African Journal of Agricultural Research Vol. 5(17), pp. 2392-2398, 4 September, 2010
Available online at http://www.academicjournals.org/AJAR
ISSN 1991-637X ©2010 Academic Journals

Full Length Research Paper

Effect of incorporation of legumes on selected soil chemical properties and weed growth in a potato cropping system at Timboroa, Kenya

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Accepted 9 July, 2010

The effect of incorporation of lupine and garden pea on selected soil chemical properties and growth of weeds in a potato cropping system was evaluated in North Rift, Kenya. The study was carried out in a well drained, extremely deep, dusky red to dark reddish brown, friable clay, acid humic top soil. Two weeding regimes (at legume incorporation stage and/or at 50% potato flowering stage), three nitrogen levels (0, 60 and 120 kg N ha^{-1}) applied as CAN and two legumes plus a control (garden pea, lupine and none) were evaluated in a split-split plot design with weeding regimes as the main plots, N as sub-plots and legumes as the unit plots. Incorporation of legumes significantly ($p < 0.05$) raised soil pH from 3.6 - 3.9 and to 4.2; increased soil available P from 15 mg/kg to 25 and to 29 mg/kg for garden pea and lupine, respectively. The two legumes interacted with weeding regime and N reducing sheep sorrel weed density and biomass. The significantly higher lupine effects were attributed to its high biomass production suggesting that legumes may best improve soil fertility and reduce soil acidity when incorporated in the soil as green manure.

Key words: Soil fertility, soil acidity, weeds control, legumes, potato yield.

INTRODUCTION

Low crop yields in Kenya have among other factors been attributed to the rapid decline in soil fertility caused by continuous cultivation of annual crops without adequate replenishment of mined nutrients. In the North Rift, this problem has been exacerbated by the inherent low soil pH resulting from soils developed from tertiary or older basic igneous parent rocks (Jaetzold and Schmidt, 1983). Rapid decline in soil fertility coupled with low pH have favoured infestation of weeds. Hoevers (1991) reported that declining cropping conditions due to high pressure on land, changing cropping practices as well as inappropriate use of farm inputs, may lead to establishment of weeds that are hard to control, and more adapted to the adverse cropping conditions than the crops. A new weed of concern to farmers in the North Rift known as sheep sorrel (*Rumex acetosella* L.) has emerged as a major weed in Irish potato (*Solanum tuberosum* L.), maize (*Zea mays* L.) and pyrethrum (*Chrysanthemum cinerariaefolium* L.). Another weed reported by farmers as also being difficult to control in the area is wild radish (*Rhaphanus raphanistrum* L.) (Kwena et al., 1996).

Sheep sorrel also known as red sorrel, field sorrel, horse sorrel, mountain sorrel, cow sorrel or sour dock, is a perennial weed belonging to the buckwheat (*Fagopyrum esculentum*) [Polygonaceae] family. It is an herbaceous perennial weed that reproduces sexually by seeds, and asexually (vegetative) from buds that develop irregularly on creeping roots and rhizomes (Whitson et al., 2000). Except for the fine terminal roots, the whole root system is capable of producing buds. A root fragment as small as 3 cm, can form a bud and regenerate a

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new shoot. Seeds can be dispersed by wind, insects, water, and animals and can remain viable in the soil for up to 20 years and are viable even after passing through digestive tract of domestic birds and animals (Pleasant and Schlather, 1994). The weed was introduced in Kenya from Europe by white settlers through contaminated pyrethrum seed (Kiiya, 2009). Most farmers weed their potato crop at least twice in a season but have not been successful in controlling this weed nicknamed in the area as 'Ukimwi' weed (Ukimwi is the Kiswahili word for the dreaded HIV/AIDS disease for human beings whose cure is yet to be found). However, despite the difficulties experienced in controlling this weed, it was found to be absent on farms or parts of the farms where the soil was considered fertile, especially where kraals had previously been cited (Kwena et al., 1996). The weed has therefore been associated with impoverished soils. Studies elsewhere have also shown that in addition to low soil fertility, the weed is favoured by acidic soils (Ciuberkis, 2001).

