MANAGEMENT AND NUTRITIVE EVALUATION OF *MUCUNA PRURIENS* AND *LABLAB PURPUREUS*-MAIZE INTERCROPS IN THE SUB-HUMID HIGHLANDS OF NORTHWESTERN KENYA

By

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This work is dedicated to my mother whose constant encouragement and enduring love was a source of inspiration and strength to pursue knowledge to this day. May God give her the strength and courage to overcome her long-term ill health.

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Declining soil fertility and inadequate and low quality feed resources limit smallholder crop yields and dairy production in Kenya. Herbaceous legumes can provide an alternative to the use of commercial N sources for cereal crops and livestock production in these low external-input farming systems. Research reported in this dissertation was conducted to 1) determine the N contribution from relay-cropped mucuna [*Mucuna pruriens* (L.) DC. Var. utilis (Wright) Bruck] and lablab [*Lablab purpureus* (L.) Sweet cv. Rongai] to succeeding maize (*Zea mays* L.)-common bean (*Phaseolus vulgaris* L.) intercrop when part of the legume biomass is removed for fodder and 2) evaluate the nutritive value of these legumes when used as supplements for lactating cows fed napiergrass [*Pennisetum purpureum* (K. Schum) cv. Bana].

Relay-cropped mucuna and lablab survived the dry season producing a total biomass yield of 4 and 2.7 t ha^{-1} on the research station, and 2.3 and 0.75 t ha^{-1} on farmers' fields, respectively. The N contribution from mucuna and lablab residues were 78 and 57 kg

ha^{-1} on station, and 49 and 12 kg ha^{-1} on farmers' fields. Defoliation of the legumes to a 10-cm stubble removed 52 and 76% of the above-ground herbage of mucuna and lablab, and the residue quality of the remaining stubble was lower (higher lignin and lower N concentration) than that of whole above-ground biomass.

Inclusion of the green manures in the maize-bean intercrop increased subsequent bean and maize yields compared to the natural fallow control, but crop yields were relatively low on farmers' fields where soil fertility was lower than on station. Defoliation reduced the nutrient contribution from the legume residues; the impact of defoliation was greater on lablab, which has a more upright growth habit than mucuna. The mean N recovery by maize across all sampling dates ranged from 21% for the cattle manure control to 52% following undefoliated lablab. The N recovery after defoliated mucuna was 45% compared to 35% for undefoliated mucuna. After 2 yr of consecutive residue application, yields of subsequent maize were greatest under defoliated mucuna and undefoliated lablab, possibly due to their lower quality (more stem and lignin) residue which may have improved synchrony of N release with N requirement of the crops.

Defoliation of relay-cropped mucuna and lablab to 10 cm provided 1 to 1.8 t ha^{-1} yr^{-1} of high quality livestock fodder. Supplementing mucuna hay and lablab hay to dairy cows fed a basal diet of napiergrass increased total dry matter intake, apparent DM digestibility, and daily yield of 4% fat-corrected milk compared to napiergrass alone. Utilization of the high nutritive value upper canopy of mucuna and lablab as livestock feed and soil incorporating the remaining stubble has potential for improving maize yield and performance of livestock in smallholder systems in Kenya.

CHAPTER 1
INTRODUCTION

Agriculture is a very important sector of the Kenyan economy, accounting for 70% of employment, 80% of export earnings, and contributing 25% of the total gross domestic product (Kenya, 2000). Most agricultural production in Kenya is from smallholder farmers, and in northwestern Kenya, farmers practice mixed farming where dairying is integrated with the production of maize (*Zea mays* L.) intercropped with common bean (*Phaseolus vulgaris* L.), in addition to other food crops (National Agricultural Research Center [NARC], 1995).

Maize is the most important cereal crop in Kenya, with an average annual production of 3.3 million tons. It is estimated that 60% of the total national maize production occurs in western Kenya and 75 to 80% of this production is from smallholder farms (Ruto, 1992). Maize is ranked fourth out of Kenya Agricultural Research Institute's (KARI) 53 commodity and commodity group research priorities (KARI, 1991). Maize in combination with beans is the staple diet for a majority of Kenyans. Maize is inter-planted with beans, usually at the beginning of the rainy season in April; some farmers plant a second crop of beans in the maize fields in August. After harvesting maize in November, the land is left fallow during the dry season from November to March. The yields of maize are low and have been decreasing in the last few years on smallholder farms (Rees et al., 1997). The major crop production constraint facing smallholder farmers is declining soil fertility (NARC, 1995).

