American Journal of Applied Sciences 6 (10): 1788-1799, 2009
ISSN 1546-9239

Effect of N and K Fertilizers on Nutrient Leaching and Groundwater Quality under Mature Oil Palm in Sabah during the Monsoon Period

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Abstract: Problem statement: The oil palms are mainly grown in the humid tropics with high rainfall. Soluble Nitrogen (N) and Potassium (K) fertilizers are commonly required by the oil palm plantations to maximize palm productivity due to the highly weathered soils with low fertility. Thus, leaching losses of N and K nutrients may be unavoidable and these nutrients may move further downward and eventually cause groundwater pollution. This study reports the leaching of N and K nutrients in a mature oil palm field as affected by fertilizer rates and soil depths and its effect on groundwater quality during the monsoon period in Tawau, Sabah. **Approach:** The sources of N and K fertilizer were Ammonium Chloride (AC) and Muriate of Potash (MOP), respectively. Soil water samplers were installed at depths of 30, 60 and 120 cm in four fertilizer treatments, namely, N0P0K0 (Control plot, no N and K), N0P2K1 (K1 = 4.5 kg MOP palm^{-1} year^{-1}), N1P2K1 (N1 = 3.75 AC kg palm^{-1} year^{-1}) and N1P2K0. Three replications were used in the experiment. Monitoring wells were installed in the above treatment plots and in another treatment, N2P2K1 (N2 = 7.5 kg AC palm^{-1} year^{-1}) to investigate the effect of excessive N rate on groundwater quality. Samplings were done at 15 day intervals for a duration of 150 days from October 2008-February 2009 to cover the entire monsoon period in Sabah. Water samples were analyzed for NH_4-N by automated phenate method, NO_3-N + NO_2-N and NO_2-N by automated hydrazine reduction method on Auto Analyzer 3 and K by flame photometric method using flame photometer. **Results:** The mean NH_4-N concentration of N1P2K1 at 33.69 mg L^{-1} was significantly higher than N1P2K0 at 8.15 mg L^{-1}. In the presence of K, NH_4-N concentrations increased 4.1 fold when N fertilizer was applied and 3.5 times in the absence of N application. The mean NH_4-N concentration was 17.89 mg L^{-1} at 30 cm depth declining to 12.19 and 6.52 mg L^{-1} at soil depths of 60 and 120 cm, respectively. The transformation of NH_4-N to NO_3-N was not a major process during the monsoon period. The leaching losses of inorganic N were 1.0 and 1.6% of the applied fertilizer for N1P2K0 and N1P2K1 respectively. For K, the leaching losses were 5.3 and 2.4% for N0P2K1 and N1P2K1 respectively. The concentrations of NH_4-N, NO_3-N and K in groundwater ranged from 0.23-2.7, 0.07-0.25 and 0.63-9.54 mg L^{-1}, respectively. **Conclusion/Recommendations:** N and K concentrations in the soil solution decreased with soil depth and their leaching losses were related to rainfall pattern, fertilizer treatment and nutrient uptake by roots. Groundwater quality was not affected by the applications of N and K fertilizers at the optimum rates for mature oil palms.

Key words: Nutrient leaching, oil palm plantation, fertilizer rates, groundwater quality

INTRODUCTION

Nitrogen and potassium are the two most needed nutrients by oil palms in Malaysia, which are commonly met through fertilizers. When applying fertilizers to the palms, our goal is to maximize nutrient uptake by the palms from fertilizers for optimum growth and yield. Malaysia is located in a hot, humid tropical climate marked by seasonal rainfall with annual amount exceeding 2500 mm. Generally, the climate is

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influenced by the northeast and southwest monsoons. In Sabah, East Malaysia (North Borneo), most of the rains fall during the northeast monsoon (October to February). During this period, considerable amount of water will be lost through both runoff and deep percolation to beyond the rooting zone. The same processes of water loss may also carry substantial amount of soluble plant nutrients. Schroth *et al.*[1] concluded from his study that even in well-designed perennial cropping systems, high rainfall and permeable soils which are typical over large areas in the humid tropics, make it unlikely that leaching losses of soluble nutrients can be completely avoided

Leaching is the translocation of solutes[2] beyond the rooting zone. Some authorities define leaching more stringently as the removal of solutes entirely out of the solum, representing a loss of materials from the soil profile[3] but according to other experts leaching also includes the translocation of solutes within the solum[4]. Saffigna and Philips[5] considered leaching as the downward movement of fertilizer or waste in soil with the drainage water. When solute leached below the rooting zone, it is unavailable for plant uptake and therefore, lost from the soil-plant system. Depending on the amount of water draining out of the rooting zone, the leached solute may simply accumulate at depth in the soil or may pollute the underlying groundwater. Leaching losses, especially of readily soluble forms of N and K have generally been assumed to be substantial in cropped land in the humid tropics in view of the frequent and intense rain storms[6]. Furthermore, Corley and Tinker[7] surmised that nitrogen and potassium are the elements most at risk to leaching because of the rather weak adsorption of ammonium and potassium ions and nil adsorption of nitrate. Omoti *et al.*[8] reported an average leaching losses of 11 kg N (34%) and 10 kg K (18%) of the applied NK fertilizers from both young and mature plantations. Chang and Zakaria[9] in their review showed that the combined losses of N and K from leaching and runoff from catchment with young oil palm to be less than 2 kg N and 8 kg K ha^{-1} $year^{-1}$. Although Foong[10] found that fertilizer losses in a lysimeter when the palm was 1-4 years old were 17% for N and 10% for K, he confirmed that the losses were low at 2.1% for N and 2.7% for K when the palm was 5-14 years old. He ascribed the much higher leaching losses when the palm was immature to smaller plant nutrient uptake and soil disturbance during the construction of lysimeter and planting of the palm.

The most commonly used inorganic nitrogen fertilizers in the oil palm plantations are ammonium nitrate, ammonium sulphate, ammonium chloride and urea. Nitrogenous fertilizer may be lost in the form of ammonium (NH_4^+) or nitrate (NO_3^-). However, studies have shown that different sources of nitrogen fertilizer have different effect on N leaching[11-14]. Also, the fertilizer rates have a strong impact on nutrient leaching in many crops[15-18]. Currently, information on the effect of fertilizer rates on leaching losses of nutrient in the oil palm plantation is still scanty.

Groundwater is that portion of water beneath the surface of the earth that can be collected with wells, tunnels, or drainage galleries, or that flows naturally to the earth's surface via seeps or springs[19]. Price[20] defined groundwater as water in the saturated zone that is below the water table. Groundwater pollution caused by agricultural activities is a serious problem in many regions of the world. Phillips and Burton[21] expressed concerns that surface-applied fertilizers such as Di-Ammonium Phosphate (DAP) and potassium chloride (KCl) may be contributing to a decline in local groundwater quality under pine tree planted on sandy soil. High rates of N fertilizer used in the production of continuous corn have resulted in excessive nitrate-N leaching in groundwater which frequently exceeded the maximum contamination level of 10 mg L^{-1}[22]. Babiker *et al.*[23] investigated the nitrate contamination of groundwater by agrochemical fertilizers in Central Japan using geographical information system and found that the nitrate concentration of groundwater under vegetable fields was significantly higher than those under urban land or paddy fields. The adverse health effects of high nitrate levels in drinking water are well documented[24-26]. The most well known are methemoglobinemia, gastric cancer and non-Hodgkin's lymphoma. While the usual level of ammonium (NH_4^+) ion does not pose a direct risk to human health, a high NH_4^+ concentration may suggest the presence of more agricultural contaminants, such as pesticides. Furthermore, in aerobic condition, NH_4^+ may be transformed to nitrate (NO_3^-) via nitrification[27]. Since groundwater is an indispensable water resources for human consumption especially in developing countries and the fact that eventually contaminants in the groundwater will be discharged into the river or streams which is also a source of drinking water, most authors referred to the drinking water standard guidelines as a baseline to assess the contamination level[27-29]. WHO[30] has set a maximum admissible limit in drinking water for NO_3-N as 10 and NH_4-N as 0.5 mg L^{-1}. While there is little evidence that K in drinking water is detrimental to human health, an increase in K^+ concentration in groundwater may lead to a breach of the drinking water limit of K^+ of 12 mg L^{-1}[30,31].