Green manure legumes can play an important role in soil fertility improvement (Cherr et al., 2006). When incorporated into the soil, green manure legumes have been shown to improve soil organic matter, moisture retention (Gachene et al., 2000) and soil workability (Fischler, 1996). Onim et al. (1990) working in western Kenya reported that 13,603 kg dry matter of sesbania produced in the region contained 448 kg N, 31 kg P and 125 kg K per ha.

They further showed that addition of 4,806 kg ha^{-1} dry matter of pigeon pea residue provided 161 kg N, 4 kg P and 26 kg K, while 7,793 kg ha^{-1} of maize stover added 120 kg N, 5 kg P and 7 kg K ha^{-1}. Available evidence also suggests that green manure legumes may lower soil acidity (Sakala et al., 2004). The objective of this study was to determine the effect of incorporation of lupine and garden on selected soil chemical properties, growth of sheep sorrel and wild radish weeds in a potato cropping system.

MATERIALS AND METHODS

Prior to laying out the experiment, five composite topsoil samples were randomly taken from the area (using a soil auger 75 mm in diameter) at a depth of 0 - 20 cm for determination of baseline soil characteristics. At the end of each season, one composite soil sample was taken from each plot and analysed for pH, soil available phosphorus, total nitrogen, exchangeable calcium and magnesium following procedures outlined by Okalebo et al. (2002). There were a total of 18 treatments replicated thrice in a factorial arrangement laid out in a split-split plot design. The main plots were weeding regimes (one hand weeding at legume incorporation stage and/or a second weeding at 50% potato flowering stage) while the sub-plots were inorganic nitrogen levels (0, 60 and 120 kg N ha^{-1}) applied on potato crop as calcium ammonium nitrate (CAN) in two equal splits. The first split of CAN was applied two weeks after potato emergence while the remaining nitrogen level was applied at legume incorporation stage. Green manure legumes (none, garden pea or lupine) incorporated at 50% flowering stage were the unit plots.

The green manure legumes were planted three weeks prior to planting "Asante" potato variety recommended for high elevations (Kari-Tigoni, 1997). The legumes were planted in alternate rows between potato rows at an intra-row spacing of 30 cm, two seeds per hole. Triple super phosphate (TSP) fertilizer at the rate of 25 kg P ha^{-1} was applied at planting (Sarrantonio, 1991) the legumes and an additional 75 kg P ha^{-1} was applied on potatoes. Potatoes were spaced at 75 cm between rows and 30 cm between hills, one tuber per hill in plots measuring 5.25 m wide by 4.5 m long. This plot size gave a total of eight potato rows and seven legume rows, out of which the five central potato rows were used for data collection. All legume plants in each plot were cut at the soil level at 50% flowering stage, fresh weights taken and 10 randomly selected plants weighed and dried in the oven at 65°C until constant weight was attained. The percent moisture content for the samples was used to calculate dry matter (DM) per hectare. The rest of the fresh legume materials were chopped into small pieces and incorporated into respective plots during the first weeding.

Sheep sorrel and wild radish weed densities and above ground biomass were determined prior to first potato weeding and at 50% potato flowering stage. A quadrat measuring 0.5 m by 0.5 m was randomly thrown four times in each plot and all the weeds rooted within the quadrat were counted and cut at the ground level. Sheep sorrel and wild radish weeds were then separated from other weeds and placed in separately labelled bags. The remaining weeds were placed in a third bag labelled as 'other weeds'. The weed samples were dried at 65°C for 48 h. The mean weight of the weed DM from the harvested area was expressed in tons per hectare. The average number of weeds counted per plot was expressed in weed counts per m^2. At potato physiological maturity, stand count was taken for the five central rows which were thereafter harvested and the fresh potato tubers weight taken and used to determine fresh potato tuber weight in tons per hectare. All the data collected were analyzed statistically using SAS package (SAS Inst., 1990) and means separated using the LSD test at 5% significance level.

