# RETENTION OF MACRONUTRIENTS IN A SANDY SOIL AMENDED WITH VERMICULITE UNDER TANZANIAN FIELD CONDITIONS

Ernest M.M. Marwa, Andrew A. Meharg, and Clive M. Rice

1. Department of Plant and Soil Science, University of Aberdeen, Cruickshank Building, AB 24 3UU, United Kingdom. E-mail: a.meharg@abdn.ac.uk

2. Department of Geology and Petroleum Geology, University of Aberdeen, Meston Building, AB24 3UE, UK. E-mail: c.rice@abdn.ac.uk.

Present address: Department of Soil Science, Sokoine University of Agriculture, P. O. Box 3008, Morogoro, Tanzania. E-mail: emagesa@yahoo.com.

**Abstract**

The study assessed the ability of vermiculite to enhance the retention of extractable nitrogen (N), phosphorus (P), and potassium (K) in arable Tanzanian soils. Raw and expanded vermiculites pre-heated at 600 oC were mixed with a sandy soil in varying amounts. Inorganic fertilizers N, P and K were added to the soil-vermiculite mixes and buried at 0-15 and 15-30 cm depth in litter bags for three months during the rainy season. After that period, extractable N, P and K retained in the mixes were determined. The result showed that less than 10% of the applied N was retained whereas for K it was 26-48%. Phosphorus was highly retained and in part fertilized from vermiculite over the control. The maximum extractable fertilizer P retained in soil amended with expanded vermiculite was 78%, whereas in soil with raw vermiculite it was 141%, suggesting that vermiculite also retains soil P mineralized over the course of the experiment. More retention of N, P and K occurred at 15-30 cm than at 0-15 cm and increased with the amount of vermiculite mixed with the soil. Thus, use of vermiculite enhances soil productivity by retaining extractable essential macronutrients which could be used for crop production.

Key words: Fertilizer; Nutrients; Retention; Sandy soil; Vermiculite

## INTRODUCTION

Crop productivity in many tropical countries, particularly in Africa, is generally low. Among the factors behind this low productivity is the poor capacity of some soils under crop production to retain adequate plant-available nutrients (Sanchez, 2002). Many tropical soils weather while losing their capacity to retain plant nutrients, resulting in poor soil fertility (Kellman, 2002). This problem is alleviated usually by manure and/or mineral fertiliser addition, but not all applied nutrients are effectively retained in the soil and made available to plants. Some nutrients are lost easily by leaching or lateral flow, whilst others volatilize as gases or get fixed in soil constituents (Sanchez, 2002). Thus, the application of plant nutrients alone is not a solution to the decline in crop yields and fertility status experienced in most tropical soils.

Many tropical soils generally have low organic carbon (C) and total nitrogen (N) contents because of low biomass production and a high rate of decomposition (Mokwunye et al., 1996). The low concentration and solubility of phosphorus (P) in soils frequently makes it a limiting factor in plant nutrition. Fixation of fertilizer P by many tropical soils is also another factor that is lowering its availability for plant uptake (Van der Eijk et al., 2006). Phosphorus deficiency is widespread in East Africa and the Sahel (Sanchez, 2002), including Tanzania, where this study was conducted. Loss of plant nutrients in tropical agricultural soils is high. For instance, it is estimated that 4.4 million tonnes of N, 0.5 million tonnes of P, and 3 million tonnes of potassium (K) are lost each year from cultivated land in Africa (Sanchez et al., 1997). That loss of nutrients is above the estimated rate of Africa's annual fertilizer consumption (FAO, 1995). The consequence of that trend is a decline in crop productivity and food security (Sanchez et al., 1997).

