Tropical and Subtropical Agroecosystems, 14 (2011): 221 - 227

THE EFFECT OF INTRODUCED FORAGE LEGUMES ON IMPROVEMENT OF SOIL FERTILITY IN NATURAL PASTURES OF SEMI-ARID RANGELANDS OF KAJIADO DISTRICT, KENYA

[EFECTO DE LEGUMINOSAS FORRAJERAS INTRODUCIDAS SOBRE LA MEJORA DE LA FERTILIDAD DEL SUELO DE PRADERAS NATIVAS DE LOS AGOSTADEROS SEMI-ÁRIDOS DEL DISTRITO DE KAJIADO, KENIA]

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SUMMARY

A two phase study was carried out from 2002 to 2005 in the semi-arid rangelands of Kajiado District, Kenya to determine the effect of introduced forage legumes on soil fertility improvement of natural pastures. During legume evaluation phase, *Neonotonia wightii* (Glycine), *Macroptilium atropurpureum* (Siratro), *Lablab purpureus* cv. Rongai (Dolichos), *Mucuna pruriens* (Velvet bean) and *Stylosanthes scabra* var. Seca (Stylo) were screened for adaptability and growth performance under the semi-arid conditions for two years. Results of soil analysis showed there were significant increases in soil pH (4.92 to 5.36), organic carbon (1.17 to 2.57%) , nitrogen (0.17 to 0.22%) and potassium (1.23 to 1.68 me%) probably due to the large amounts of organic residues produced by the legumes (particularly Glycine, Siratro and Stylo which are perennials). The calcium content decreased significantly from 7.97 to 4.50 me% (which was attributed to plant uptake) while the decrease of phosphorus was not significant. During the second phase of study for 1½ years Glycine, Siratro and Stylo were integrated into natural pastures. The results showed that only the soil pH significantly increased from 5.23 to 5.31 while all the other nutrients decreased results, which were attributed to production of less organic residues by the legumes compared to the residues produced during the legume evaluation phase. The study concluded that Glycine, Siratro and Stylo were capable of improving the soil fertility of semi-arid natural pastures only if the respective dry matter production was 10.31, 7.81 and 3.52 tha^{-1}, amounts which were able to produce large amounts of organic residues.

Key words: Forage legumes; Grass/Legume intercrops; Semi-arid rangelands; Soil fertility.

RESUMEN

Se realizó un estudio de dos fases de 2002 a 2005 en los agostaderos semi-áridos del distrito de Kajiado, Kenia, para evaluar el efecto de leguminosas forrajeras introducidas sobre la mejora de la fertilidad del suelo de praderas nativas. Durante la fase de evaluación de leguminosas *Neonotonia wightii* (Glycine), *Macroptilium atropurpureum* (Siratro), *Lablab purpureus* cv. Rongai (Dolichos), *Mucuna pruriens* (frijol terciopelo) y *Stylosanthes scabra* var. Seca (Stylo) fueron evaluados para adaptabilidad y crecimiento bajo las condiciones semi-áridas por 2 años. Los análisis del suelo mostraron un incremento significativo en el pH (4.92 a 5.36), carbono orgánico (1.17 a 2.57%), nitrógeno (0.17 a 0.22%) y potasio (1.23 a 1.68 me%) probablemente debido a la gran cantidad de residuos orgánicos particularmente por Glycine, Siratro y Stylo que son perenes. El contenido de calcio se redujo significativamente de 7.97 a 4.50 me% (atribuido a utilización por la planta) y no se observó una reducción significativa de fósforo. Durane la segunda fase (1.5 años), Glycine, Siratro y Stylo se incorporaron a praderas nativas. Únicamente se afecto de manera significativa el pH del suelo de 5.23 a 5.31, mientras que los nutrientes restantes mostraron decrementos que fueron atribuidos a la baja producción de materia orgánica por parte de las leguminosas en comparación con la producción observada durante la primera fase. Se concluyó que Glycine, Siratro y Stylo pueden mejorar la fertilidad del suelo de las praderas de áreas semi-áridas sólo si su producción de materia seca es de 10.31, 7.81 y 3.52 t ha^{-1}, cantidad suficiente para producir los residuos orgánicos necesarios.

Palabras clave: leguminosas forrajeras; asociación pasto/leguminosa; agostadero semi árido; fertilidad el suelo.