RESULTS AND DISCUSSION

Effect of soil incorporated lupine and garden pea on selected soil chemical properties

Analysis of soil samples from each plot at the end of each season showed that there were no significant differences ($p > 0.05$) in the levels of total nitrogen, exchangeable potassium and magnesium throughout the experimentation period. The levels of these elements were considered moderate according to Okalebo et al. (2002). The results of soil pH changes in the legume incur-porated plots over the experimental period are shown in Figure 1. Incorporation of legumes significantly ($p < 0.05$) raised soil pH in the second short rains (SR) 2003 and third long rains (LR) 2004 seasons but not in the first season LR 2003. However, except for the control, the legumes were not significantly different from each other during the SR 2003 season but were significantly different during the LR 2004. During the latter season, lupine raised soil pH by 15.6% (from 3.6 - 4.2) while garden pea raised the soil

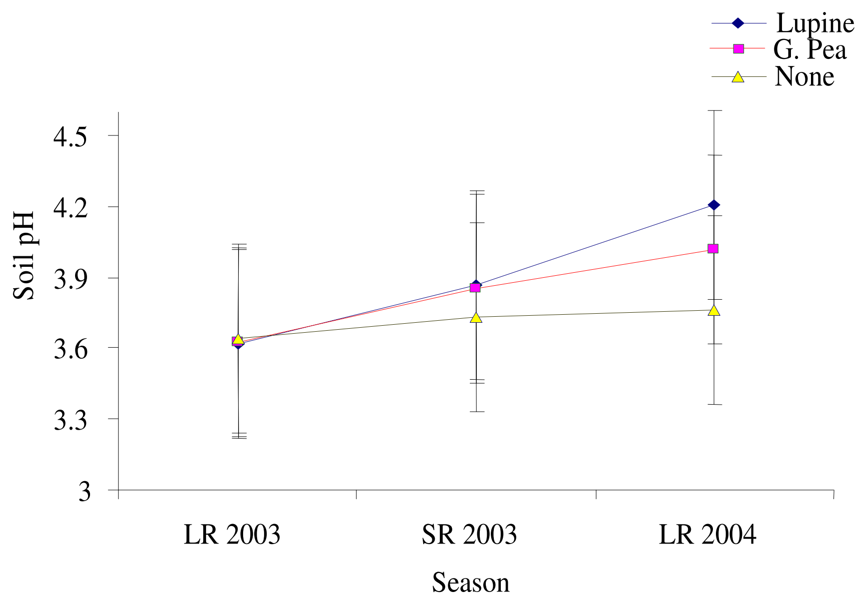

Figure 1. Soil pH changes with green manure incorporation from long rains 2003 to long rains 2004*. *- standard error bars represent differences at 5% significance level. - G. pea for Garden pea.

pH by 10.4% (from 3.6 - 4.0).

The significant difference in soil pH between the legumes in the LR 2004 was attributed to the higher lupine biomass incorporated into the soil. This demonstrated the importance of high biomass production if a given green manure legume was to be used to ameliorate acidity and improve soil fertility. The build-up of organic matter from legumes is often slower than from non leguminous material because the high nitrogen content of legumes often causes them to decompose more rapidly than other materials (Sarrantonio, 1991). The actual extent of such changes also depends on the production environment of the site where the legume is grown and management practices (Cherr et al., 2006). In this study, rapid decomposition of legumes due to high nitrogen levels may have contributed to the slow increase in soil pH. Poor performance of garden pea may have also contributed to the slow increase in soil pH. The significant differences in soil pH in the second and last seasons between the legumes may have resulted from the cumulative effect of the organic matter from the incorporated green manure residues. An important mechanism by which legume organic amendments ameliorate soil acidity is thought to be as a result of the formation of organic aluminium complexes in soil solution through release of low molecular weight organic acids such as malates and oxalates from the decomposing legumes. The organic-Al complex lowers the concentration of phytotoxic Al^{3+} in solution therefore precluding Al^{3+} from the hydrolysis reaction that increase soil pH (Haynes and Mokolobate, 2001).