The main objective of this study was to investigate the role of vermiculite as a soil amendment in enhancing the retention of extractable N, P and K in the Tanzanian soils. Studies indicate that vermiculites have a high cation exchange capacity (CEC), broadly ranging between 50 and 150 cmol(+) kg-1 (Van Straaten, 2002). Field experience shows that a medium characterized by a high CEC can retain nutrients from leaching during irrigation (Tisdale et al., 1993), but it is not known to what extent vermiculite from Tanzania can do so. Nitrogen, P and K were selected because they are the dominant macronutrients required for plant growth. Of these, N and P are the most limiting nutrients in most tropical soils of Africa (Kwabiah et al., 2003).

## MATERIALS AND METHODS

Source of vermiculite Vermiculite (MK1) from Mikese area (06o 47′ 08″ S and 37o 54′ 35″ E) in the Neoproterozoic Mozambique Belt of Tanzania was used. Semi-quantitative X-ray analysis of this vermiculite indicates that it is composed of about 74% by weight R1 hydrobiotite and 25% by weight vermiculite and a small amount of apatite and monazite as inclusions (Marwa, 2009). Thus, it is essentially hydrobiotite rather than vermiculite in mineralogical sense, but commercially all are regarded as vermiculite (Frank and Edmond, 2001).

At the site, approximately 50 kg of MK1 were excavated from 2-2.5 m depth and air-dried in a glasshouse at the Sokoine University of Agriculture in Tanzania to a constant weight. Half of the sample was exfoliated by heating for one hour at 600 oC at the Southern and Eastern African Mineral Centre (SEAMIC) Laboratories in Tanzania. Both the unheated (raw) and heated (expanded) vermiculites were ground by hand to avoid structural degradation and sieved through an 8 mm sieve before mixing with a sandy soil.

Site description and soil classification The study was carried out at Mazimbu area in Morogoro Urban District, Tanzania from March to June 2007, during the long rainy season, locally known as ‘Masika’. Most crops in the country are grown during that period. The site is situated at latitude 06º 47' 02" S and longitude 37º 37' 34" E. It is well drained, undulating, colluvial plain with a uniform gentle slope of 2-3%. The site is known for its poor fertility potential and crop yield (personal communication with the local residence). Cassava and maize are some of the crops that are usually grown in the area. During 2005 and 2006, the area was under fallow.

The soil at the site was studied and its physical and chemical properties were established. A 170 cm depth soil profile was made at the site and a Mussel Colour Chart was employed in describing the soil horizons. Soil samples were taken from each horizon, air-dried at a room temperature to a constant weight, and sieved through a 2 mm sieve for laboratory analysis. Analysis of the soil properties was done at the Soil Science Laboratories of the Sokoine University of Agriculture, in Tanzania, using the methods of Okalebo et al. (2002) and Møberg (2001). The physiochemical properties of the soils found are located in Table 1. The soil was classified as Ustic Quartzipsamment based on the Soil Survey Staff (1996) and Orthidystric Arenosol according to FAO (1998). The soil was ideal for the study because of its poor status in plant nutrients and, thus, less interference with the treatments.

Site preparation and experimental design The soil adjacent to the site, 0-30 cm depth from the surface, was sampled, air-dried to a constant weight at room temperature, and sieved through an 8 mm sieve. The soil was mixed with raw vermiculite and pre-heated vermiculite MK1 (600 oC) in varying amounts. Amounts of vermiculite added to the soil were 0, 10, 20, 30, 40, and 50% volume by volume (v/v). A total of 12 treatments was obtained, 6 treatments of soil mixed with raw vermiculite and another 6 treatments of soil mixed with pre-heated vermiculite. Each treatment was replicated three times, giving a sum of 36 samples.

Two sets of samples were made, each with 36 samples. The first set comprised 36 samples from 12 treatments for burying at 0-15 cm from the surface while another set of 36 samples were for burying at 15-30 cm depth. Thus, the total samples used were 72. Each sample weighed one kg of dry weight. Sulphate of ammonia (240 mg N kg-1 soil), triple super phosphate (TSP) (160 mg P kg-1 soil), and sulphate of potash (200 mg K kg-1 soil) were applied to each soil/vermiculite mix, mixed well by hand, and packed into labelled sample bags. The TSP was ground before mixing.