INTRODUCTION

In semi-arid regions of eastern Kenya, the rapid increase in population densities, continuous cultivation and overgrazing has contributed to the depletion of soil fertility resulting in low yields from croplands and pastures (Njarui *et al.,* 2004). The infertility of the soils, particularly lack of N, is the main contributory factor to the low productivity of such tropical soils (Giller, 2001). In addition, the frequent fires that occur especially during the dry seasons in the rangelands lead to considerable losses of N in gaseous form to the atmosphere (Brady, 1984; Grace *et al.,* 2006). According to Nyathi *et al.* (2003), some forms of tillage, particularly in arid and semi-arid areas encourage oxidation of organic matter throughout the tilled profile resulting in release of carbon to the atmosphere rather than its build-up in the soil. This leads to reduced biomass production from crops or pastures and lower carbon inputs to the soil in subsequent periods because less root matter, leaf litter and crop residues are returned to the soil.

Legumes have the potential to improve soil fertility through the release of nitrogen from decomposing leaf residues, roots and nodules which results to increased sward productivity after nitrogen uptake by the companion grasses (Guretzky *et al.,* 2004; Cherr *et al.,* 2006). The slow release of nitrogen may be better synchronized with plant uptake than other sources of inorganic N, thereby increasing nitrogen uptake efficiency and crop yields while reducing nitrogen loss through leaching (Cherr *et al.,* 2006). Thus integration of forage legumes into natural pastures is an option to improve soil fertility through addition of organic residues and soil nutrients (especially nitrogen) in the semi-arid rangelands of Kajiado District. This study was therefore carried out with the aim of introducing suitable forage legumes into semi-arid natural pastures as a way of improving the soil fertility.

MATERIALS AND METHODS

Study site

The study site was located in Mashuru Division of Kajiado District at an altitude of 1280 m above sea level from October 2002 to February 2005 on a farm used for extensive grazing. Most parts of the division lies in agro-climatic zone V which is classified as semi-arid (Sombroek *et al.,* 1982). The mean annual rainfall for 15 years for the study area is 838 mm and a mean annual temperature of 21.6 to 24.0 ˚C (jaetzold *et al*., 2006). Only 7% of the district's land lies in agro-climatic zone IV which has some potential for rain fed cropping (Ojwang' *et al.,* 2006). According to Sombroek *et al.* (1982), rainfall is the major limiting factor for maximum primary production in the area. The rains are received in two distinct rainfall seasons, with the long rainfall season occurring between March and May while the short rainfall season occurs between October and January of each year. The soils are well drained with clay to clay loam texture and a pH of 4.9 to 5.5 which is categorized as acid to slightly acid (landon, 1984). The soils were classified as Ferral-Haplic Lixisol (FAO, 1997). The dominant farming system is agro-pastoralism by the Maasai community who keep large herds of livestock as their main source of livelihood.

Legume screening experiments

The first phase of the study was legume screening to identify suitable forage legumes for integration into natural pastures for enhancement of soil fertility. The forage legumes selected were: *Neonotonia wightii* (Arn.) Lackey (Glycine), *Macroptilium atropurpureum* (DC) Urb. (Siratro), *Lablab purpureus* cv. Rongai (L.) Sweet (Dolichos), *Mucuna pruriens* (L.) DC (Velvet bean), and *Stylosanthes scabra* var. *seca* Vog. (Shrubby Stylo). These legumes were selected because they had been identified as green manure legumes for soil fertility improvement in cultivated smallholder agriculture in Kenya (LRNP, 1999). The five legumes (treatments) were sown as monoculture stands and soil samples collected at beginning and end of the two year study period. Soil pH was determined in a 1:2.5 soil: water suspension. The soil organic carbon was determined through the Walkley and Black method as described by Okalebo *et al.* (2002). The soil nitrogen was determined by the macro-Kjedahl method while the exchangeable cations (phosphorus, potassium and calcium) were determined through the Mehlich Double Acid Method following procedures described by Okalebo *et al.* (2002). The litter production of the legumes was determined during the month of August 2003 which was the peak of the long dry season (June to October) by collection of all litter drops within an area of 1 m^2 in each experimental plot on a daily basis for three weeks. Other data collected (but not presented in this paper) included dry matter production at a two and four months clipping interval and rooting characteristics of the five legumes, five months after planting.

Grass/Legume integration experiments

Results from the legume screening experiment showed that Glycine, Siratro and Stylo were perennial, deep rooted, and yielded high dry matter and litter drop than Dolichos and Velvet bean. They were therefore integrated into natural pastures through sowing along 20 cm wide bands cleared of vegetation. The treatments were: Natural pasture (NP), monoculture stands of Glycine, Siratro and Stylo, and intercrops of

NP+Glycine, NP+Siratro and NP+Stylo. Soil samples were collected at beginning and end of the 1½ year study period for soil fertility assessments.

