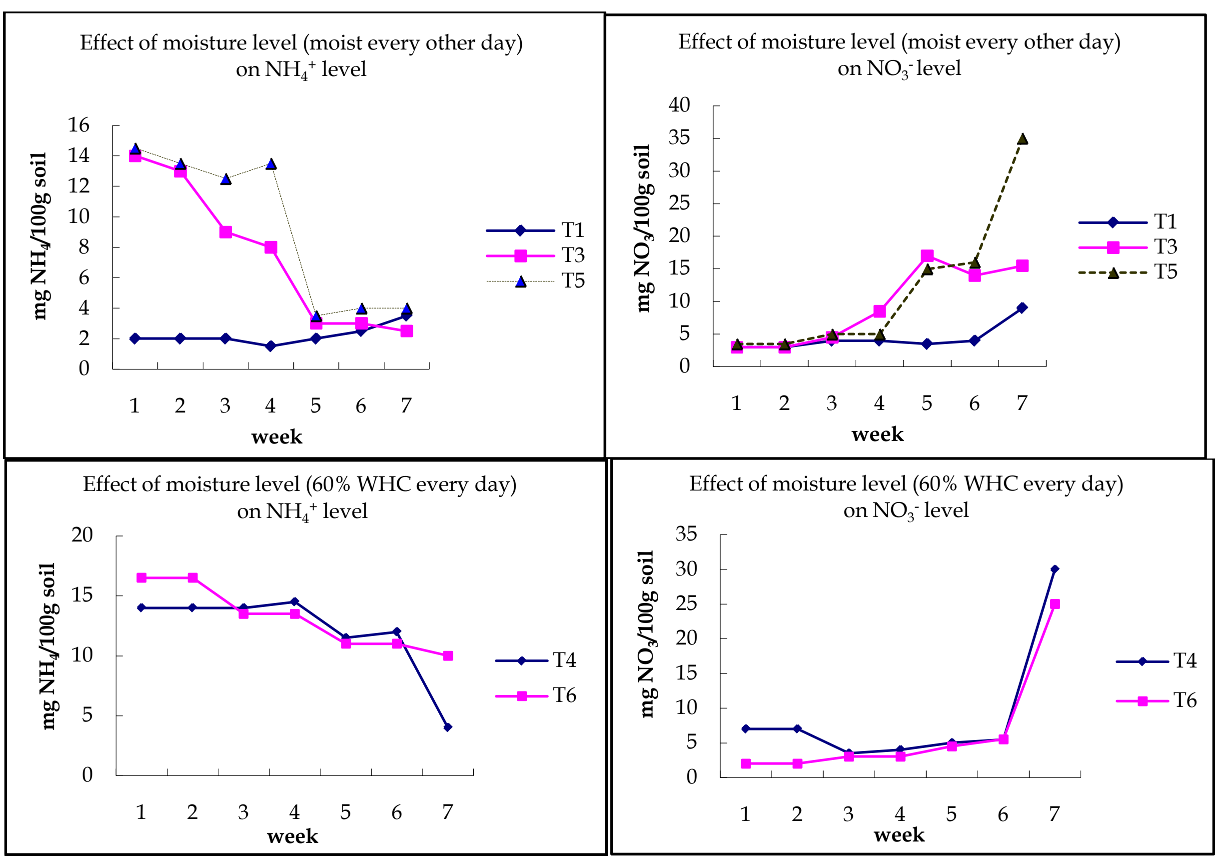

Figure 1. Effect of moisture level and fertilizer on NH_4^+ and NO_3^- levels in Typic Hapludert of central highlands of Ethiopia. [T_1 (w/o NK moist every other day); T_3 (with N moist every other day); T_4 (with N 60% WHC); T_5 (with NK moist every other day) and T_6 (with NK 60% WHC)].