The results of the analysis of soil available phosphorus are presented in Figure 2. Like for soil pH, soil available phosphorus from plots where lupine and garden peas were incorporated were not significantly different from each other ($p > 0.05$) during the SR 2003 but were both significantly higher than the control. There were signifycant differences between the two legumes during LR 2004 season in which lupine raised soil available phosphorus by 52.8% (from 20.3 - 31.0%) while garden pea raised soil available phosphorus by 45% (from 20.3 - 29.4%). The significant difference between the two legumes during the LR 2004 was attributed to the higher lupine biomass incorporated as compared to that of garden pea.

The results for LR and SR 2003 are in line with findings by Bumaya and Naylor (1988) that phosphorus availability may not immediately increase following green manure incorporation since soil microbial biomass and soil sorption processes competed for available phosphorus. However, the increase during the LR 2004 is consistent with studies by other scientists. Tisdale et al. (1985) reported that the decomposition processes which are stimulated when green manure residues are incorporated into the soil increased phosphorus by releasing CO_2 which formed H_2CO_3 in the soil solution resulting in the dissolution of primary P-containing minerals. Sharpley and Smith (1989) reported that the organic acids released during green manure decomposition dissolved soil mineral phosphorus but Easterwood and Sartain

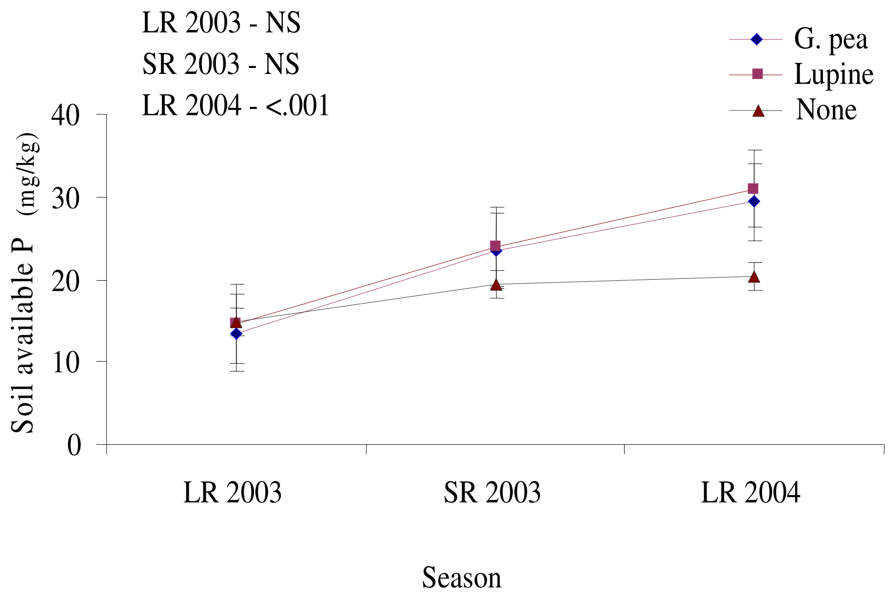

Figure 2. Effect of incorporation of green manure legumes on soil available P from long rains 2003 to long rains 2004*. *- standard error bars represent differences at 5% significance level. - G. pea for Garden pea.