Data analysis

Analysis of variance (ANOVA) was conducted to determine the treatment effects in respective experiments using the MSTAT-C computer programme (Bricker, 1990). Significant treatment means were then separated at P≤0.05 using the Student-Newman-Keul's Test. The ANOVA was conducted using a 2-factor Randomized Complete Block Design (RCBD), where the factors were treatments and beginning/end effect.

RESULTS AND DISCUSSION

Soil fertility during screening phase

The results of soil analysis at beginning and end of the experimental period showed that soil pH, carbon (C), nitrogen (N) and potassium (K) significantly (P≤ 0.05) increased by end of the experiment (Table 1). However, calcium (Ca) significantly (P≤0.05) decreased while P had a non-significant (P≥ 0.05) decrease from the soil by end of the experiment.

The increase in soil pH was attributed to the addition of organic residues from the legumes in form of leaf litter drops and probably from the decay of roots and nodules. Bationo (2008) also reported that in Sadore, Niger, the pH in unmulched control plots was 4.3, but in plots where crop residues were added, the pH increased to 4.7 over 14 years. During the current study, Glycine, Siratro and Stylo contributed highest amounts of leaf litter which was significantly (P≤0.05) higher than that of Dolichos and Velvet bean (Figure 1). These results are in conformity with those of Njunie *et al.* (1996) who conducted a leaf drop study at coastal KARI-Mtwapa Research Station for 18 herbaceous legumes. The authors concluded that *M. lathyroides* (L.) Urb, *L. purpureus* and *M. atropurpureum* were capable of improving soil fertility by providing leaf mulch *in situ* and hence improving the soil organic matter content.

Table 1: Effect of legumes on soil fertility during the screening phase

Period	pH	C (%)	N (%)	P (ppm)	K (me%)	Ca (me%)
Beg	4.92 [b]	1.17 [b]	0.17 [b]	178.8	1.23 [b]	7.97 [a]
End	5.36 [a]	2.57 [a]	0.22 [a]	177.0	1.68 [a]	4.50 [b]
SE	0.08	0.12	0.01	5.52	0.06	0.79

Means with different letters in a column are significantly different at the 0.05 level of probability

During decomposition and mineralization of organic residues, nutrients are released to the soil due to increased soil microbial activities which are activated by more favourable soil conditions and availability of C (Landon, 1984; Muriuki and Qureshi, 2001) after an initial N immobilization by soil microorganisms (Giller and Wilson, 1991). Therefore, it may be argued that with an increased soil organic matter due to addition of plant residues by the legumes, the soils microbial activity increased. In addition, the shading effect by the legumes may have favourably improved the micro-environment of the soil in terms of soil temperature and moisture conditions, thus favouring increased microbial activity. This was reflected in the rise of total soil N by 29 % by end of the experiment, which indicated the positive contribution by legumes as regards enhancement of soil fertility. Lascano and Peters (2007) stated that legumes contain large amounts of N which upon decomposition becomes available, resulting in significant increases in the soil.

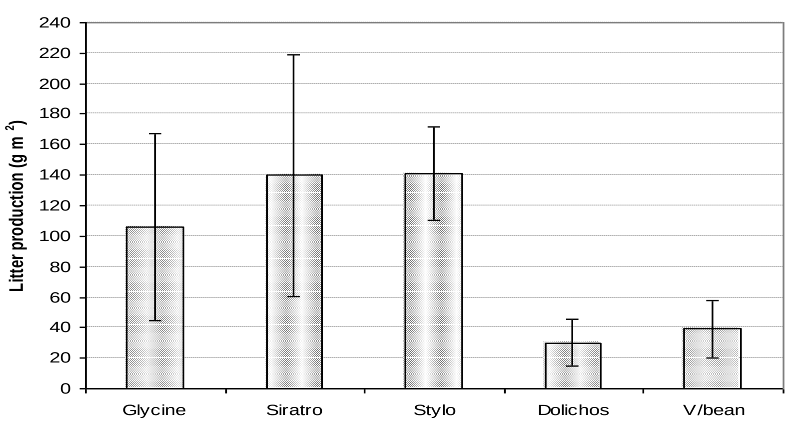

Figure 1. Litter production (g m^2) of experimental legumes at peak of the long dry season