But nitrification in pots treated with potassium (37.5 mg K/pot) was intensive and significantly high compared with untreated once. This proved that potassium has substituted NH_4 ion from the surface and lattice layers of the clay mineral and exposed it for nitrification. In pots maintained at 60% water holding capacity (WHC) every day and without potassium or treated with potassium (T_5 & T_6) both NO_3 and NH_4 contents remained constant up to 4th week and after 5th week there were sudden fall of NH_4 and sharp increase of NO_3 content. This result indicates that maintaining moisture at constant at the field capacity has delayed nitrification of NH_4, but was not able to stop nitrification process completely. Abbasi and Adams (2001), Rochestert *et al.* (1996), Powells and Prosser (1986) and Rodgers and Ashworth (1982) have reported similar results in their studies on different soil types. They concluded that inhabitation of ammonium oxidation was possible to certain extent and has assisted the recovery of mineralized nitrogen by crops.

Growth parameters of test crop

The test plant showed significant difference in stock diameter during the first two weeks and plant height within the first seven weeks until the crop started heading. But the difference between treatments was not significant (Fig. 2). In treatments where substrata received water every other day application of both nitrogen and potassium brought significant difference in crop stock diameter compared with treatments under constant 60% water holding capacity, but the height has remained the same. From the result it was possible to conclude that maintaining moisture at 60% water holding capacity has dis couraged K assimilation without affecting nitrogen uptake significantly. Under both moisture levels from initial up to 6th week potassium played a role in stock development.