Schroth *et al.*[32] studied the spatial pattern of oil palm root system and concluded that in the absence of roots in the inter-tree spaces between the palms, nitrate would eventually be leached out of the soil profile and into the groundwater. Although various studies on groundwater contamination due to fertilization in different crops have been explored, there is still very little information on the effect of fertilization on groundwater quality in the oil palm plantation especially in Malaysia.

The economic success of the oil palm plantation may be the first concern, but it is now essential to determine the potential impact of fertilization in agriculture on the environment as a way of showing that the plantation company is involved in agricultural practices, which is sustainable, both economically and environmentally. In view of this, a study was carried out to study the downward movement and leaching of N and K nutrients as well as groundwater quality as affected by fertilizers during the monsoon period in Sabah, Malaysia.

MATERIALS AND METHODS

The experiment was located within an existing long term N, P and K fertilizer response trial on oil palm in Tawau, Sabah, Malaysia. Tenera (Dura × Pisifera) oil palms were planted in the field in 1982 in a triangular pattern with a planting distance of 9.2×9.2×9.2 m. The site was undulating to rolling with slope of 0-6°. The soil type was mapped as Kumansi soil series (Typic Hapludults) or Haplic Acrisols under the FAO classification. The experimental design of the fertilizer response trial comprised a 3×3×2 factorial combination of N, P and K arranged in a Randomized Complete Block Design (RCBD) with 3 replicates. The plot size was 30 palms. To achieve the objectives of this study, 4 treatments from each replicate were selected as follows: N0P0K0, N0P2K1, N1P2K1 and N1P2K0. The N and K fertilizers were applied in the palm circle, about 1-2 m from the palm stem. Annually, 3 rounds of N and 2 rounds of K were applied. P fertilizer was broadcast evenly in the inter row areas and over the frond heaps once a year. The N source was Ammonium Chloride (AC) which has an N concentration of 25%. The N rates were 0 kg AC palm^{-1} year^{-1} (N0), 3.75 kg AC^{-1} palm year^{-1} (N1) and 7.5 kg AC palm^{-1} year^{-1} (N2). The K source was Muriate of Potash (MOP) (K = 49.8%) which was applied at 0 kg MOP palm^{-1} year^{-1} (K0) and 4.5 kg MOP palm^{-1} year^{-1} (K1). Jordanian Rock Phosphate (JRP) was used as a source of P with application rates of 4.0 kg JRP palm^{-1} year^{-1} (P2) and 0 kg JRP palm^{-1} year^{-1} (P0).

The soil water sampler was a standard vacuum lysimeter (Soil Moisture Equipment Corp., Santa Barbara, Canada; Model: 1900L), which was commonly used for studying pore liquid sampling from vadose zone in order to measure leaching losses[18,33]. It is also called a suction lysimeter. It comprised a Polyvinyl Chloride (PVC) tube with an external diameter of 4.85 cm and a porous ceramic cup with length of 5.8 cm mounted to one end. To install the lysimeter, a vertical hole was drilled with a soil auger, which had a diameter similar to that of the lysimeter. To optimise the contact surface between the suction ceramic cup and the soil, a small amount of slurry with the soil material from the auger was made and poured back into the hole before inserting the suction lysimeter. Once the lysimeter was located at the correct depth, the hole was backfilled with the same soil material from the auger. The soil was then stamped firmly around the lysimeter to prevent surface water from running down the cored hole. In order to study the downward movement of N and K nutrients, the lysimeters were installed at depths of 30, 60 and 120 cm in each treatment.

The monitoring well was constructed based on the principle described by Bouwer[19]. It comprised a PVC pipe with an external diameter of 6.0 cm. Due to soil and geological constraint, monitoring wells were only installed in 6 plots with treatments comprising N0P0K0, N0P2K1, N1P2K1 and N1P2K0, N2P2K1. The water samples from both lysimeter and monitoring well were collected at 15 day intervals starting from the first fertilizer application on 23/9/2008. The samplings were carried out for a period of 5 months from October 2008 to February 2009 (150 days) or a total of 10 samplings, which basically covered the entire monsoon period in Sabah.

All water samples were collected and stored in a narrow mouth polyethylene bottle with cap[34]. In this study, water samples collected from the monitoring well was referred to as groundwater[19,20] and that from the lysimeter at 120 cm depth as leachate[35]. The samples were preserved with 2-4 mL of chloroform per litre of water to retard bacteria decomposition prior to laboratory analysis. Samples were then analysed immediately upon arrival at the laboratory or were refrigerated at 4°C if analysis cannot be carried out on the same day[34]. Samples were filtered and analysed for ammonium-N (NH_4-N) using automated phenate method, nitrate N (NO_3-N) + nitrite N (NO_2-N) and NO_2-N using automated hydrazine reduction method on a Bran and Luebbe AutoAnalyzer 3[34]. Potassium (K) concentration was analysed using flame photometric method with a Sherwood flame photometer[34]. The concentration of total inorganic N was calculated as the sum of N concentration in each form of inorganic N

(NH_4-N + NO_3-N + NO_2-N) in the sample. NO_3-N concentration was obtained by subtracting NO_3-N + NO_2-N with NO_2-N.

The experiment was carried out using a split plot design where fertilizer treatments were randomised in the main plots and depths of lysimeter in the sub plots. To test treatment effects on leaching over time, analysis of variance was performed using GenStat statistical software by treating times of sampling as repeated measures. The effect of fertilizer treatments on groundwater was examined by regarding the fertilizer x time as a factorial combination without replication and the higher interaction was used as an error term.

RESULTS

Ammonium nitrogen: The mean NH_4-N concentration of N1P2K1 at 33.69 mg L^{-1} was significantly higher than N1P2K0 at 8.15 mg L^{-1} (Fig. 1). Both treatments had higher NH_4-N concentrations than treatments without N (N0P0K0 and N0P2K1). In the presence of K, NH_4-N concentrations increased 4.1 fold when N fertilizer was applied and 3.5 times in the absence of N application.

Most of the NH_4-N was found in the top 60 cm of the soil profile where majority of the palm roots may be located[7]. However, the mean NH_4-N concentrations decreased significantly with soil depth (Fig. 2). It was 17.89 mg L^{-1} at 30 cm depth declining to 12.19 and 6.52 mg L^{-1} at soil depths of 60 and 120 cm, respectively. The decline in NH_4-N concentration was more rapid between 30 and 60 cm compared with the lower soil depths.