The experimental site (10 m by 30 m) was cleared, ploughed, and harrowed to remove all vegetation in order to avoid interference from plant nutrient uptake. Two main plots were made, one for burying the samples at 0 -15 cm and another plot for burying the samples 15 -30 cm from the surface. Each plot was further subdivided into two sub-plots. One sub-plot was for replicated samples mixed with raw vermiculite and another sub-plot for replicated samples applied with pre-heated vermiculite.

Sample burial holes were made using a hoe. A ruler was used to check for the maximum depths (15 and 30 cm from the surface). In each hole, a small litter bag (polyethylene net) with a capacity of carrying about 2 kg of soil/vermiculite mix was inserted. The prepared samples were put into the litter bags and covered by soil. Sample locations were marked using labelled plastic pegs. The samples were spaced 150 cm apart in each of the sub-sub plots and were buried for 90 days. Weeding was done regularly by hand.

Rainfall and soil moisture at the site were recorded daily during the entire period of the field experiment. The rainfall was recorded using a rain gauge while soil moisture at 0-15 cm depth from the surface was automatically measured using time domain reflectometry (TDR) probes. The instruments were installed at the site by the Department of Soil Science of the Kyoto University from Japan.

After 90 days, the buried samples were carefully excavated, ground by hand, and sieved through a 2 mm sieve for laboratory analysis. Analysis of extractable nutrients retained by the soil/vermiculite mix was carried out at the University of Aberdeen, Department of Plant and Soil Science, in the United Kingdom. The samples were analysed for ammonium and nitrate after digestion with 1M KCl (Allen, 1989) by flow injection analysis (Tecator FIAstar 5010 Analyser). The samples for extractable P and K were digested by using acetic acid (Allen, 1989). Extractable P was determined by flow injection analysis (Tecator FIAstar 5010 Analyser), while the K was analysed by flame emission spectrometry (Perkin Elmer Aanalyst 100). All instruments are from International Scientific Instruments (ISI) of Europe.

Data analysis Analysis of variance (ANOVA) was done using the MSTATC software and separation of the treatment means were carried out using the Duncan's multiple-range test at the 5% level of significant (Freed et al., 1991).

## RESULTS AND DISCUSSION

Site rainfall and soil moisture Rainfall recorded at the site was low and unevenly distributed with several days of dry spells (Fig.1). The total precipitation was 216 mm. Daily rainfall distribution was between 0 - 30 mm, with 0.1 mm as the median. The total amount received was far below the average annual rainfall of 1042 mm received in the country (Agrawala et al., 2003). The low and erratic rainfall during growing seasons with periods of dry spells is a common phenomenon in most parts of Tanzania (Mapande and Reason, 2005).

Volumetric soil moisture content at the site was also low and ranged between 0.02 and 0.1 cm3/cm3 (Fig.1). The moisture content corresponded closely to the magnitude of precipitation, with high values obtained immediately after heavy rainfall. Although the soil texture influences moisture content, the short duration and low intensity of precipitation experienced at the site might have been the main contributing factors for the low moisture content. A similar observation has also been reported by Pan et al. (2008).

Fig.1. Site rainfall and soil moisture recorded from 6/3/07 to 6/6/07 during the field experiment in Tanzania. The curve represents the soil moisture content at 0-15 cm depth from the surface, while histograms denote the rainfall received at the site. (Source: Department of Soil Science, Kyoto University, Japan).

Retention and fertilization of plant nutrients in soil Vermiculite burial depth caused a significant difference ($P<0.05$) in the retention of extractable nitrate, K and P but not ammonium (Table 2). The retention of those nutrients was more at 15-30 cm than at 0-15 cm due to the variation in temperature and soil moisture from rainfall. Temperature and soil moisture from rainfall are the factors that enhance the solubility and mobility of the nutrients and are usually higher at the surface than at depth. The temperature enhances P solubility (Kwari and Batey, 1991), while more soil moisture increases the degree of P saturation and mobility (Casson et al., 2006) and, thus, more leaching of P at the surface than at depth. Similarly, more soil moisture from rainfall at the surface dissolves water soluble K+ and transport it down the soil profile. In addition, surface temperature enhances both the availability of exchangeable K+ (Grava et al., 1961) and the intensity of leaching during rainfall.

