Research Article

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Journal of Plant Sciences and Agricultural Research

2018
Vol.2 No.2:14

Soil Fertility Dynamics of Ultisol as Influenced by Greengram and Mucuna Green Manures

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Received date: March 22, 2018; **Accepted date:** April 17, 2018; **Published date:** April 25, 2018

Citation: Saria AG, Sibuga KP, Semu E, Høgh-Jensen H (2018) Soil Fertility Dynamics of Ultisol as Influenced by Greengram and Mucuna Green Manures. J Plant Sci Agric Res. Vol. 2 No. 2:14.

Abstract

Synchronisation between supply of plant available nutrients to crops' needs and uptake is a major challenge in Sub-Saharan Africa. Experiments were set to evaluate release patterns and availability of nutrients by leguminous green manures in soil. Mucuna and greengram materials were buried 10 cm in mesh bags. Replicated bags removed weekly and analysed to determine decomposition rates and quantities of nutrients released into soil. Mucuna decomposition was faster compared to greengram, from third to twelve weeks of incubation. This implies that greengram has relatively more resistant materials to decomposition compared to mucuna. Maximum effect on soil nutrient content occurred in sixth and seventh weeks after application of green manures. Total organic C in soils increased by a factor of 2.3 to 3.2. Total N increased significantly from 1.28% to 2.64% at sixth week in soil with greengram and 2.83% at seventh week in soil with mucuna. Available P content of soil increased from 0.03 to 0.39 and 0.37 mg kg^{-1} in soil treated with greengram and mucuna. Optimum microbial population was attained from fifth to seventh week after manure application, with 2.3 × 108 in soil with greengram and 3.08 × 108 with mucuna, significantly improved compared to original population.

Keywords: Green manure; Soil fertility; Incubation period; Cover crop

Introduction

Poor soil fertility has been one among the major problems in agriculture in Sub-Saharan Africa, leading to poor crop productivity [1] Agriculture in many African countries is subjected to poor nutrient replenishment in soils, leading to soil degradation and hence poor productivity [2-4]. However, the use of inorganic fertilisers alone cannot be a long-term solution for soil fertility management among poor African farmers, and thus integrated soil fertility management has been proposed [5]. The synchronisation between sufficient supply of plant available nutrients like phosphorus (P), potassium (K) and nitrogen (N) to the crops needs and uptake is a major challenge [6-8]. However, the use of leguminous plants as green manure can be a good alternative for replenishing soil fertility and diversify farm productivity in intensive production because legumes generally are nutrient rich [8,9].

Therefore, agriculture intensification in poor fertility soils can be supported through natural means of improving and sustaining the soil fertility [10]. Cover crops, which are used for pests control in organic agriculture, can be a good source of nutrients as green manure [11,12] and increase soil organic matter content which can support soil microbial activity [13]. The use of cover crops as green manure and for weed control was adopted as strategy for replenishing soil nitrogen that had been taken up by crops and to provide organic matter for maintaining soil's fertility and improving its properties [14]. Marandu et al. (2011) observed an increase of about 12.4 mg mineral N kg^{-1} soil when maize was grown in rotation with greengram [15]. There is evidence on the ability of Mucuna spp green manure to influence soils' physical and biological and chemical properties [16,17]. However, lack of synchrony between mineralization of organic N from green manure and plant N requirements of a subsequent crop is a major challenge [18,19]. Understanding the nutrient release patterns of the green manure applied is thus a prerequisite to optimize an efficient use of the green manure and to sustain a high value vegetable crop [20,21].

The objective of the current study consequently was to determine relative decomposition patterns, nutrient release rates and microorganism proliferation as influenced by two leguminous green manure crops, mucuna (*Mucuna pruriens*) and greengram (*Vigna radiata* (L.), that were incorporated into the soil under field conditions in Morogoro, Tanzania, using the mesh bag approach.