The changes in NH_4-N concentrations among fertilizer treatments and between soil depths varied significantly across time (Fig. 3 and 4). At day 15, which was the first sampling date after treatments, the NH_4-N concentrations in the soil solution of N0P0K0 and N0P2K1 were 1.99 and 5.48 mg L^{-1}, respectively (Fig. 3). This indicated that even without N fertilizer, there were NH_4-N ions present in the soil solution probably from the native soil N and decaying palm biomass. These values provided the baseline NH_4-N concentrations in the soils in the experimental site implying poor N fertility. With N treatments, N1P2K0 and N1P2K1, the NH_4-N concentrations at the 15^{th} day were 20.82 and 121.35 mg L^{-1}, respectively. The NH_4-N concentrations of N1P2K1 treatment decreased sharply between day 15 and day 30 and then more gradually until it reached 1.86 mg L^{-1} at day 150. However, the NH_4-N concentrations were statistically similar to the baseline values from day 75 after treatment. The NH_4-N concentrations of N1P2K0 also declined rapidly and reached the baseline value 30 days after treatment. It continued to decrease to 1.60 mg L^{-1} at day 150.

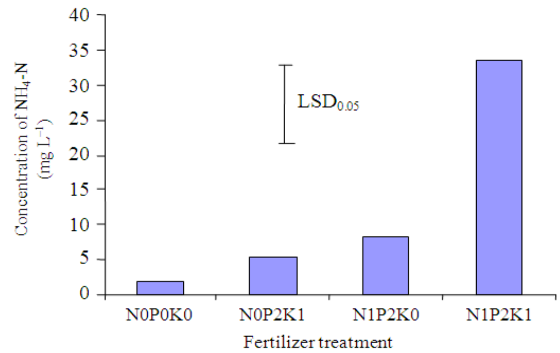

Fig. 1: Concentration of NH_4-N in soil solution for each fertilizer treatment

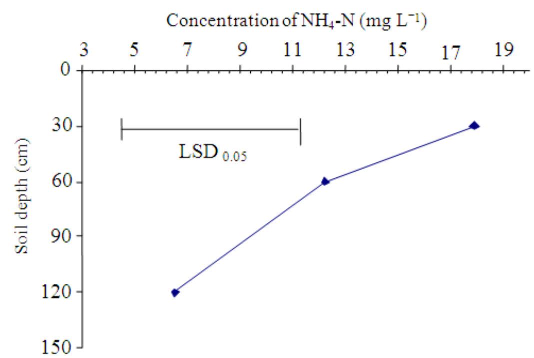

Fig. 2: Concentration of NH_4-N in soil solution across soil vertical profile

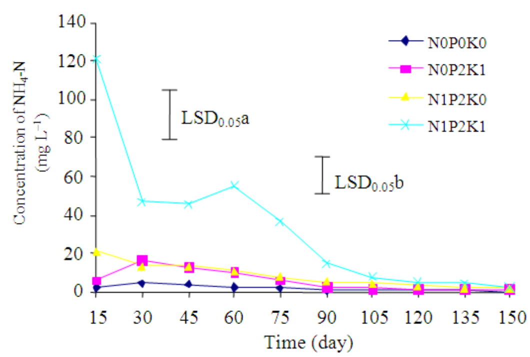

Fig. 3: Fertilizer × time effect on concentration of NH_4-N in soil solution (a) for comparing two times at difference level of treatments (b) for comparing two times at the same level of treatments

Fifteen days after treatments, the NH_4-N concentrations in the soil solution were similar at soil depths of 30 and 60 cm (Fig. 4). They were 40.45 and 50.55 mg L^{-1}, respectively and both concentrations were higher than at 120 cm depth of 21.23 mg L^{-1}.

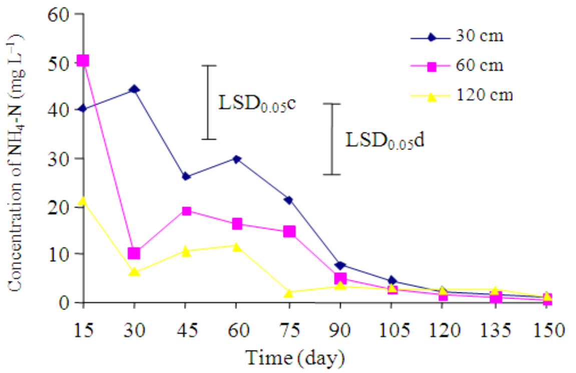

Fig. 4: Depth × time effect on concentration of NH_4-N in soil solution (c) for comparing two times at difference level of depths (d) for comparing two times at the same level of depths

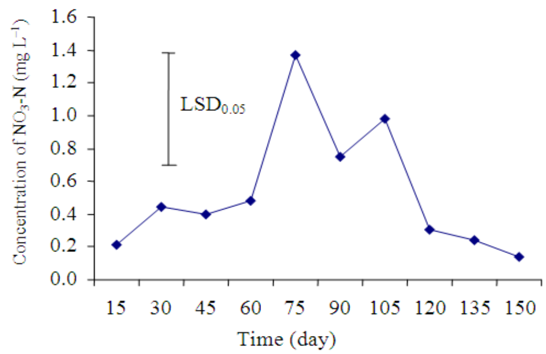

Fig. 5: Concentration of NO_3-N in soil solution over time

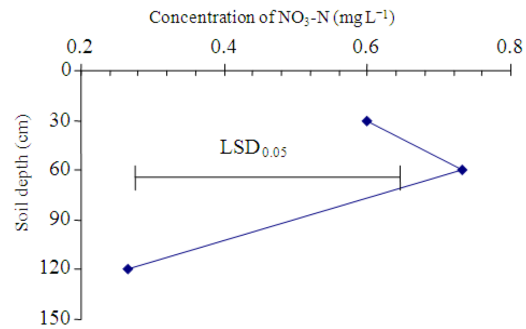

Fig. 6: Concentration of NO_3-N in soil solution across soil vertical profile

The NH_4-N concentrations in all soil depths decreased rapidly and reached similar values after 90 days from treatments. The NH_4-N concentration at day 150 at 30 cm depth was 1.1 mg L^{-1}, 60 cm depth 0.73 mg L^{-1} and 120 cm depth 1.32 mg L^{-1} (Fig. 4).

Nitrate nitrogen: The average NO_3-N concentration at 15 days after treatment was low at 0.214 mg L^{-1} (Fig. 5). It gradually rose to 0.485 mg L^{-1} at day 60. A period of relatively dry weather between day 45 and 60 seemed to enhance nitrification resulting in the NO_3-N concentration increasing significantly to 1.37 mg L^{-1} at day 75. However, it declined continuously to 0.141 mg L^{-1} at day 150 indicating that the transformation of NH_4-N to NO_3-N was not a major process during the monsoon period.

The mean NO_3-N concentrations between 30 and 60 cm soil depth were 0.599 and 0.732 mg L^{-1}, which were significantly higher than at 120 cm soil depth of 0.266 mg L^{-1} (Fig. 6). The proportion of NO_3-N to total inorganic N was in the range of 0.03-0.06 only indicating relatively low nitrification rate.