Table 2. Effect of burial depth on the retention of ammonium, nitrate, extractable P and K in soil amended with vermiculite

The applied N-fertilizer dissolves easily when there is sufficient soil moisture and undergoes hydrolysis to ammonium, via nitrification it leads to denitrification (Bijoor et al., 2008). Apart from nitrification and denitrification, N is also lost from agricultural soils by ammonia volatilization, a phenomenon that is enhanced with the increase in temperature and soil moisture (Sigunga et al., 2002). Also the mobility of nitrate is increased with the increase in soil moisture (Sànchez-Martìn et al., 2008). Since there were no plants grown at the site for plant off take, leaching by infiltrating water might have been the main mechanism through which P and K were lost, whereas leaching as nitrate and emission to the atmosphere as gas might have been the mechanism behind the loss of the applied sulphate of ammonia.

The soil at the site is loamy sand (Table 1). Loamy sands have a high proportion of drainage pores and, thus, are permeable (Haygarth and Jarvis, 1999). When it rains, rainwater and dissolved plant nutrients are rapidly lost from the upper layers. Interception of some of the infiltrating rainwater by the upper soil horizon and loss through evaporation reduces the amount of water at 15-30 cm depth and, thus, reduction in loss of nutrients at that level. A similar observation was made by Cai et al. (2002) when studying N losses from buried fertilizers.

Burial depth for the control did not cause any difference in the retention of the applied macronutrients (Table 2). In addition, the amount of nutrients retained in the control was significantly lower than that retained in soil applied vermiculite, with the exception of ammonium. Retention of nitrate, P and K increased with the increase in the amount of vermiculite added to the soil (Table 3). This indicates that vermiculite contributed to enhancing nutrient retention in the sandy soil.

Extractable P was highly retained in soil amended with raw vermiculite than expanded vermiculite (Table 4). The high P in soil mixed with raw vermiculite might be due to the contribution of extractable P from apatite and monazite, which was significantly suppressed in expanded vermiculite as a result of heating (Marwa, 2009). Contrary to P, extractable K was marginally higher in soil amended with expanded vermiculite than in soil with raw vermiculite, probably due to the increased availability of exchangeable K+ caused by heating vermiculite (Marwa, 2009). According to Marwa (2009), the exchangeable K+ in expanded vermiculite MK1 heated at 600 oC is 10 fold more than in raw vermiculite, but the observed difference in the amount of K retained between the two products was quite small. Probably, part of the exchangeable K+ in expanded vermiculite was lost by leaching or fixation.

Retention of nitrogen as nitrate and ammonium showed a different pattern from that of P and K. The amount retained was very low as compared to P and K. In addition, retention of ammonium did not show any significant difference among the treatments. In proportion, nitrate in soil amended with expanded vermiculite was slightly lower than in soil that was applied raw vermiculite (Table 4).

The results of the combined effects of the burial depth with the type and amount of vermiculite added to the soil on the retention of the applied nutrients are summarized in Table 5. From that table it shows that retention of applied nutrients increased with the depth of burial and the amount of vermiculite added to the soil. Ammonium and nitrate were much less retained than the other nutrients. The maximum ammonium retained was 4 mg kg-1 in the soil mixed with 50% expanded vermiculite and buried at 0-15 cm. The amount retained was less than 2% of the original 240 mg kg-1 of N-fertilizer applied. For the nitrate, maximum retention was 23.8 mg kg1 and was found in soil amended with 50% expanded vermiculite and buried at 15-30 cm. Similarly, this retention was insignificant (< 10%) when compared to the 240 mg kg-1 of Nfertilizer applied.