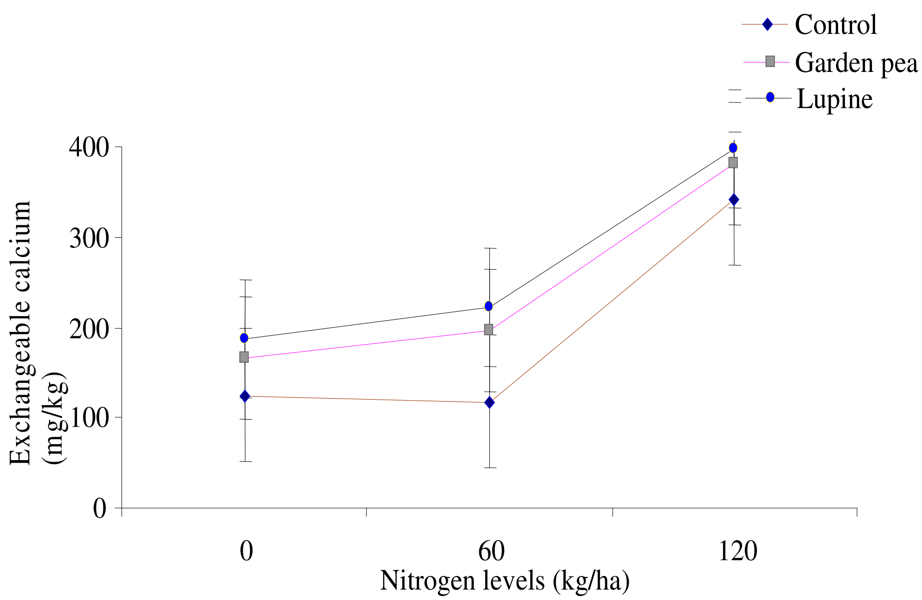

Figure 3. Effect of nitrogen and incorporation of green legumes on soil exchangeable calcium during the long rains 2004*. *- standard error bars represent differences at 5% significance level. - G. pea for Garden pea.

(1990) noted that such organic compounds increase phosphorus availability in soils with high P-fixing capacities by blocking P-adsorption sites.

The results of the interaction effect of nitrogen and legumes on soil exchangeable calcium for the LR 2004 are presented in Figure 3. There were significant interaction effects on soil exchangeable calcium in all the three seasons. The significant interaction effects led to

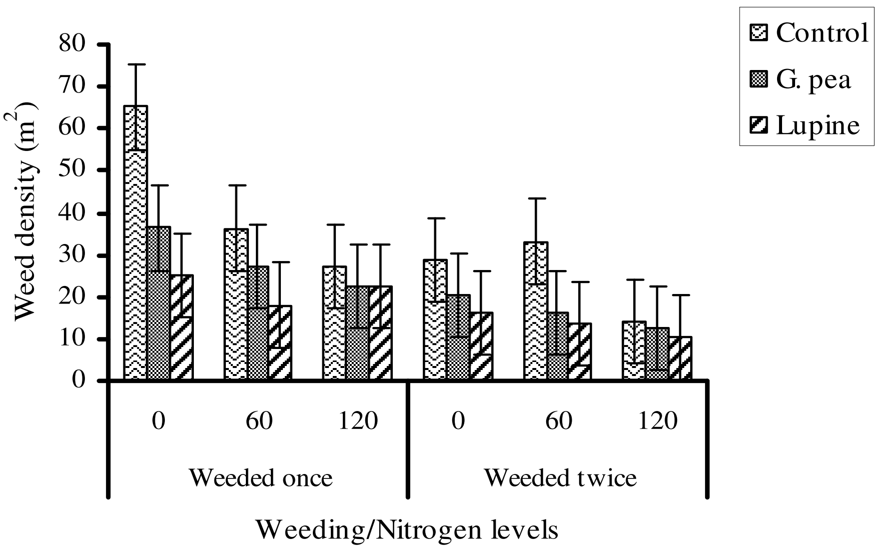

Figure 4. Effect of weeding, nitrogen and legumes on sheep sorrel weed density during the long rains 2004*. *- standard error bars represent differences at 5% significance level. - G. pea for Garden pea.

increased soil exchangeable calcium with the highest concentration levels attained when nitrogen was applied at the rate of 120 kg ha^{-1}.

The results therefore showed that at high N levels, incorporation of legumes led to an increase in the release of exchangeable calcium. Incorporation of lupine resulted into a much higher impact of soil exchangeable calcium than garden pea. The increase in exchangeable calcium could, in addition to the direct supply from the CAN fertilizer, be attributed to enhanced release due to the rapid decomposition of the organic matter in the green manure legumes. This observation concurs with Teasdale et al. (1991) who reported an increase in the rate of organic matter decomposition and nutrient release with increased nitrogen application.