Total inorganic nitrogen: The total inorganic N was mainly composed of NH_4-N and thus the effects of fertilizer treatments on its concentrations were similar to NH_4-N concentrations as discussed earlier. Briefly, the total inorganic N concentration of N1P2K1 at 35.03 mg L^{-1} was significantly higher than the other three fertilizer treatments (Fig. 7). Although the total inorganic N concentrations in the first three treatments were statistically insignificant, there was a clear trend showing higher N concentrations in the presence of K (6.09 mg L^{-1}) and N (8.45 mg L^{-1}) compared with control (1.69 mg L^{-1}) as shown in Fig. 7.

The mean total inorganic N concentration at 30 cm soil depth was 18.71 mg L^{-1} decreasing to 12.94 mg L^{-1} at 60 cm depth and 6.79 mg L^{-1} at 120 cm. Thus, 150 days after fertilizer treatments, a large proportion of inorganic N was still found in the top 60 cm soil depth where most palm roots were present despite the high rainfall during the monsoonal period.

The three factor interaction, fertilizer × depth × time, was significant for total inorganic N concentration. This significant interaction was mainly due to the sharp increase in inorganic N concentration upon the applications of N and K fertilizers, N1P2K1, compared with those without N input. For example, the inorganic N concentrations of N0P0K0 were very low and fluctuated between 0.37-12.11 mg L^{-1} at 30 cm soil depth over the 150 days of measurements after treatment (Fig. 9). They were even lower with inorganic N concentrations ranging from 0.39-1.75 and 0.32-1.10 mg L^{-1} at 60 and 120 cm depth, respectively. In contrast, the inorganic N concentration of N1P2K1 at 30 cm depth was about 10 fold higher at 127 mg L^{-1} just 15 days after application.

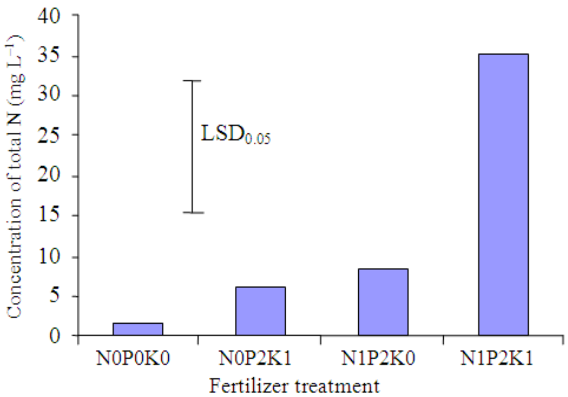

Fig. 7: Concentration of total inorganic N in soil solution for each fertilizer treatment

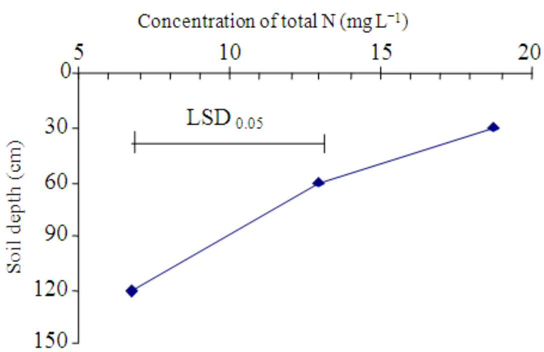

Fig. 8: Concentration of total inorganic N in soil solution across soil vertical profile

In fact, the inorganic N seemed to have move downwards to at least 60 cm depth where its N concentration was even higher at 179 mg L^{-1}. However, at all soil depths, the inorganic N concentrations of N1P2K1 decreased rapidly where by 105 days after treatments, they were similar to the other treatments except at 120 cm depth. The inorganic N concentrations appeared to hover around 13.5 mg L^{-1} between 90 and 135 days after treatment (Fig. 9) before declining to 4.3 mg L^{-1} at day 150.

Potassium: Similar to N, the K concentrations in the soil solution decreased with soil depth where the concentrations were 105, 75 and 48 mg L^{-1} at 30, 60 and 120 cm soil depth respectively (Fig. 10). However, unlike N, the decline in K concentration was much smaller and between 30 and 120 cm, it was only about 2 fold.

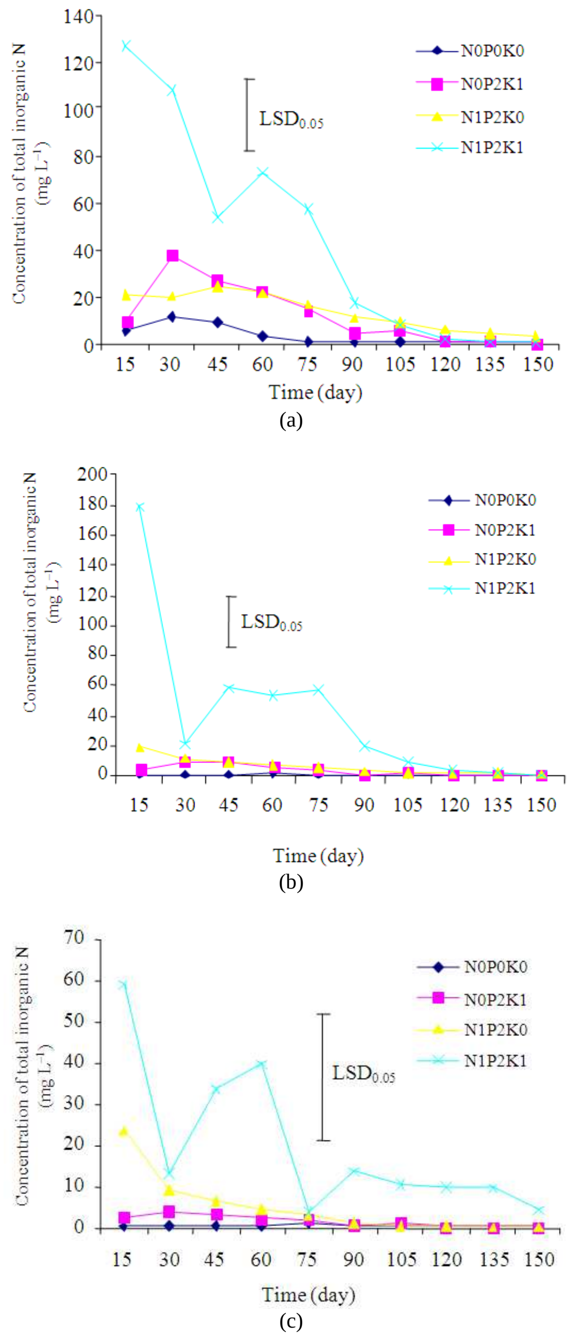

Fig. 9: Effect of fertilizer × time × depth on concentration of total inorganic N in soil solution (a) 30 cm depth (b) 60 cm depth (c) 120 cm depth

In the absence of K application such as treatments, N0P0K0 and N1P2K0, the K concentrations were very low ranging from 1.3-10.7 mg L^{-1} (Fig. 11). Upon K application, the K concentrations were increased to