Material and Methods

Experimental site

The field decomposition study was carried out at Sokoine University of Agriculture (SUA) Crop Museum in at an average elevation of 534 m.a.s.l. The location has bimodal rainfall of 800-1000 mm annually with the short rains in November to January and the longest from March to May. Rainfall patterns for the twelve weeks at the experimental area during the experiment are presented in Figure 1.

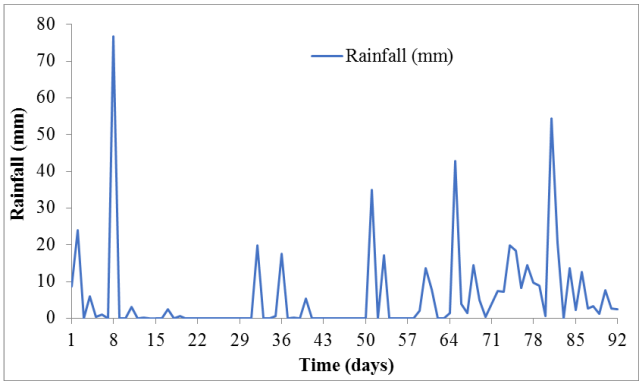

Figure 1: Rainfall patterns at the experimental site during the twelve weeks of the experiment.

For the previous three seasons the field was used for cultivating various annual crops. The initial soil analysis of the experimental site within SUA crop museum was done for a composite soil sampled diagonally diagonal across the site within the 0-20 cm depth. The area is characterized by kaolinitic clay soils which are well drained. The physiographic features of the area are characteristically an undulating convex land and the slope is about 4% [22]. The sample was air dried and ground to pass through a 2 mm sieve.

Experimental layout and sampling

Mucuna (*Mucuna pruriens*) and greengram (*Vigna radiate* L.) were grown adjacent to the experimental site to the 50% flowering stage. The crops were harvested just above the soil surface, chopped and 500 g fresh weight filled into polyethylene plastic mesh bags (20 × 20 cm) of 2 mm mesh size. The litter-bags were buried 5-10 cm deep into the soil in four replicates. For twelve consecutive weeks, with exact intervals of 7 days, four replicated mesh bags were sampled for decomposition analysis. The 5 cm soil located directly below the mesh bags was collected. The plant and soil samples were air dried in a screen house for 72 hours and then oven dried for 24 hours at 70°C to constant weight. The samples were ground ready for analysis to determine their decomposition patterns.

Plant analysis

Total nitrogen: 0.2 g of the sample of green manure was transferred to a 500 ml Kjeldahl tube and two grams of mixed salts catalyst (K_2SO_4+$CuSO_4$+selenium powder, in the ratio of 10:10:1 by weight) was added. Ten ml of H_2SO_4 were added. The mixture digested for one hour at 360°C. After cooling, 50 ml of water were added, followed by 25 ml of H_3BO_3 and 50 ml of 40% NaOH. The mixture was distilled and about 200 ml of distillate collected. The distillate was titrated using 0.05N H_2SO_4 [23].

Phosphorus content: extractable P was determined using the Bray 1 method [24]. A sample of three grams was taken in to the extraction bottle, 20 ml of extraction solution and shaken thoroughly. Then the mixture was filtered through filter paper. Five millilitres aliquot of the sample mixture was transferred to 50 ml volumetric flask and 10 ml of water added. Two millilitres of phosphate reagent were added, and the volume was made to 50 ml, the colour could develop in 15 minutes. Then phosphorus content in solution was determined in a spectrophotometer at 882 nm.

Soil analysis

Organic soil carbon: Organic carbon analysis of the green manure was done using the Walkely-Black method (Yeomans and Bremner 1988). Duplicate samples of 1 g were weighed in an Erlenmeyer flask, 10 ml of 1N $K_2Cr_2O_7$ was added followed immediately by 20 ml concentrated H_2SO_4 and hand shaken for about a minute to oxidize the soil's organic carbon. Then the mixture could stand on asbestos plates for 30 minutes. About 100 ml of water were added followed by 10 ml orthophosphoric acid and 10 drops of diphenylamine indicator. The solution was titrated with $FeSO_4$ to determine the organic carbon.