Effect of incorporation of lupine and garden pea on the growth of weeds

The results of the interaction effect of weeding regime, nitrogen and green manure legumes on sheep sorrel weed density for the long rains 2004 are presented in Figure 4. The highest weed density was obtained where weeding was done once, nitrogen not applied and no legume planted. Sheep sorrel weed density declined with nitrogen application, a trend observed in all the three seasons. Application of 120 kg N ha^{-1} and incorporation of lupine with one weeding was equivalent to weeding twice in terms of reducing sheep sorrel weed density. However, there were no significant differences between where weeding was done once and 120 kg N ha^{-1} applied and where weeding was done twice with neither nitrogen nor green manure applied. Application of 120 kg N ha^{-1} and incorporation of lupine therefore reduced sheep sorrel weed density to the same extent as weeding twice. Lupine reduced sheep sorrel weed density better than garden pea. Since nitrogen was applied on potatoes, sheep sorrel weed density decrease was probably attributed to increased potato vegetative growth which virtually excluded the weed from direct exposure to sunshine. Sunlight being important for seed germination (Lowe et al., 1999), it became evident that due to such high potato ground cover, germination of weed seed was reduced.

There was a significant three-way treatment interaction effect on sheep sorrel weed biomass during the SR 2003 and LR 2004. Means average across these seasons is presented in Figure 5. Generally, a similar trend to that of weed density was observed in terms of progressive reduction in weed dry matter. However, apart from where weeding was done twice and 120 kg N ha^{-1} applied, there were no significant differences between lupine and garden pea in terms of sheep sorrel weed biomass.

The results obtained were consistent with the findings of Dyck and Liebmann (1994) who working at the University of Maine in U.S.A found that common lambsquarter's (*Chenopodium album* L.) above ground biomass accumulation was 46% lower where crimson clover residue had been incorporated than the non residue treatments at 23 days after planting and remained 26% lower at 53 days after planting. Theories put forward as to the possible causes of the reduced weed density and dry matter yield resulting from green

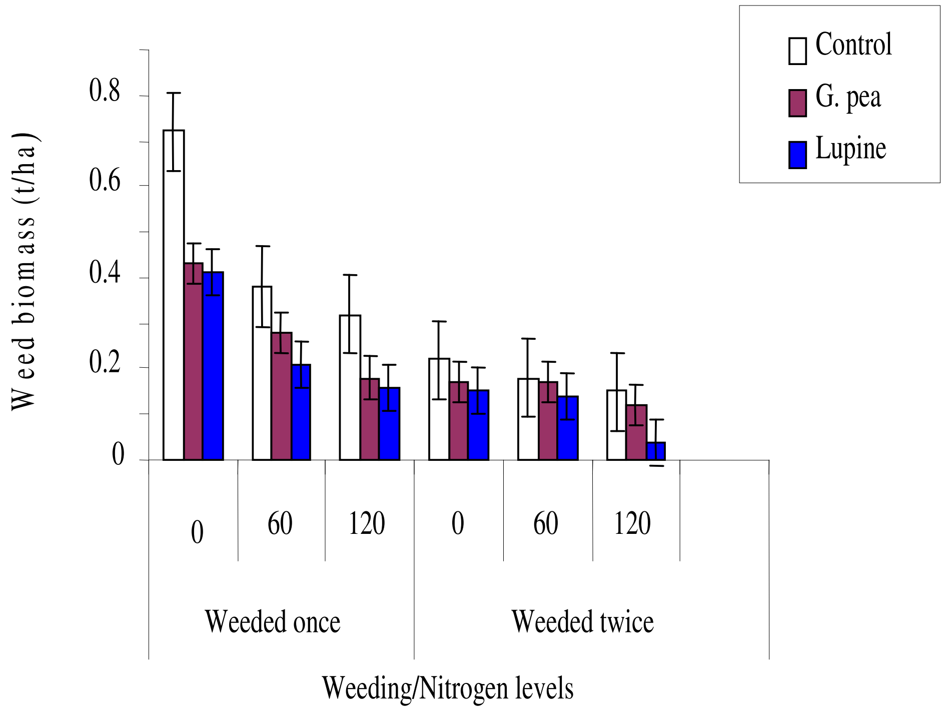

Figure 5. Effect of weeding, nitrogen and legumes on sheep sorrel biomass – means averaged for long rains 2003 and 2004. - G. pea for Garden pea.