By end of the experiment, the P content in the soil decreased. This decrease was non-significant and was attributed to uptake by the legumes after it became more available as a result of the rise in soil pH. The decrease in soil P by end of the experiment was attributed to P uptake by legumes. Phosphorus is required for growth and development of leguminous cover crops as it is critical for both nodulation (number and density of nodules) and nitrogen fixation in some legumes (Chemining'wa *et al*., 2006). Bationo (2008) citing Hafner *et al*. (1992) reported that root length density and total P uptake increased from 3.4 kg ha^{-1} with no crop residue application to 10.6 kg P ha^{-1} after application of crop residues. However, once P contained in organic matter was released through mineralization into the soil, it can either be immobilized by soil micro-organisms and plants or become fixed in the soil (Rowell, 1994).

By end of the experiment, K significantly ($P \leq 0.05$) increased in the soil, an increase that may be attributed to the release of nutrients after decomposition and mineralization of the legume's organic residues. K is the next mineral element with a high concentration in plant parts after N and hence, large amounts are added to the soil after organic residues decompose (Rowell, 1994; Marschner, 1995). During mineralization of organic matter, there occurs a rapid release of K followed by slower releases of N, P and Ca (Thomas and Lascano, 1995). However, the release of N, K and Ca is usually greater in legume litter due to tenderness of legume leaves compared to the slow release from grasses due to their higher lignification (Thonnissen *et al.,* 2000).

Available soil Ca content decreased significantly ($P \leq 0.05$) by 44 % by end of the experiment. Muriuki and Qureshi (2001) stated that as the soil pH rises from 5.0 to 8.0, Ca becomes more available to plants. Results from the current study showed that the pH rose from 4.92 to 5.36 by end of the experiment, a rise that may have led to increased Ca uptake by the legume plants therefore leading to a decrease from the soil. Calcium also raises pH level of the soil, which in turn enables successful nodulation of the legumes by their associated *Rhizobium* bacteria (Skerman *et al.,* 1988). Therefore, it implied that high demand of Ca for the growth of legume meristematic tissue and the nodules may have led to a decreased Ca content in the soil. Rutunga *et al*. (2001) found that Ca is also among nutrients that are released during the initial period of litter decomposition (from 0 to 56 days) and may either be taken up by plants, immobilized in soil minerals or micro-organisms or lost by leaching.

In addition to enhancing soil fertility, legume litter fall has other beneficial effects on the soil. Karuku *et al.* (2006) found that legume residues acted as an energy dissipater which absorbed raindrop impacts and prevented direct evaporation and dispersal of soil aggregates. The study found that infiltration rate of the soil was higher under dead or live mulch because the structural porosity of the soil was maintained and there was no surface sealing and crust formation. Further, macro-pores open to the soil surface remained intact and functional in transmitting water through the soil and biological activity of soil fauna was maintained which further provided additional pores for water conduction.

Soil fertility during grass/legume integration

The results showed that soil pH significantly ($P \leq 0.05$) increased from 5.23 at beginning of the experiment to 5.31 by end of the experiment (Table 2). This increase in pH was similar to that obtained in the screening experiment. The results further showed that percent C, N, K and Ca significantly ($P \leq 0.05$) decreased while the decrease of P was not significant ($P \geq 0.05$).

Table 2: Effect of forage legumes on soil fertility at beginning and end of grass/legume integration experiment

Time	pH	C (%)	N (%)	P (ppm)	K (me%)	Ca (me%)
Beginning	5.23^b	1.37^a	0.18^a	170.3	1.32^a	6.70^a
End	5.31^a	1.30^b	0.13^b	165.5	1.09^b	3.08^b
SE (Means)	0.04	0.04	0.01	7.35	0.06	0.53

Means with a different letter in a column are significantly different at the 0.05 level of probability

The increase in soil pH after addition of legume residues is in agreement with Bationo *et al*. (1995) who stated that application of organic residues to the soil is one way of increasing soil pH. As a result, aluminum toxicity which inhibits plant growth is alleviated. Therefore, it can be argued that addition of organic residues, their decomposition and mineralization through action of soil micro-organisms may have resulted in increased soil pH. Miles and Manson (2000) added that a change of soil pH to less acidic conditions causes the release of major nutrients like C, N, P, K, Ca, Mg and S which becomes available for plant uptake, thereby decreasing in the soil.