It is estimated that more than 18% of the total recorded, marketed agricultural production in Kenya is derived from livestock, out of which dairy products account for 33% (Kenya, 2000). Smallholder farmers produce over 80% of the milk sold to the formal market in Kenya (Mbogoh, 1992). Dairy ranks first of the Kenya Agricultural Research Institute's 53 commodity and commodity groups research priorities (KARI, 1991). In northwestern Kenya, the major production constraint to dairy production is inadequate feed for livestock, particularly lack of protein during the dry season (Wandera, 1996; Nyambati, 1997).

Due to land limitations, farmers practice continuous cropping and grazing with little or no fertilizer application, which has led to declining soil fertility and productivity of both crops and livestock. In the intensively cultivated highlands of eastern Africa, losses of N, P, and K are estimated at 112, 3, and 70 kg ha^{-1} yr^{-1}, respectively (Smaling, 1993; Stoorvogel et al., 1993; Van den Bosch et al., 1998). These losses are much higher than the average of 5 to 10 kg $ha^{-1}$of inorganic fertilizers used in sub-Saharan Africa (FAO, 1995; Heisey and Mwangi, 1996; Larson and Frisvold, 1996), leading to nutrient-depleted cropping systems (Sanchez et al., 1997). Soil N and P are the major limiting nutrients (Smaling et al., 1997). Although cycling of biomass through livestock and use of manure and urine to fertilize soil have been an important link between livestock and soil fertility (Powell and Valentine, 1998), the quantities of manure available on farms are usually not enough to replenish nutrients harvested in grain and crop residues (Williams et al., 1995). Intercropping of the common bean with maize provides little or no N to concurrent or subsequent maize, as the majority of N fixed by bean is harvested in the grain (Giller et al., 1991; Giller et al., 1994; Amijee and Giller, 1998).

Intercropping of soil-improving legume green manures with cereal crops is a promising, low-cost, ecological means of improving soil fertility (Giller et al., 1997). Legumes managed as green manures have the potential to furnish all or part of the N needed by a succeeding non-legume crop (Bowen et al., 1993). Legume cover crops and green manures may contribute from 30 to 60 kg N ha^{-1} (Utomo et al., 1992) to 110 kg N ha^{-1} (Hairiah and Van Noordwijk, 1989; Tian et al., 2000) to the subsequent cereal crop. Beneficial effects of legume cover crops for food crop production have been reported from West Africa (Carsky et al., 1999; Tian et al., 1999; 2000), East Africa (Fischler et al., 1999; Fischler and Wortmann, 1999; Wortmann et al., 2000) and elsewhere (Burle et al., 1992; Hairiah et al., 1992; Buckles, 1995). Although some adoption of green manures has been reported from West Africa (Manyong et al., 1996) and Central Africa (Balasubramanian and Blaise, 1993), the adoption of herbaceous legumes in Africa is generally low (Thomas and Sumberg, 1995; Drechsel et al., 1996).

Although green manures often give greater yields of subsequent crops than intercropping with grain legumes, they suffer the handicap of occupying the land unproductively; thus additional benefits are necessary for farmers to adopt them (Becker et al., 1995; Versteeg et al., 1998a). It is unlikely that farmers with food security problems, like those of small-holder farmers in western Kenya, will adopt legume green manures purely for soil fertility improvement alone. Apart from improving soil nutrient status the legume herbage has high protein concentration, palatability, and digestibility, and could be useful as a supplement to livestock being fed mature tropical grasses and cereal crop residues that are often of low nutritive value (D'Mello and Devendra, 1995). This would be particularly useful to smallholder farmers who lack the financial resources

to purchase commercial concentrates. These two potential uses of green manure legumes, however, compete for the nutrients in the above-ground biomass. Thus, it is important to understand the tradeoff between incorporating all the herbage from green manures into soils or using part of the herbage as livestock feed.