Total soil nitrogen and phosphorus: these elements were also determined using the same methods used for the analysis of the plant materials.

Ca and Mg content: the exchangeable Ca and Mg were determined from the same solution used to determine P using atomic absorption spectrophotometer [25].

Cation exchange capacity: the soil remained after exchangeable bases extraction filtration was washed using 100 ml of ethanol and then placed into plastic bottles. 50 ml of 4% KCL were added and shaken for 30 minutes, distilled and the distillate collected over Boric acid. Then the distillate was titrated with 0.1N H_2SO_4 and the titre value was used to calculate the CEC [26].

Total microbial count: Microbial count was done by determining moisture content of the sample. Ten grams sample was placed in 90 ml water and shaken vigorously to uniform suspension to detach microbial cells from soil particles in to the suspension. One ml of the suspension was transferred to 9 ml water, and similarly the dilution was continued up to a dilution of 107. Then the 103 to 107 dilutions were plated into petri dishes with nutrient agar and spread evenly. The plates were incubated 21°C for four days and then plates with 30-300 colonies were selected for microbial population counting and calculation of microbial populations. The microbial population per gram of soil was calculated using the formula:

$$\text{Microbial population} = \frac{\text{colony count} \times \text{dilution counted}}{\text{Weight of soil}}$$

Data analysis

Data were subjected to analysis of variance using GENSTAT statistical program (Genstat release 6.1 Laws Agricultural Trust). Treatment means were ranked using Duncan's Multiple Range Test at $P \leq 0.05$.

Results

Decomposition patterns of the green manures

The decomposition patterns of the green manures were assessed using decreases of organic carbon (C), total nitrogen (N), phosphorus (P) content and associated changes in nutrient content and total microbial populations in the mesh bags and in the soil just below the mesh bags. Initially the weight of the green manure incubated in the soil decreased with time immediately from the first week throughout the incubation period (Figure 2) following a first-order negative exponential curve (mucuna: R2=0.98 and greengram R2=0.98) as commonly found in other studies [27-29].

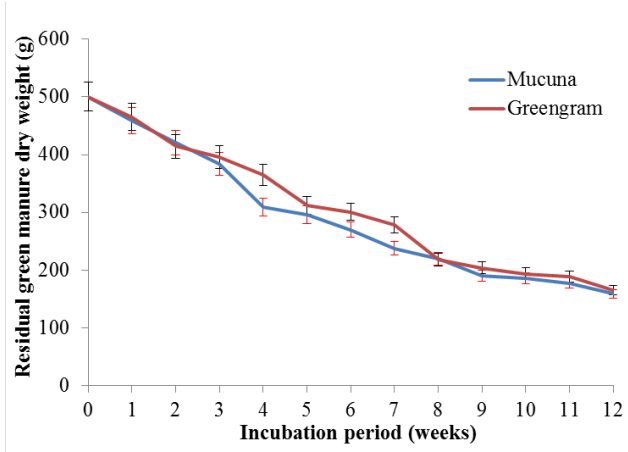

Figure 2: Averaged decrease in dry weight per mesh bag (mean for all treatment each week) of the green manure materials upon incubation over time.

The proportion of organic C content in the plant materials was about 40% for mucuna and 35% for greengram. However, the half-life (t1/2) of the two materials was similar as both attained their half-life at the fifth week of incubation (Figure 2). Due to the negative exponentially, the decomposition pattern of the two green manures were fast to about the seventh week of incubation which concur with other studies [30,31]. This pattern of decomposition lead to the rapid decrease of the proportion of organic C in the mesh bags in first six to seven weeks of incubation. Some of the C is respired but others are eventually added and incorporated in the soil below the mesh bag (Figure 3).