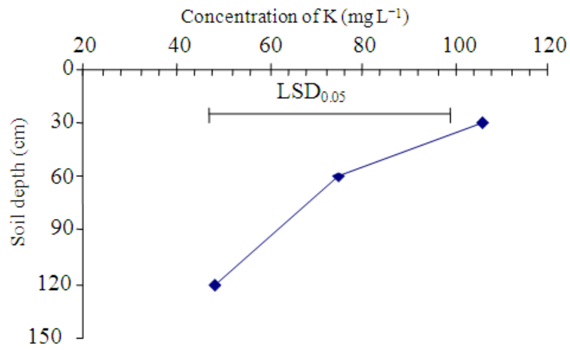

Fig. 10: Concentration of K in soil solution across soil vertical profile

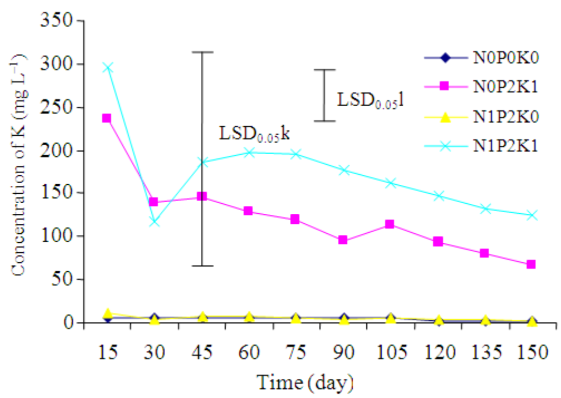

Fig. 11: Fertilizer × time effect on concentration of K in soil solution (k) for comparing two times at different level of treatments (l) for comparing two times at the same level of treatments

237 mg L^{-1} after just 15 days in N0P2K1 and 295 mg L^{-1} in N1P2K1. The K concentrations for both treatments then decreased rapidly in the next 15 days before a more gradual decline was observed. At day 150, the K concentration of N0P2K1 was 67 mg L^{-1} and that of N1P2K1 was 126 mg L^{-1}. The difference in K concentration at day 150 was about 59 mg L^{-1} which was similar to the differential at day 15 suggesting that the trend lines over time were parallel for both treatments. It also implied that this differential K concentration was due to the displacement of exchangeable K to the soil solution by NH_4^+ and the "disappearance" of K from the soil solution across time was not affected by N application.

Leaching losses at 120 cm soil depth: The amount of leaching losses measured at 120 cm soil depth over 150 days was based on the volume of soil solution

Table 1: Cumulative leaching losses of N and K fertilizers under mature oil palms as influenced by fertilizer treatments

Fertilizer treatment	Leaching losses ($g\ m^{-2}$) NH_4-N	NO_3-N	Total N	K	Leaching losses (%) N	K	Yield (kg $palm^{-1}\ year^{-1}$)
N0P0K0	0.036	0.0061	0.043	0.089			175
N0P2K1	0.051	0.0055	0.057	6.349		5.3	203
N1P2K0	0.300	0.0194	0.320	0.090	1.0		209
N1P2K1	0.554	0.0342	0.589	2.922	1.6	2.4	264
$LSD_{0.05}$	1.212	0.0408	1.251	11.43			

and nutrient concentrations for two replicates only to avoid missing values (Table 1). The leaching losses of inorganic N ranged from 0.043-0.589 g m^{-2}. For treatment, N1P2K1, it translated into a leaching loss of N of only 1.6% of the applied N fertilizer. This was agreeable with the results of Foong[10] for mature palms. Most of the N loss was in the form of NH_4-N since nitrification rate seemed low in the soils.

Without the application of K fertilizer, the leaching losses of K were only 0.09 g m^{-2} (Table 1). Applications of K fertilizer increased the leaching losses of K over 150 days to 6.35 and 2.92 g m^{-2} for N0P2K1 and N1P2K1, respectively (Table 1). These were equivalent to 5.3 and 2.4% of the applied K fertilizer for the above treatments, respectively. The higher K losses from the applied fertilizer in the absence of N (N0P2K1) might be attributed to the poorer yield compared with N1P2K1 and thus, lower K uptake from the soils by the palms (Table 1).

Groundwater quality: The NH_4-N concentrations in the groundwater of the monitoring wells were similar for N treatments at N0 or N1 rate regardless of K application rate (Fig. 12). They were mainly below the WHO's maximum admissible limit of drinking water of 0.5 mg L^{-1}. However, when excessive N rate, which was about twice the optimal N rate for oil palm, was applied, the NH_4-N concentration in the groundwater was increased to 2.7 mg L^{-1}. This indicated that contamination of the groundwater of monitoring well might occur if large amount of unabsorbed N from soluble N fertilizer was present in the soils during the monsoon period.

The NO_3-N concentrations in the groundwater were also raised by the applications of N fertilizer ranging from 0.07-0.25 mg L^{-1} (Fig. 12). However, they were all below the WHO's maximum admissible limit of drinking water of 10 mg L^{-1}.

Without K application, the K concentrations in the groundwater were very low at less than 1 mg L^{-1} (Fig. 12). The applications of K fertilizer increased the K concentrations of groundwater to between 4.28 and 9.54 mg L^{-1}. The higher concentration of K in the groundwater in the absence of N (N0P2K1) compared with N1P2K1 might be contributed by the higher leaching losses due to poorer K uptake by the palm as reflected the poorer yield (Table 1). However, only when excessive rate of N was applied (N2P2K1), the concentration of K in the groundwater was increased which was higher than at N0P2K1 and N1P2K1.