Mucuna pruriens var. Utilis (L) DC (Wright) Burck (mucuna or velvetbean) and *Lablab purpureus* L. (Sweet) cv. Rongai (lablab or dolichos) are promising legume green manures that have been successfully intercropped with maize in different parts of the world. They have been shown to increase grain yields of subsequent maize compared to continuously grown maize (Hairiah and Van Noordwijk, 1989; Buckles, 1995; Mandimba, 1995; Thomas and Sumberg, 1995; Ibewiro et al., 1998; Versteeg et al., 1998a; Ibewiro et al., 2000a; Tian et al., 2000). Even incorporation of only the roots of mucuna or lablab had a positive effect on subsequent maize as compared to a control where no residue was applied (Ibewiro et al., 1998).

One reason for the success of mucuna and lablab is that they have shown a greater competitive ability than many herbaceous forage and grain legumes under the shade of long-season maize cultivars when planted after maize (Maasdorp and Titterton, 1997). Mucuna and lablab could fit well in small-scale farms where the cut and carry system of dairying is practiced. Although information on the contribution of whole-plant biomass incorporation on subsequent maize yields is available, information on the contribution of roots or roots plus stem stubble after removing some shoot biomass for feed is still limited. Also, lack of information on their potential as livestock feed and their effects on maize grain yield hamper the integration of these legumes into the farming systems of northwestern Kenya.

The research reported in this dissertation was designed to answer the most critical management questions for use of these legumes among the financially constrained small-holder farmers in western Kenya, not only as dry-season forage but also for soil improvement purposes. The broad objectives of this research were to 1) determine if alternative cropping systems (legume intercrop and green manure) to the current maize-bean system affect maize and bean yields, 2) evaluate fodder production and nutritive value of legumes in alternative cropping systems and assess their value as a supplement to lactating cows during the dry season, and 3) determine the extent to which harvesting topgrowth of legumes for fodder reduces their beneficial impact on soil fertility as measured by yield of subsequent maize and beans.

CHAPTER 2
LITERATURE REVIEW

Cereal-Legume Cropping Systems

The use of legumes in mixed cropping systems is one of the traditional soil-fertility maintenance strategies. The most common production systems of integrating legumes into cropping systems include the following: simultaneous intercropping, relay intercropping, rotations, and improved fallows (Weber, 1996). The use of legumes in cropping systems offers considerable benefits because of their ability to fix atmospheric N_2 (Weber, 1996; Giller et al., 1997). Two mechanisms have been postulated by which cereal crops benefit from legumes in these multiple cropping systems (Giller et al., 1991; Giller et al., 1994; Giller and Cadisch, 1995): (1) through immediate transfer in which N travels from the legume directly to the associated crop, and (2) through residual effects in which N_2 fixed by the legumes is available after senescence of legume residue to an associated sequentially cropped non-legume. It is generally believed that the second mechanism is more important. According to Ledgard and Giller (1995), N benefits of these systems may accrue more to subsequent crops after root and nodule senescence and decomposition of fallen leaves. Cereal-grain legumes are the most common intercropping systems in mixed farming systems of sub-Saharan Africa. However, these grain legumes contribute little or no N to associated cereal crops because a large proportion (60-70%) of the N is removed during grain harvest (Giller et al., 1998).

The use of forage legumes in many parts of the tropics is limited because they do not contribute directly to the human food supply. Forage legume-cereal intercropping often

increases the quantity and quality of residues, but may decrease the yield of the companion cereal crop (Mohamed-Saleem, 1984). Ibrahim (1994) showed that the dry matter (DM) yields and land equivalence ratio (LER) of sudangrass (*Sorghum sudanense*)-lablab (*Lablab purpureus*) intercrops were higher compared to those of monoculture stands, but the highest protein yield was obtained from sole lablab. Although the beneficial effects of intercropping forage legumes have been demonstrated by intercropping cereals with a few legumes such as lablab, the same cannot be said for all legumes. This is because intercropped legumes produce much lower above-ground yields and their root systems are probably less developed than roots of legumes cultivated as pure stands (Nnadi and Haque, 1988).