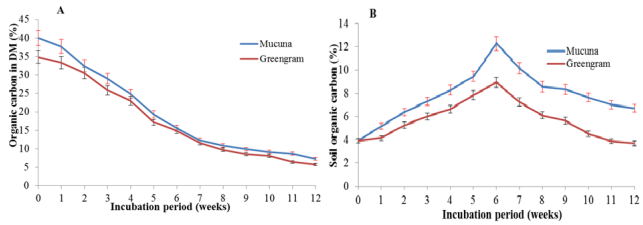

Figure 3: Organic carbon content in dry matter of residue plant material and in soil just below mesh bags, (A) the mean proportion of organic carbon in residue plant material DM and (B) the mean amount of organic carbon accumulation in soil sampled just below the mesh bags.

Decrease in nitrogen in the residual plant materials and nitrogen gains in soil

For both green manure materials, the trend in the proportion of N in the mesh bag mirrored the trend in the proportion of carbon (Figure 4A). The net release of N from the mesh bag was evident in the soils below the mesh bag (Figure 4B) until week 7, after which release rates must have decreased substantially as the microbial biomass started to decrease (Figure 6), precipitation increases and the content in the soil stabilized (Figure 4B).

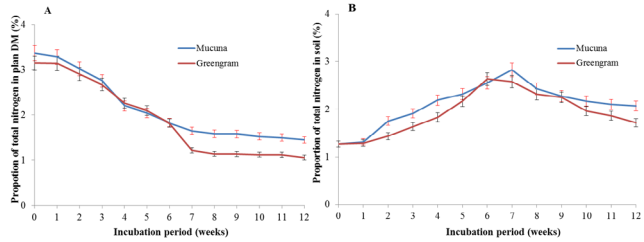

Figure 4: Total Nitrogen content in the dry matter of the plant material and in soil just below the mesh bags, (A) the mean proportion of total nitrogen in plant material DM and (B) the mean amount of total nitrogen accumulation in the soil sampled just below the mesh bags.

Phosphorus decrease in decomposed residual plant materials and P gains in soil

The P content of the degrading green manures followed a linear decline (Figure 5A) with R2=0.94 for mucuna and R2=0.95 for greengram. The degradation of P from both types of plant materials did not differ significantly. In both green manures the P release was fast up to the ninth week and then became stagnant. However, the quantity of P in the decomposing mucuna materials was higher for the first five weeks as compared to that in greengram and then it dropped below that of greengram at the tenth to twelfth weeks of incubation.

Interestingly, the amount extractable inorganic P (Bray 1) accumulation in the soil was faster and higher in the soil under

mucuna compared to greengram (Figure 5B). At the fourth week, soil incubated with mucuna had attained 0.35% of P compared to 0.1% of greengram (Figure 5B). At the sixth week, the extractable P had reached the same level, but green gram had a slower start.

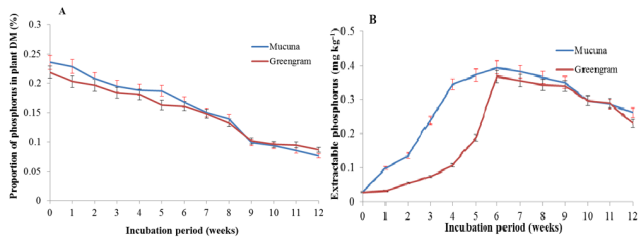

Figure 5: Phosphorus content in dry matter of plant material and in soil just below mesh bags, (A) the mean proportion of phosphorus in residue plant material DM and (B) the mean amount of extractable phosphorus accumulation in soil sampled just below mesh bags.

Decrease in calcium in plant materials and calcium gains in soil

The trend of Ca release by the green manures and gain by the soil is presented in Figure 6. Calcium release from the plant materials proceeded steadily, with the rate decreasing somewhat in the last three weeks. Throughout the incubation period the residual green manures did not differ in their Ca contents and the release into the soil below it. The faster rate of decomposition and nutrient release by green manure was also observed by Cobo et al. [32], where mucuna had high release of Ca up to the twentieth week after incorporation in the soil, as revealed by higher accumulation in the soil. This was also observed in the present study where the plant materials continued to release Ca for all the twelve weeks.