In the soil environment, ammonium and nitrate ions are very mobile and biologically labile. When applied as mineral fertilisers in soils they are easily lost by leaching or lost into the atmosphere in gaseous forms (Cai et al., 2002), thus explaining the low recovery. The loamy sand at the site has a high permeability which would have favoured leaching. Nitrate in agricultural soils is commonly depleted by leaching to the deeper layers below the rooting zone where it accumulates or enters the saturated phase (Fang et al., 2006). From this study, it is clear that vermiculite is incapable of prolonging the retention of appreciable amount of N as ammonium or nitrate in the soil for plant growth for more than 90 days.

Although K retained in the soil increased with the amount of vermiculite applied, the overall fraction retained was slightly low as compared to the original 200 mg K kg-1 applied to the soil. Potassium in the control regardless of the burial depth was about 25%. In the soil which raw vermiculite was added, the K retained ranged between 26-34%, whilst in soil applied expanded vermiculite was 29-48%. The observed low K in both treatments might have been caused by leaching or fixation in vermiculite as a result of climate-controlled wetting and drying cycles (Carter and Singh, 2004). Contractions of the interlayer space in vermiculite on drying can lead to the entrapment of the K (Sparks and Huang, 1985) and, thus, reduction in extractable fractions.

The amount of P–fertilizer applied (TSP) to the soil was 160 mg P kg-1. The fraction retained in the control at 0-15 cm depth was 25-26%, whilst at 15-30 cm was 38-39%. In soil amended with raw vermiculite, P retained at 0-15 cm ranged from 33 to 111%, while at 15-30 cm was 51141%. It is obvious that raw vermiculite not only retained the applied P, but also fertilized the soil by adding more extractable P. Fertilization might have been attributed to the extractable P from apatite and monazite as mentioned earlier. Phosphorus recovered from the soil applied with expanded vermiculite was 29-74% at 0-15 cm and 41-78% at 15-30 cm. Thus, in comparison with N and K, P was more retained and in some cases fertilized by applied vermiculite. Vermiculite should preferably be buried at 15-30 cm from the surface for better performance.

Phosphorus dynamics in soils is complex. It undergoes slow sorption (fixation) and desorption (release) processes (Sanchez et al., 1997). The presence of organic matter enhances its mobility while the presence of Fe and Al oxides and hydroxides reduces its mobility by fixation (Kwabiah et al., 2003). However, it is considered to be less mobile particularly in fine-textured soils, but leaches in a substantial amount when applied to sandy soils (Humphreys and Pritchett, 1971). Since P was applied to the sandy soil and a substantial amount was retained by the soil for more than 90 days over the control, it is a proof that vermiculite enhanced its retention and fertilization. Thus, from this study we can conclude that this Tanzanian vermiculite has a marked ability of enhancing the retention of extractable P when applied to the sandy soil under a tropical climate.

## CONCLUSIONS

The study has established that vermiculite is incapable of adequately enhancing the retention of N as ammonium and nitrate in a sandy soil for more than 90 days under the tropical Tanzanian climate. Potassium was slightly retained but the fraction retained was less that 50% of the originally applied amount. In addition, part of the exchangeable K+, which is 10-fold more in expanded vermiculite than in raw vermiculite was also lost. In comparison with N and K, P was more retained and in part fertilized by vermiculite applied to the soil. The maximum P retained in soil applied with expanded vermiculite was 78%, whereas in soil amended with raw vermiculite the amount retained and fertilized was 141%. Fertilized P came from apatite and monazite, which are accessory minerals in vermiculite. Thus, it was concluded that vermiculite when added to a sandy soil under tropical condition has a marked ability of enhancing the retention and fertilization of P followed by K. More retention occurs when vermiculite is buried at 15-30 cm from the surface than at 0-15cm. Effective utilization of vermiculite can reduce the burden of replenishing tropical soils with the same amount of P and K-fertilizers.

**ACKNOWLEDGEMENT**

The first author is much indebted to the Commonwealth Commission in the United Kingdom for supporting this research as part of his PhD studies at the University of Aberdeen.

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