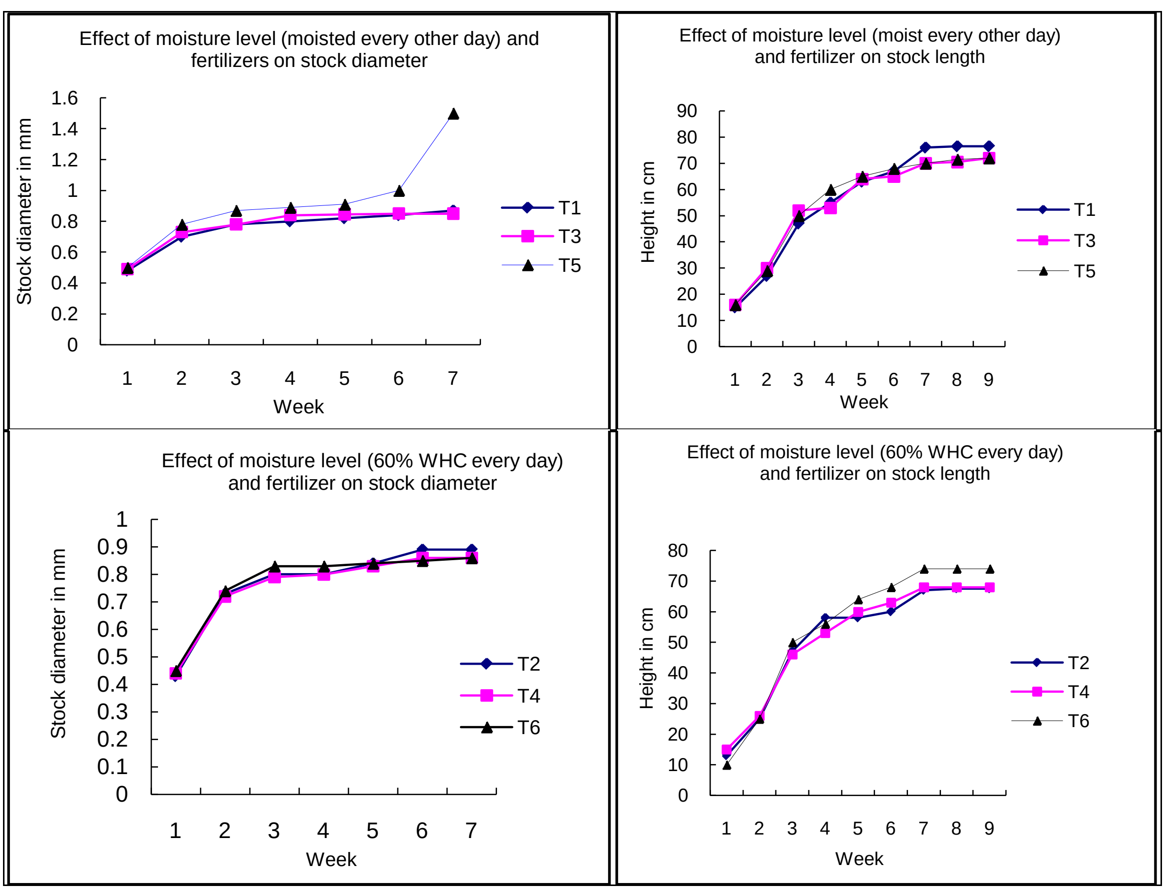

Figure 2. Effect of moisture level and fertilizer on stock diameter and length of bread wheat (*Triticum aestivum. L*) grown on Typic Hapludert of central highlands of Ethiopia. [T_1 (w/o NK moist every other day); T_2 (w/o NK 60% WHC); T_3 (with N moist every other day); T_4 (with N 60% WHC); T_5 (with NK moist every other day) and T_6 (with NK 60% WHC)].

After the 6th week, the change in stock development was low and non-significant between treatments except plants growing in pots received 83 mg N and 37.5 mg K and watered every other day (T_5). Even if it was not possible to prove the influence of external factors such as temperature and light in this study it is expected to contribute considerably to plant height and diameter and this phenomenon has been proved by Rabey and Bate (1978).

Between the two fertilizer treatments combinations under the two moisture levels the influence of potassium on stock diameter or colour of the leaves was not observed. However, plants without potassium treatment showed weak physiological development at the initial phase. But, on the latter phase this difference has disappeared. Application of potassium has shortened the day to flowering by one week compared with untreated once.

Nutrient uptake and balance

In general maintaining soil moisture at higher level has discouraged the uptake of nutrients (Fig. 3). Moisten the soil every other day has encouraged the uptake of nitrogen, potassium and magnesium ions compared with samples maintained at 60% WHC. Among ions, the uptake of K was significantly high and showed paralleled trend with uptake of nitrogen. Application of potassium fertilizer improved potassium uptake in both water treatments. This proved that applied potassium was not adsorbed on the surface of the clay minerals rather the largest proportion has remained in the soil solution and