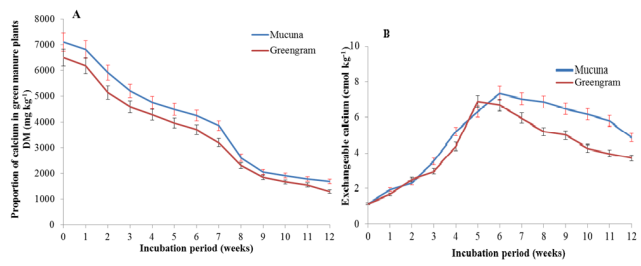

Figure 6: Calcium content in dry matter of plant material and in soil just below mesh bags, (A) the mean proportion of calcium in residue plant material DM and (B) the mean amount of extractable calcium accumulation in soil sampled just below mesh bags.

In the soil, the Ca gain trend was similar between the two green manures. However, soils incubated with mucuna attained highest total Ca at the sixth week, which was one week later as compared to greengram which attained its peak at the fifth week. The decrease of Ca observed in the present study beyond the fifth and sixth weeks was due to its high immobilisation in the soil. Cobo et al. observed a similar trend of Ca release from decomposing green manure; however, no consistent trend was found on the Ca accumulation patterns due to its high immobilisation [33]. Other authors reported high ability of Ca immobilisation in the decomposing materials in different ways and through its accumulation in fungi found in the decomposing materials [33,34].

Decrease in magnesium in plant materials and magnesium gains in soil

The release of Mg from the two green manures and its gain in the soil throughout the incubation period (Figure 7). Mucuna released slightly higher amount of Mg as compared to the greengram.

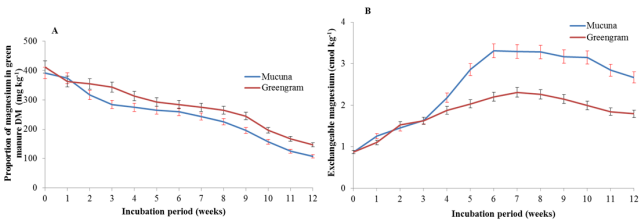

Figure 7: Magesium trends in dry matter of plant material and in soil just below mesh bags, (A) the mean proportion of magnesium in residue plant material DM and (B) the mean amount of extractable magnesium accumulation in soil sampled just below mesh bags.

Soil incubated with mucuna had the highest amount of Mg at the sixth week after incubation, while that with greengram reached its highest level at the seventh week. Thereafter, there was a slight decrease in soil Mg.

Microbial populations in the soils under decomposing green manure materials

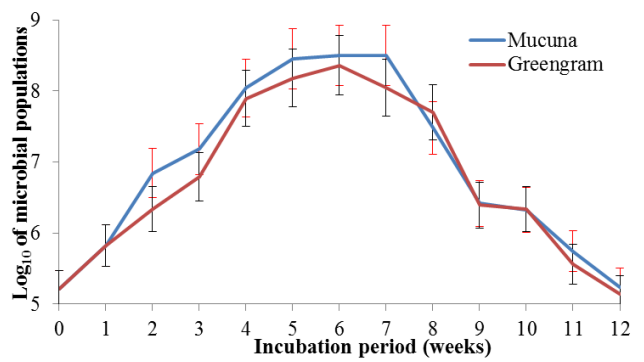

Figure 8: Average total microbial population in in soil just below mesh bags with decomposing green manure materials over time.

The total microbial population following the introduction of the two green manures increased for six weeks, with a subsequent decrease. The population in the initial soil was about 1.628 × 105, which increased up to 2.3 × 108 in the soil with greengram and up to 3.08 × 108 in the soil with mucuna. Transformed into Log10, these values translated to 5.21, 8.05 and 8.50, respectively (Figure 8).