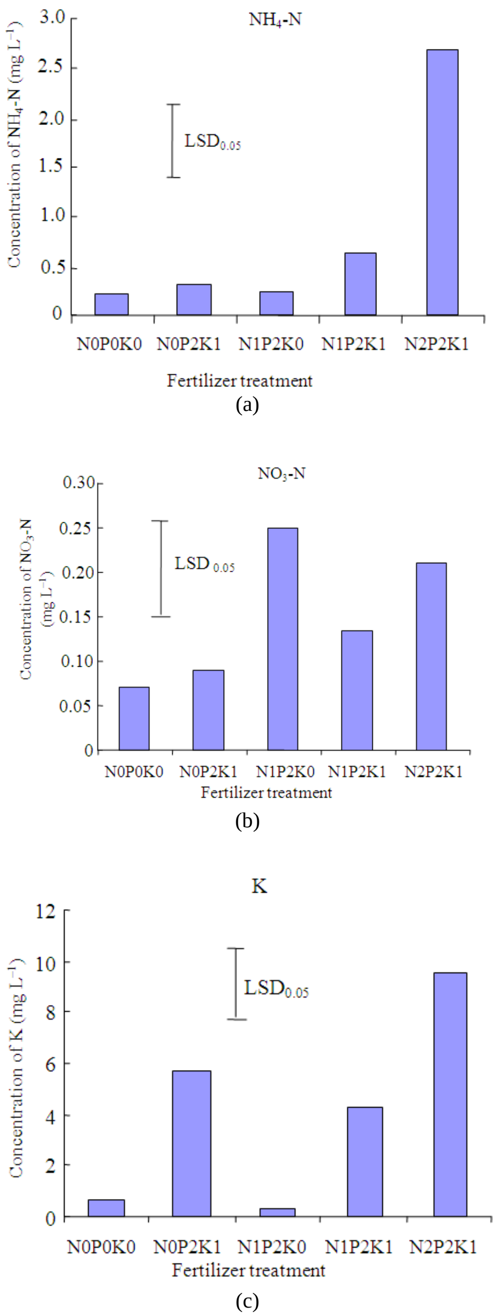

Fig. 12: Effect of fertilizer treatments on groundwater quality

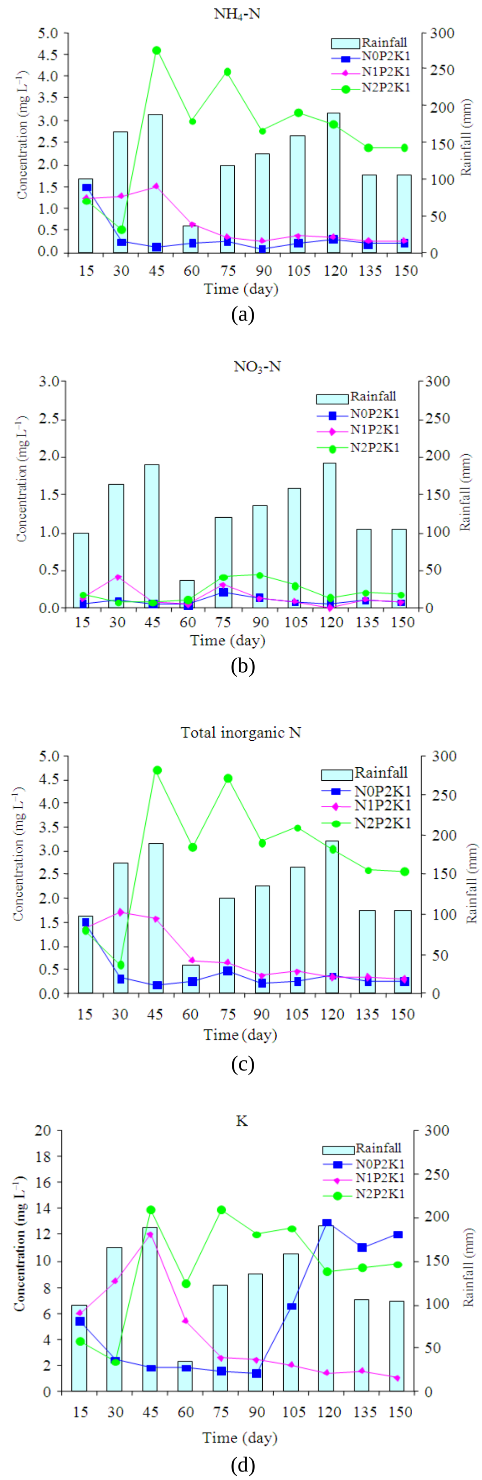

Fig. 13: Rainfall pattern and N and K concentrations in groundwater during the monsoon period (Oct 08-Feb 09) in Sabah at 15 days interval for a period of 150 days

Rainfall pattern and nutrient concentrations in groundwater in monitoring well: The NH_4-N concentrations were relatively similar between the fertilizer treatments in the first 30 days after application (Fig. 13). However, the continuous heavy rains over the next 15 days resulted in a sharp rise in NH_4-N concentration in the groundwater of N2P2K1. It then showed a declining trend in NH_4-N concentration although high rainfall tended to increased it temporary. The NH_4-N concentration in the groundwater of N1P2K1 started to decrease 45 days after fertilizer application whereas in N0P2K1 treatment, it declined to its baseline value after only 30 days. The NH_4-N concentrations of both treatments were similar from day 75 onwards.

The NO_3-N concentrations in the groundwater of all fertilizer treatments were low but despite this, the fluctuations in NO_3-N concentration seemed to correspond with the rainfall pattern particularly for N2P2K1 (Fig. 13). The temporal variation in total inorganic N concentrations was similar to NH_4-N concentrations since the latter ion dominated the fraction of inorganic N (Fig. 13).

The K concentrations in the groundwater of the fertilizer treatments, N2P2K1, N1P2K1 and N0P2K1, were similar 15 days after applications. However, the heavy rains between day 15 and 45 which caused an increase in NH_4-N concentration as discussed above probably also displaced soil K with consequent higher K concentrations in the groundwater of treatments, N2P2K1 and N1P2K1. In treatment N2P2K1, the K concentration declined during the period of 45-60 day when rainfall was low before increasing again probably due to the excess applied K reaching the groundwater. However, the same effect was not seen in treatment, N1P2K1, because there was no excess K^+ reaching the groundwater. Without N, the K concentration in the groundwater declined continuously until 90 day before it increased again. This implied that it took about 90 days before the applied K which was not absorbed by the palms reached the groundwater during the monsoon period.

DISCUSSION

Downward movement of N and K: The concentrations of inorganic N in the soil solutions throughout the vertical soil profile were mainly dominated by NH_4^+ ion rather than NO_3^- because the source of N fertilizer was ammonium chloride. Significant increased in NO_3-N in the soil solution was only observed 75 days after fertilizer application. This implied that nitrification was relatively slow in the soil during the monsoon period. This might be attributed to the high NH_4^+ concentration which inhibits the activity of nitrifiers in the soils and the low soil organic matter which reduces the population of nitrifiers[40].

The concentrations of N and K in the soil solution decreased with soil depth being highest at 30 cm from the soil surface followed by 60 and 120 cm. Similar findings were reported by Schroth *et al.*[32]. This nutrient profile might be partially explained by dilution effect as the solubilized N and K fertilizers seeped downward with the surplus soil moisture from the high rainfall during the monsoon period. Besides this, nutrient uptake by palm roots will remove some of these ions resulting in lower nutrient concentrations in the soil solution with deeper soil depth. Furthermore, Kee *et al.*[36] reported that roots reduced the movement of exchangeable K down the soil profile. This implied that soil solution K^+ as well as NH_4^+ also reduced as ions moved downward. At all three depths, higher concentration of inorganic N was obtained at N1P2K1 compared with N1P2K0. This could be to K enhancing the downward movement of NH_4^+ in the soil solution[37].

We also found higher K concentration in the soil solution when N was applied (N1P2K1 versus N0P2K1). This could be due to the displacement of K^+ from the soil colloidal surfaces to soil solution by NH_4^+ from the nitrogen fertilizer. Moreover, vegetative uptake of NH_4^+ will increase the production of H^+ in the soil[38] which then displaced K^+[15] into the soil solution.

Forty five days after fertilizer application, the NH_4^+ concentration in the top 30 cm was significantly lower by about 33% (Fig. 4). Although part of the NH_4^+ disappearance can be accounted for by palm uptake, probably a larger amount had moved beyond its depth as indicated by the increased NH_4^+ concentrations in the lower soil depths. By 105 days, almost all the applied NH_4^+ had disappeared from the top 30 cm of the soil profile. The rate of decline in NH_4^+ concentration in the soil solution was about 1.3 mg L^{-1}. Thus, the interval of applying N fertilizer during the monsoon period should be between 90 and 105 days to avoid excess NH_4^+ in the soil solution. The disappearance of total inorganic N in the top 30 cm was even more rapid when both N and K fertilizers were applied (Fig. 9). The rate of decline in K^+ concentration was about 1.4 mg L^{-1} and virtually all the applied K disappeared at about the same time as NH_4^+ ion since both nutrients are likely to move down the profile together[36].

N and K leaching losses: The amount of N and K in the leachate obtained at 120 cm depth are considered as leaching losses since most oil palm roots are found within the top 60 cm of the soils[7,39]. The quantity of N and K leaching losses in this study were a function of the volume of water in the soil, fertilizer treatment and rate of nutrient uptake by the palm roots. The overall leaching losses of inorganic N were 1.0 and 1.6% of the applied fertilizer for N1P2K0 and N1P2K1, respectively. This conforms with the findings of Chang and Zakaria[9] and Foong[10]. These authors ascribed the low N leaching losses under mature oil palms to the high uptake of both soil moisture and N to sustain productivity. The N leaching loss was higher in the presence of K fertilizer due to the displacement of NH_4^+ ion by K^+ ion as discussed earlier.