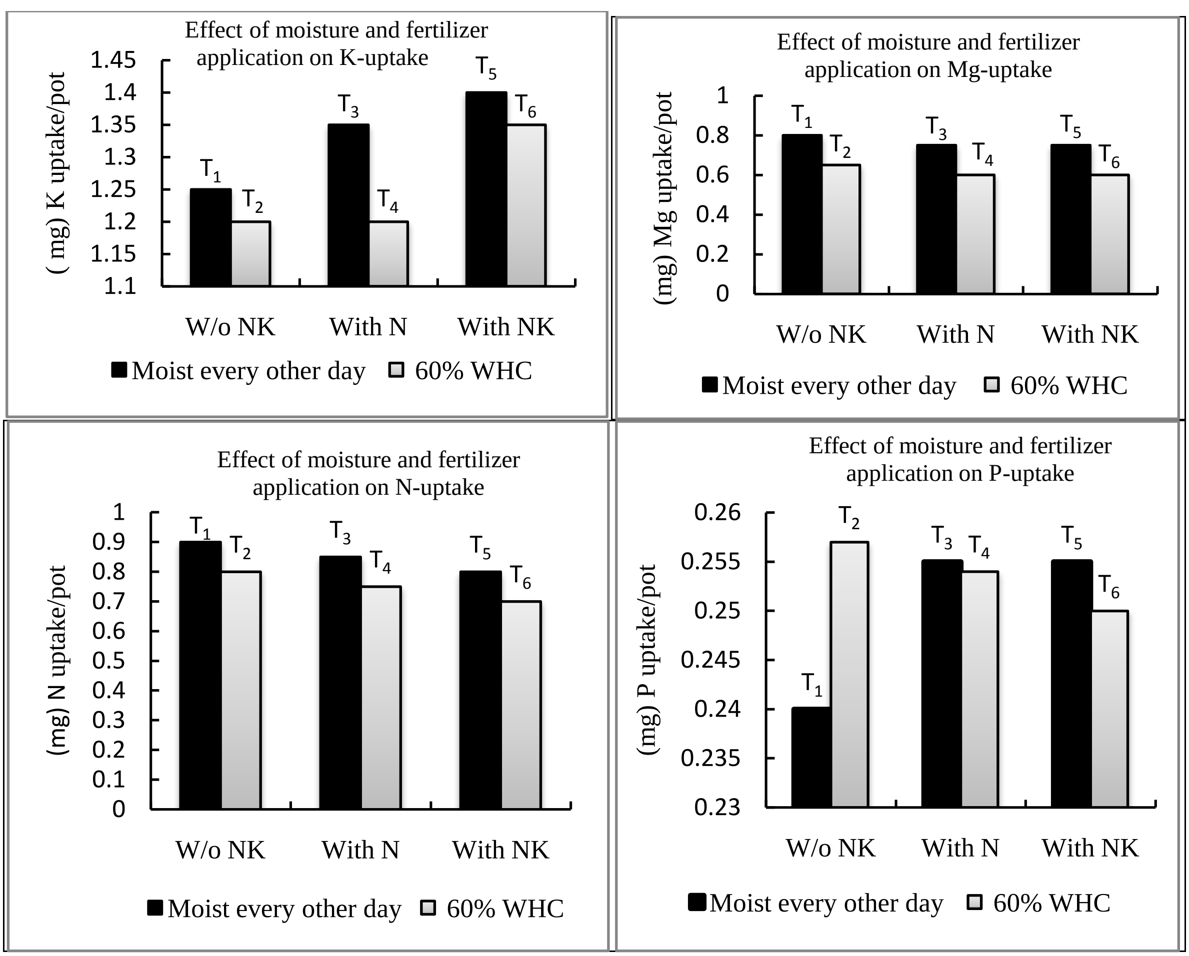

Figure 3. Effect of moisture and fertilizer application on N, P, Mg^{2+} and K^+ uptakes by bread wheat (*Triticum aestivum. L*) grown on Typic Hapludert of central highlands of Ethiopia. [T_1 (w/o NK moist every other day), T_2 (w/o NK 60% WHC), T_3 (with N moist every other day), T_4 (with N 60% WHC), T_5 (with NK moist every other day) and T_6 (with NK 60% WHC)].

a small quantity has replaced NH_4^+ and improved nitrogen up take. Both NH_4^+ and K^+ ions was expected to lower Mg^{2+} uptake, but it was found out that treatments that were moisten every other day have absorbed more Mg^{2+} up to 7th week, which was the active growth period of the test crop. There was significant difference in Mg^{2+} uptake between the two moisture levels, but the difference between treatments maintained at 60% WHC was not significant and neither NH_4^+ nor K applications encourage Mg^{2+} uptake. Maintaining soil at 60% WHC and K application has also discouraged phosphorous uptake significantly. Higher K saturation in treatment maintained at 60% WHC has encouraged NH_4-N uptake until the plant reached flowering stage, but was not reflected on plant appearance.

The test crop absorbed about 20% of the total nitrogen during the first nine weeks whereas from the remaining 80%, quite a small quantity was retain in form of NH_4^+ in the soil and the large quantity was lost in form of NO_3^- in the soil system. The major part of the absorbed N and P assimilated in the seed whereas cations such as K^+, Mg^{2+} and Ca^{2+} were concentrated in the vegetative parts. Application of NH_4 fertilizer has significantly affected K^+, Mg^{2+} and Ca^{2+} uptakes and, however, K uptake was favoured more. The highest uptake of K^+ in sample watered every other day was the reflection of ion exchange phenomena, i.e. K^+ was replaced by NH_4^+ in the inter lattice and made it available for uptake.