CEC changes in soil supplemented with mucuna and greengram

The soil treated with mucuna and greengram green manure attained higher CEC in the seventh week, as presented in Figure 9. The CEC in the soil treated by mucuna was 31.5 while that with greengram was 30.6 cmol kg^{-1}, respectively, at the seventh week as compared to the original soil whose CEC was 10.8 cmol kg^{-1} (Figure 9).

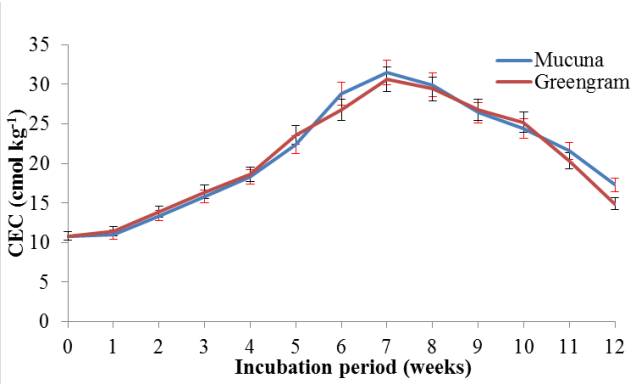

Figure 9: Averaged changes in CEC in soils just below mesh bag with decomposing green manure materials upon incubation over time.

Discussion

The organic C compounds released from the plant materials could be seen accumulating in the soil immediately below the decomposing material in the first six weeks. The accumulation did not continue throughout but reached its optimum at the 6th week and subsequently decreased (Figure 3B). This dynamic is attributed to the early build-up of the soil microbial population (Figure 6) that use the organic compounds as substrate and to the fact extensive that leaching has taken place due to excess of precipitation during the last 5-6 weeks of the experiment (Figure 1).

In accordance with the negative exponential degradation pattern, amounts and rates of C being released from the mesh bags decreased substantially after the seventh week and simultaneously the release rates from the mesh bags most likely also decreased due to the stabilisation of the litter, i.e. the carbon content approaching stability (Figure 3A) as the C:N ratio of the residual litter approached 8-9 at week 5 after incubation after which the microbial activity may have been slowed down [36].

For both manure substrates, the C:N ratio decreased from approximately 12 initially to 5 at week 12 after burying the litter bags, following a simple linear pattern (data not shown). This demonstrates the potency of the green manures in the sense that it decomposes very rapidly (Figure 2) and at the 12th week had reached a structure that resembled soil. The relative low C:N ratio will also lead to a net release of N almost instantly. The apparent linearity agrees with theory [35,36] whereby these substances, as green manures with an initially low C:N ration of approximately 12, must be viewed towards at the late period of the exponential process.

The relatively low C:N ratios is the exact reason for terming these substrates “green manure”. The low C:N ratios indicate that the degradation of the organic materials will not cause a net immobilisation but be able to net release inorganic N into the soil matrix that can benefit crop growth. The rapid decomposition under the current conditions contrast with relatively low mineralisation rates under north European conditions [37].

The experimental site had been used for cropping the previous cropping during seasons and yet it has a good total N content (1.28%). The inclusion of the green manures however was a high injection of N to the soil such that a high flux of inorganic N must be anticipated (not measured). Other studies [38,39] also observed significant increase of N in different soils treated with different green manures in long term application, explaining the difference in N contribution to the soil by these different green manures. The higher soil N under mucuna may be since mucuna had higher leaf: stem ratio than stem materials which accounts for the higher total N (Figure 4). These results agree with Cobo et al. (2002) who observed mucuna released higher amount of N as compared to the other green manures [32]. In addition to that, in a similar decomposition study, Chikowo (2004) showed prolonged N immobilisation while in under field conditions [40]. After the seventh and eighth weeks, the amount of N in soil started to decrease since most of the N released was nitrified and then lost or leached as nitrate upon watering, where it was leached beyond the sampling zone.