manure legume use are diverse. White et al. (1989) postulated that probably the chemical constituents of a green manure legume or products of its decomposition could inhibit weed growth. They showed that the aqueous and volatile extracts of such legumes as sweet clover (*Melilotus spp.*), beseem clover (*Trefoil alexandrine* L.), crimson clover, and hairy vetch reduced weed germination and early seedling growth in bioassay studies.

The effects of weeding regime, nitrogen and incorporation of green manure legumes on wild radish weed density and biomass were not as evident as for sheep sorrel weed. There were no consistent trends observed on wild radish density and biomass due to application of nitrogen and incorporation of green manure legumes. Lack of significant nitrogen effect on wild radish weed density was attributed to the fact that the function of nitrogen in a plant is in protein synthesis and in the photosynthetic process and had therefore no role on the number of plants germinating. Application of nitrogen was therefore not expected to change either the number or biomass of wild radish weed. Since nitrogen was applied as a top dress fertilizer on potato crop immediately after first weeding when weeds had been ploughed in, the weed plants had not re-emerged in order for it to absorb and benefit from the nitrogen in terms of increased biomass.

Effect of incorporation of lupine and garden pea on potato tuber yield

Green manure legumes had no effect on potato yields in both the long and short rains 2003 but interacted with nitrogen at the higher rate of 120 kg ha^{-1} during the long rains 2004, increasing potato yields. The yield increase was between 11.5% (garden pea) and 24.7% (lupine) when green manure was applied compared to the control. The yield increase was attributed to the high availability of nitrogen from the CAN and green manure legumes. The increase may also have been caused by the reduced sheep sorrel weed density and biomass occasioned by the high potato canopy cover at 120 kg N ha^{-1}. The effects of green manure legumes on potato yield were not realized until the LR 2004. The two legumes may have been different in their decomposition rate. The rate of decomposition has been shown to be dependent upon tissue carbon to nitrogen ratio, lignin, polyphenolic contents, temperature and soil moisture (Nyambati, 2002). These are the primary factors influencing the rate of mineralization and nitrogen availability to crops (Sisworo et al., 1990). Legume stem hardiness associated with cell wall lignin levels also affects the rate of decomposition. On this basis, garden pea decomposed within 21 days while lupine took up to 60 days, an indication that the latter had probably higher lignin levels.

However, leaves for the two legume species decomposed within a period of 14 days. Analysis of leaf samples showed that garden pea had significantly ($p < 0.05$) higher leaf nitrogen content (3.0%) than lupine (2.8%). However, lupine may have compensated for its low N levels with the higher biomass.

Conclusion

The study showed that legumes produced high herbage yields and had therefore the potential of accumulating high biomass. When incorporated into the soil, the high biomass increases soil organic matter and through increased organic matter raise soil pH leading to calcium and phosphorus availability. The legumes are therefore capable of ameliorating soil acidity and improving soil fertility as a result of increased soil pH and availability of P and exchangeable calcium. However, the positive effects of the green manure legumes may not necessarily be realized in one season since the decomposition rates of the legume species varied due to differences in tissue carbon to nitrogen ratio, lignin, and polyphenolic contents. The positive effects on soil pH could, however, be compromised if applied in localised areas such as in pot experiments because of accumulation of organic acids released by the decomposing legumes. The decomposing legumes may instead contribute to increased soil acidity. When incorporated into the soil, lupine and garden pea interacted with weeding regime and inorganic nitrogen fertilizer significantly reducing sheep sorrel weed density and biomass. The highest reduction was by lupine which was attributed to the higher lupine biomass that was incorporated into the soil.

ACKNOWLEDGEMENTS

The authors acknowledge the Rockefeller Foundation through the Legume Research Network Project and Director, Kenya Agricultural Research Institute for financial and administrative support of this research.

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