The result in Table 5 clearly indicated that without the test plant T_1, T_3 and T_5 showed relatively high NO_3 compared with T_2, T_4 and T_6. The high NO_3 content in T_1, T_3 and T_5 was associated with better mineralization of organic matter and NH_4 as compared with T_2, T_4 and T_6. Moreover, the low NH_4 nitrification process in T_2, T_4 and T_6 has contributed to low NO_3 availability and assimilation. In T_1, T_3 and T_5 NO_3^- was a major source of nitrogen where as in T_2, T_4 and T_6 NH_4 ions.

Change in nutrient dynamic

The change in nitrogen status of the Typic Hapludert at the end of vegetative growth for pots with and without vegetation is given in Table 4. Under all treatments, the oxidation of $(NH_4)_2SO_4$ into NH_4 ions took place relatively in a very short period and in treatments T_1, T_3 and T_5 86–88% of $(NH_4)_2SO_4$ was converted to NO_3 -N within 15 days where as in T_2, T_4 and T_6 34–44% of the applied $(NH_4)_2SO_4$ oxidized to NO_3 –N within 22 days. In general, it was found that higher water content of a soil has significantly discouraged the nitrification process. On the soil, which has 22.6 ppm exchangeable potassium, the application of 37.5 ppm potassium did not show any change on its exchangeability and water solubility. Thus, it was not possible to trace the change on availability. However, its application has improved plant uptake (Fig. 3) without influencing the stock diameter and length significantly. In Typic Hapludert of Ethiopian highlands soil Mg^{2+} is about 0.98 cmol (+) kg soil and the level of moisture significantly affected uptake. At 60% moisture content under the two fertilizer treatments, there was a good Mg^{2+} uptake.

Table 5. Nitrogen status of the soil under different moisture level and fertilizer treatments (ppm).

Treatment	With test crop			Without test crop		
	NH_4	NO_3	NH_4^+ NO_3^-	NH_4	NO_3	NH_4^+ NO_3^-
T_1 (w/o NK moist every other day)	10.25	7.71	17.96	9.63	131.13	140.76
T_2 (w/o NK 60% WHC)	16.84	2.89	19.73	9.63	157.94	167.57
T_3 (with N moist every other day)	11.11	2.37	13.48	10.94	152.69	163.63
T_4 (with N 60% WHC)	10.73	2.75	12.08	10.50	118.57	129.07
T_5 (with NK moist every other day)	8.05	1.93	9.98	9.19	140.88	150.07
T_6 (with NK 60% WHC)	8.23	7.92	16.15	6.63	121.19	127.82

CONCLUSION AND RECOMMENDATION

The Typic Hapludert of the central highlands of Ethiopia, which is dominated by smectite, contains relatively high quantities of illite and/or vermiculite that are responsible for high K fixation and low availability. Thus, it is possible to conclude that the soil contains significant amounts of K in the form of micaceous K and, therefore, it is important to estimate K release potential from the non-exchangeable K pool of the total K before the introduction of K fertilization program in the central highlands of Ethiopia.

Moisture level was found to have significant impact on the nitrification process and soils with higher moisture level have low nitrification as long as soil temperature is maintained at low level. Thus, if fertilizer is applied in the form of NH_4, it can be protected from loss and available in NH_4 form. The applications of K fertilizer in illitic soils expose inter-lattice NH_4 and encourage nitrification. If K is applied at low moisture level, nitrification will start after a week whereas under high moisture levels it will start after two weeks. In the highlands of Ethiopia in Uderts areas nitrification can be minimized or blocked only up to 5th week. Thus, on Uderts the selection of the type of nitrogen-fertilizer and time of application would be highly appreciated in order to minimize N-loss at the beginning of the growing season. Potassium application could facilitate the nitrification of NH_4 and cause nitrogen losses. Thus, unless critical shortage of K is being observed, there is no need of K application. However, this also requires further investigation.

The current study, which has taken only one soil type with water logging problem from the central highlands of Ethiopia, calls for similar studies in various parts of the country to generate information on NH_4^+ nitrification process that could help in the selection of the kind of nitrogen fertilizer and introduction of potassium fertilizer in the Ethiopian farming system.

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