The K leaching losses were higher than N at 5.3 and 2.4% for N0P2K1 and N1P2K1, respectively. These results were agreeable with those of Foong[10] where K leaching rate was higher than N in the higher weathered tropical soils. Unlike N, the K leaching losses were lower in the presence of N fertilizer. This might be indirectly related to better K uptake by the palms in well balanced fertilizer treatment resulting in better productivity (Table 1) and thus, higher K off-take via the fresh fruit bunches which contain large amount of K[7]. The consequent is lower K^+ concentration in the soil solution.

Groundwater quality: The groundwater quality was only affected by the NH_4^+ where its concentration went beyond the WHO[30] limit of 0.5 mg L^{-1} when N fertilizer was applied at twice the optimum rate for oil palms. This was mainly contributed by the large amount of unabsorbed N from the soluble N fertilizer which was still present in the soils during the monsoon period. The concentration of NO_3-N in the groundwater was very low at 0.5 mg L^{-1} even at the highest N fertilizer rate tested which agreed with our contention that nitrification rate was low in this soil. The NO_3-N concentration was far below the maximum limit set by WHO[30], which was 10 mg L^{-1}. Most of the N from the fertilizer that reached the groundwater in the monitoring well was mainly dominated by NH_4^+ rather than NO_3^+ which corresponded well with the composition of inorganic N in the soil solution as discussed earlier.

The applications of K fertilizer increased the K mean concentrations of groundwater to between 4.28 and 9.54 mg L^{-1} which were below the WHO[30] limit of 12 mg L^{-1}. The higher K concentration in the groundwater in the absence of N (N0P2K1) compared with N1P2K1 might be partially explained by its higher leaching losses due to poorer K uptake by the palm. Nevertheless, in certain days during the monsoon period, the K concentration in the well exceeded 12 mg L^{-1} but it was only for a short period and only occurred when excessive N (N2) was applied. Furthermore, the K rate in this study was above the optimum rate for oil palm to ensure its sufficiency for full expression of yield responses to N and P.

CONCLUSION

The downward movement of N fertilizer was mainly in the form of NH_4-N with very little NO_3-N because the source of fertilizer was NH_4Cl. This study also indicated that the rate of nitrification was probably slow during the monsoon period. The concentration of N and K in the soil solution decreased with soil depth being highest at 30 cm from the soil surface followed by 60 and 120 cm. The N leaching losses of the applied N fertilizer during the monsoon period in Sabah, North Borneo were 1.0 and 1.6% for treatments, N1P2K0 and N1P2K1, respectively. Higher K leaching losses were obtained at 5.3 and 2.4% for N0P2K1 and N1P2K1, respectively. The groundwater quality under mature oil palms did not exceed the contamination level set by WHO when N and K fertilizers were applied at their optimum rates for oil palm. However, there was a possibility of pollution of groundwater quality when excessive N fertilizer was applied which was mainly in the form of NH_4^+ ion. The concentration of NO_3^- ion in the groundwater was below 0.5 mg L^{-1} even when excessive N fertilizer was applied due to low nitrification rate.

ACKNOWLEDGEMENT

The first researcher and her colleagues would like to thank their Principals, Boustead Plantations Bhd. and Kuala Lumpur Kepong Bhd. for permission to publish this study. We also appreciate our colleagues and support staff in Sabah for their assistance in conducting this experiment. This research was financially funded by the Advanced Agriecological Research Sdn. Bhd. Malaysia.

REFERENCES

1. Schroth, G., L.F. da Silva, R. Seixas, W.G. Teixeira, J.L.V. Macedo and W. Zech, 1999. Subsoil accumulation of mineral nitrogen under polyculture and monoculture plantations, fallow and primary forest in a ferralitic Amazonian upland soil. Agric. Ecosyst. Environ., 75: 109-120. DOI: 10.1016/S0167-8809(99)00068-7

2. Moody, L.E., 2006. Leaching and Illuviation. In: Encyclopedia of Soil Science, Lal, R. (Ed.), 2nd Edn., Marcel Dekker, USA., ISBN: 10: 0849350530, pp: 1022-1025.
3. Buol, S. W Southard, R.J., Graham, R.C. and McDaniel, P.A. 2003. Soil Genesis and Classification. 5th Edn., Iowa State Press, Ames. ISBN: 10:0-8138-2873-2, pp. 1-117
4. Tan, K.H., 1994. Environmental Soil Science. Marcel Dekker, New York, pp: 304. http://orton.catie.ac.cr/cgi-bin/wxis.exe/?IsisScript=BFHIA.xis&method=post&formato=2&cantidad=1&expresion=mfn=006213
5. Saffigna, P.G and I.R. Philips, 2006. Fertilizers: Leaching Losses. In: Encyclopedia of Soil Science, Lal, R. (Ed.), 2nd Edn., CRC Press, USA., ISBN: 0849350530, pp: 688-690.
6. Henson, I.E., 1999. Comparative Ecophysiology of Oil Palm and Tropical Rainforest. In: Oil Palm and the Environment-a Malaysian Perspective, Gurmit Singh *et al.* (Eds.). Malaysian Oil Palm Growers Council, Kuala Lumpur, Malaysia. ISBN: 983-808-098-5, pp: 9-39.
7. Corley, R.H.V. and P.B.H. Tinker, 2003. The Oil Palm (World Agriculture Series). 4th Edn., Wiley-Blackwell, Oxford UK., ISBN: 978-0-632-05212-7, pp: 592.
8. Omoti, U., D.O. Ataga and A.E. Isenmila, 1983. Leaching losses of nutrients in oil palm plantations determined by tension lysimeters. Plant Soil, 73: 365-376. DOI: 10.1007/BF02184313
9. Chang, K.C. and A. Zakaria, 1986. Leaching losses of N and K fertilizers from mature fields of perennial crops in Malaysia-A review of local work. Planter, Kuala Lumpur, 62: 468-487. http://www.fao.org/agris/search/display.do?f=./1987/v1318/MY8605822.xml;MY8605822
10. Foong, S.F. 1991. Potential evaporation, potential yield and leaching losses of oil palm, Proceeding of the 1991 PORIM International Palm Oil Conference, Sept. 9-14, Agriculture Palm Oil Research Institute, Malaysia, pp: 105-119. http://www.bookfinder.com/dir/i/Proceedings_1991_PORIM_International_Palm_Oil_Conference-Progress,_Prospects/9679610284/
11. Paramasivam, S. and A.K. Alva, 1997. Leaching of nitrogen forms from controlled-release nitrogen fertilizers. Commun. Soil Sci. Plant Anal., 28: 1663-1674. http://cat.inist.fr/?aModele=afficheN&cpsidt=2117831
12. Owens, L.B., W.M. Edwards and R.W. van Keuren, 1999. Nitrate leaching from glassed lysimeters treated with ammonium nitrate or slow release nitrogen fertilizer. J. Environ. Q., 28: 1810-1816. http://jeq.scijournals.org/cgi/content/abstract/28/6/1810
13. Maedaa, M., B. Zhaoa, Y. Ozakia and T. Yoneyama, 2003. Nitrate leaching in an Andisol treated with different types of fertilizers. Environ. Pollut., 121: 477-487: DOI: 10.1016/S0269-7491(02)00233-6
14. Broschat, T.K. and K.K. Moore, 2007. Release rates of ammonium-nitrogen, nitrate-nitrogen, phosphorus, potassium, magnesium, iron and manganese from seven controlled-release fertilizers. Commun. Soil Sci. Plant Anal., 38: 843-850. DOI: 10.1080/00103620701260946
15. Van Es, H.M., K.J. Czymmek and Q.M. Ketterings, 2002. Management effects on nitrogen leaching and guidelines for a nitrogen leaching index in New York. J. Soil Water Conserv., 57: 499-504. http://www.jswconline.org/content/57/6/499.abstract
16. Pedersen, L.B., C.J. Christensen and M. Ingerslev, 2006. Leaching versus input of nitrogen, potassium and magnesium in different fertilizer regimens in Christmas tree stands of *Abies nordmanniana* in Denmark Scandinavian. J. For. Res., 21: 130-142. DOI: 10.1080/02827580600614083
17. Adomaitis, T., Z. Vaisvila, J. Mazvila, G. Staugaitis and M.A. Fullen, 2008. Influence of mineral fertilizer on nitrogen leaching. Acta Agric. Scandinavica, Sec. B-Plant Soil Sci., 58: 3199-207. DOI: 10.1080/09064710701593012
18. Aparicio, V., J.L. Costa and M. Zamora, 2008. Nitrate leaching assessment in a long-term experiment under supplementary irrigation in humid Argentina. Agric. Water Manage., 95: 1361-1372. DOI: 10.1016/j.agwat.2008.06.003
19. Bouwer, H., 1978. Groundwater Hydrology. McGraw Hill, USA., ISBN: 0-07-006715-5, pp: 480.
20. Price, M., 1996. Introducing Groundwater. 1st Edn., Routledge, UK., ISBN: 10: 0748743715, pp: 304.
21. Phillips, I. and E. Burton, 2005. Nutrient leaching in undisturbed cores of an acidic sandy Podosol following simultaneous potassium chloride and di-ammonium phosphate application. Nutr. Cycl. Agroecosyst. 73: 1-14: DOI: 10.1007/s10705-005-6080-8