Despite the delay in enriching the soil in extractable P (Bray-1) for greengram it still reached the same high level as mucuna and its still justified to call them green manures when it comes to supplying plant available P to the crops, which concur with Randhawa et al. (2005) [41]. The chemical composition of the source material did not differ (Figure 5A) so we speculate that differences may be caused by the morphological differences between the two species, particular the leaf:steem ratio [42]. This has been seen to influence the release rate in other studies and possible interactions between the leaf-stem due to high soluble C contents in the stem [33,43]. The fast decrease of P in the residual of the decomposing plant materials may be due to its soluble nature in the plant cell. Studies by Frossard et al. (1995) and Giacomini et al. (2003) observed that soluble P in plant tissues is also available in the form of diesters (nucleic acids, phospholipids, and phosphoproteins) which can easily be released through microbial decomposition activities [44,45]. This led to the release of most of the P from the two green manures in the first eight weeks of incubation. The difference P content

compared to the N content in the litter is since P to a higher degree is organically bound [43,46] whereas a higher proportion of the N content initially is soluble [47].

Mg release from plant materials was almost similar in both green manures. In both plant materials the trend of decomposition was similar, with a somewhat steady rate of decomposition throughout. The difference between the two types of green manures was in the gains of Mg in the soil, whereby the soil incubated with mucuna gained more Mg as compared to that incubated with greengram. Other studies have also observed that soil Mg usually accumulated and became higher mainly in the top soil then decreased with depth [48].

The increase in soil microbial the population was a result of increase in the energy and nutrient sources for the microorganisms due to the addition of the green manures. Bakken et al., (2006) and Lavelle and Spain (2001) observed that organic material provided by green manure promotes the activity of soil organisms, as a source of energy and nutrients [49,50]. Cover crops and mulch increase the populations of macro-organisms and microorganisms, and their activities in the soil, because they increase the total inputs of organic materials to the soil [51]. Increase in total microbial population density in the soil is ascribed to the ability of a green manure to provide conducive environments like increased soil moisture content, ensuring moderate changes in soil temperatures, providing food sources at the soil surface and retention of soil burrows that favour growth and multiplication of macro and microorganisms. A study by Elfstrand et al. (2007) on the responses by soil microbial communities to green manuring detected an increase in soil microbial biomass [18]. Lundquist et al. (1999) also reported an increase of 24 to 52% of active bacteria due to the application of rye green manure [13]. Some studies have revealed the ability of mucuna plants to increase soil organic matter and improve soil moisture regimes [32]. Other studies have shown that the increase in microbial population depended on the availability of the organic matter supplied by the soil amendment materials and that the population increase is rather short lived following plant incorporation [13].

The improvement of CEC was mainly due to the ability of the two green manures to release the bases like Ca and Mg, as well as other cations, upon decomposition. This was also observed by Kimetu et al. (2008) who explained the importance of green manure in the improvement of soil CEC [2]. The soil CEC protects cations from leaching out of the plant root zone and makes them available to plant roots [52].

The decrease in CEC beyond the seventh week was due to the oxidation of NH_4^+ to give NO_3^- which is highly soluble and in turn is leached beyond the sampling zone. Chikowo et al. (2004) observed the accumulation of NO_3^- beyond 40 cm depth of soil just three weeks after the beginning of the rainy season [41]. On the other hand, NH_4^+ which is lost from the soil as ammonia gas through the process of volatilization contributes to the decrease in CEC beyond the seventh week. This was also observed by Zhenghu and Honglang (2000) who found a negative correlation between ammonium volatilization and soil CEC.

Conclusions and Perspectives

Using mucuna and greengram as green manure can be of great potential in increasing soil fertility, which can contribute to improving crop production. However, to achieve this, the optimal period when the plant can benefit from the nutrients released should be well synchronized with the optimal release of the nutrients from the decomposing green manures. The sixth to eighth weeks after incorporation seem to maximize nutrients release form the green manure, and planting of main crops should target to take advantage of this maximum release period of the green manure. This investigation provides justifiable insights for improving soil fertility and demonstrates the suitability of mucuna and green manures as suitable in the overall scenario of integrated soil fertility management strategy to enhance soil nutrient dynamics and plant nutrition under these tropical soil conditions.

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