The results showed a decrease of organic C, N, P and K from the soil in contrast to results of the screening experiment where these nutrients significantly ($P \leq 0.05$) increased in the soil, except P. These different results may be attributed to the less amounts of dry matter (hence less organic residues) produced by the legumes during the grass/legume integration phase as compared to the dry matter produced during the legume screening phase. The highest dry matter yield produced by Glycine, Siratro and Stylo during screening period was 10.31, 7.81 and 3.52 t ha^{-1}, respectively, compared to 8.43, 3.46 and 3.29 t ha^{-1} produced by the same legumes, respectively, during the grass/legume integration study. Therefore, the results indicated that more organic residues from the legumes were returned to the soil during the screening study than during the grass/legume integration study. Another possibility why the nutrients decreased during the grass/legume integration phase is the probable competition for nutrients by grasses and legumes as compared to the legume screening phase where the legumes grew in monoculture stands.

According to Landon (1984), N-rich plant materials like those from legumes decompose more rapidly than those usually low in N. This statement is in conformity with the findings of Crespo *et al.* (2005) who reported that litter from *Desmodium ovalifolium* and *Stylosanthes guianensis* legumes decomposed after 180 days compared to 210 days for litter from *Pueraria phaseoloides*, *Neonotonia wightii*/*Macroptilium atropurpureum*. However, the rate of litter disappearance was low in grasses with 30, 15 and 10 % of the original litter deposition remaining after one year in the case of *Cynodon nlemfuensis*, *Panicum maximum* and *Brachiaria decumbens*, respectively. Skerman *et al*. (1988) stated that the main source of available N in natural pastures is from soil organic matter, therefore the mineralization of soil N is the most important source of N for the growth of unimproved grasslands. However, in improved pastures containing legumes, soil N was supplemented by N fixed by the legume-*Rhizobium* symbiosis. The authors added that the fixed N was used first for the growth of legume plants which later contributed to growth of other plants in the pasture.

By end of the experiment, organic C, N and K significantly ($P \leq 0.05$) decreased in the soil while the decrease of P was not significant ($P \geq 0.05$). These results are in conformity with those of Mureithi *et al*. (1994) who reported that after opening up virgin land for cultivation, C, N, P and K decreased up to the second year. However, during the third year of cropping, C, N and P increased (though not significantly) due to application of mulch from *Leucaena leucocephala* (Lam) De Wit. The authors concluded that in the long term, improved soil nutrients will likely result not from direct addition of mulch from outside sources, but from large amounts of cover crop residues for soil fertility replenishment.

The significant ($P \leq 0.05$) decrease in Ca content from the soil was similar to the decrease obtained during the screening experiment. The results from the integration experiment implied that as soil pH rose from 5.23 at beginning of experiment to 5.31 by end of the experiment, soil calcium became more available for plant uptake which is in agreement with Muriuki and Qureshi (2001). However, these results are in contrast to those by Hassen *et al.* (2007) who reported an increase of soil Ca after on-station intercropping of *Chloris gayana* with *Stylosanthes hamata*, *Desmodium intortum* or *Macrotyloma axillare*. At the beginning of the fallows, soil Ca was 6.99 which increased to 8.48, 7.49 and 7.98 (meq 100 g^{-1}), respectively. However, the author's cautioned on interpretations of the results since they were based on single composite samples per treatment and no statistical analysis was done. According to Marschner (1995), dicotyledons such as legumes required higher levels of calcium than monocotyledons such as grasses for optimum growth. In addition, the process of nodule formation in legumes was dependent on calcium which is required by the associated *Rhizobium* bacteria (Skerman *et al*., 1998).

CONCLUSION

Addition of organic residues to the soil by the legumes improved the soil fertility by enhancing the soil pH, carbon, nitrogen and potassium. However, phosphorus and calcium levels in the soil decreased possibly due to utilization by the legumes during the nodulation and growth processes. The amount of legume residues returned to the soil determined the amount of soil nutrients released to the soil for subsequent uptake by the companion grasses. Glycine, Siratro and Stylo sown into natural pastures improved the soil fertility due to the addition of organic matter by the legume residues. Therefore, livestock fed on fodder from grass/legume mixed pastures may benefit more than those fed on natural pastures alone.

ACKNOWLEDGEMENTS

The authors are grateful to the Rockefeller Foundation for funding the research work through the Legume Research Network Project of the Kenya Agricultural Research Institute. The authors are also grateful to Mwalimu Gaddiel, the farmer who allowed this study to be carried on his farm.

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Submitted November 21, 2009 – Accepted May 25, 2010
Revised received June 01, 2010