22. Owens, L.B., R.W. Malone, M.J. Shipitalo, W.M. Edwards and J.V. Bonta, 2000. Lysimeter study of nitrate leaching from a corn-soybean rotation. J. Environ. Qual., 29: 467-474. http://jeq.scijournals.org/cgi/content/abstract/29/2/467
23. Babiker, I.S., A.A. Mohamed, M.A.A. Mohamed, H. Teraob, K. Kato and K. Ohta, 2004. Assessment of groundwater contamination by nitrate leaching from intensive vegetable cultivation using geographical information system. Environ. Int., 29: 1009-1017. DOI: 10.1016/S0160-4120(03)00095-3
24. Ward, M.H., S.H. Zahm, D.D. Weisenburger, G. Gridley, K.P. Cantor and A. Blair *et al*., 1994. Dietary factors and non-Hodgkin's lymphoma in Nebraska (United States). Cancer Causes Control, 5: 422-432. DOI: 10.1007/BF01694756
25. Fan, A.M. and V.E. Steinberg, 1996. Health implications of nitrate and nitrite in drinking water: An update on methemoglobinemia occurrence and reproductive and developmental toxicity. Regul. Toxicol. Pharmacol., 23: 35-43. DOI: 10.1006/rtph.1996.0006
26. Gangolli, S.D., P.A. van den Brandt, V.J. Feron, C. Christine Janzowsky and J.H. Koeman *et al*., 1994. Nitrate, nitrite and N-nitrosocompounds. Eur. J. Pharmacol., 292: 1-38. http://grande.nal.usda.gov/ibids/index.php?mode2=detail&origin=ibids_references&therow=84345
27. Umezawa, Y., T. Hosono, S.I. Onodera, F. Siringan, S. Buapeng and C. Yoshimizu *et al*., 2009. Erratum to "Sources of nitrate and ammonium contamination in groundwater under developing Asian megacities. Sci. Total Environ., 407: 3219-3231. DOI: 10.1016/j.scitotenv.2009.01.048
28. Kolahchi, Z. and M. Jalali, 2007. Effect of water quality on the leaching of potassium from sandy soil. J. Arid Environ., 68: 624-639. DOI: 10.1016/j.jaridenv.2006.06.010
29. Bouman, B.A.M., A.R. Castaneda and S.I. Bhuiyan, 2002. Nitrate and pesticide contamination of groundwater under rice-based cropping systems: Past and current evidence from the Philippines Agriculture. Ecosyst. Environ., 92: 185-199. DOI: 10.1016/S0167-8809(01)00297-3
30. WHO., 1993. Guidelines for Drinking Water Quality. 2nd Edn., Geneva, World Health Organization, ISBN: 9241544600, pp: 118.
31. Griffioen, J., 2001. Potassium adsorption ratios as an indicator for the fate of agricultural potassium in groundwater. J. Hydrol., 254: 244-254. DOI: 10.1016/S0022-1694(01)00503-0
32. Schroth, G., M.R.L. Rodrigues and S.A. D'Angelo, 2001. Spatial patterns of nitrogen mineralization, fertilizer distribution and roots explain nitrate leaching from mature Amazonian oil palm plantation. Agric. Ecosyst. Environ., 87: 37-49. DOI: 10.1111/j.1475-2743.2000.tb00197.x
33. Askegaard, M. and J. Eriksen, 2008. Residual effect and leaching of N and K in cropping systems with clover and ryegrass catch crops on a coarse sand. Agric. Ecosyst. Environ., 123: 99-108. DOI: 10.1016/j.agee.2007.05.008
34. APHA., 1998. Standard Methods for the Examination of water and Wastewater. 20th Edn., American Public Health Association, Washington DC., ISBN: 0-87553-235-7, pp: 1200.
35. Canarache, A., I. Vintila and I. Munteanu, 2006. Elsevier's Dictionary of Soil Science. Elsevier, USA., ISBN: 978-0-444-82478-3, pp: 1360.
36. Kee, K.K, Goh, K.J and Chew, P.S. 1995. Effects of NK Fertilizer on soil pH and exchangeable K status on acid soils in an oil palm plantation in Malaysia. In plant-soil interactions at low pH: Principles and management. Proceedings of the 3rd International Symposium on Plant Soil Interactions at Low pH, (PSIL'95), Kluwer Academic, Brisbane, Queensland. Netherlands, pp: 809-815.
37. Currie, W.S., J.D. Aber and C.T. Driscoll, 1999. Leaching of nutrient cations from the forest floor: Effects of nitrogen saturation in two long term manipulations. Can. J. For. Res., 29: 609-620. DOI: 10.1139/cjfr-29-5-609
38. Galloway, J.N., 1995. Acid deposition: Perspectives in time and space. Water, Air, Soil Pollut., 85: 15-24. http://cat.inist.fr/?aModele=afficheN&cpsidt=3028476
39. Jordan, C. and H. Rey, 1997. Architecture and development of the oil-palm (*Elaeis guineensis Jacq*.) root system. Plant Soil, 189: 33-48. DOI: 10.1023/A:1004290024473
40. Erickson, H., M. Keller and E.A. Davidson, 2001. Nitrogen oxide fluxes and nitrogen cycling during postagricultural succession and forest fertilization in the humid tropics. Ecosystems, 4: 67-84. DOI: 10.1007/s100210000060