Rotations Involving Forage Legumes

The potential of forage legumes to increase the productivity of crop-livestock systems has received increased attention in recent years because declining soil fertility and scarcity of livestock feeds are major constraints limiting agricultural productivity in these systems. These legumes are grown as rotation leys, cut and carry, or fodder banks. Studies conducted at the International Livestock Center for Africa (ILCA) (Nnadi and Haque, 1988) showed that rotations involving cut and carry forage legumes (*Trifolium steudneri*, *Vicia dasycarpa*, *Trifolium tembese*) preceding cereal crops [sorghum (*Sorghum bicolor*), maize (*Zea mays* L.), and wheat (*Triticum aestivum*)] increased the grain yields compared to cereal grown on plots that were previously planted to oat (*Avena sativa*).

An alternative system is to rotate cereal crops with short–term fallows of forage legumes (Tarawali and Mohamed-Saleem, 1995; Tarawali and Peters, 1996; Muhr et al., 1999a; 1999c). In reviewing the role of forage legume fallows in supplying improved

feed and recycling N in sub-humid West Africa, Tarawali and Mohamed-Saleem (1995) showed that cattle with access to *Stylosanthes* (*S. hamata* and *S. guianensis*) fallow in the dry season produced more milk, lost less weight, and had shorter calving interval and better calf survival than those in non-supplemented herds. They also showed that maize following *Stylosanthes* had greater grain yields than following natural fallows, but the responses varied depending on species. These positive effects were attributed to improved soil properties such as soil bulk density, soil moisture retention, cation exchange capacity (CEC), organic C, and soil N. Thomas and Lascano (1995) showed that the potential rates of N mineralization were greater in soils under 5- or 14-yr-old pastures containing legumes compared with similar grass-only pastures. The yield of the first cereal crop was higher after grass-legume pasture compared with the grass-only pasture when no N fertilizer was applied.

Studying the rotational effects of forage legumes, Muhr et al. (1999c) found that even though large amounts of N, P, and K (up to 120, 10, and 135 kg ha^{-1}, respectively) were removed as dry season herbage, nutrient accumulation in the remaining green manure biomass increased grain yields of subsequent maize grown on the legume plots. The nutrient export in legume fallow biomass removed in the preceding dry season apparently did not preclude the subsequent yield response of maize, but responses varied depending on the sites' fertility status.

Green manure legumes grown in rotation with cereal crops have the capacity to provide high quality organic inputs to meet N demands of subsequent crops (Carsky et al., 1999; Tian et al., 2000), but incorporating these non-food legumes in the farming system requires a sacrifice of land and labor that is normally devoted to crop production

(Drechsel et al., 1996). Reviewing studies on organic matter technologies for integrated nutrient management in smallholder farming systems of southern Africa, Snapp et al. (1998) concluded that green manures grown as relay intercrops have a lower N yield potential, but land and labor use may be more efficient and the system is flexible around farmer needs. The challenge is how to integrate these legume green manures into the current production systems. On-farm research in West Africa has shown that integration of these legumes into the farming systems and adoption by farmers could be improved if the legumes have multiple uses (Becker, 1995; Becker and Johnson, 1998; Versteeg et al., 1998a). In intensive agricultural production systems, rotations or simultaneous intercrops involving green manures may not be practical, thus: relay-cropping green manure legumes, in which partial rather than whole total biomass is harvested as fodder, could be the most feasible option of reducing competition for land between livestock and crops.

Intercropping and Adaptation Characteristics of Mucuna and Lablab

Mucuna (*Mucuna pruriens*) and lablab in-row intercropped at the same time with long-season maize for silage production showed high competitive ability under the shaded conditions of the intercrop (Maasdorp and Titterton, 1997). These intercrops had a higher percent legume in total DM (30 and 15, respectively) compared to several other forage and grain legumes [silverleaf desmodium (*Desmodium uncinatum*), siratro (*Macroptilium atropurpureum*), archer (*Macrotyloma axillare*), lucerne (*Medicago sativa*), lupins (*Lupinus albus, L. angustifolius, L. luteus*), forage soya (*Glycine max*), semi-trailing cow pea (*Vigna unguiculata*), scarlet runner bean (*Phaseolus coccineus*), and grain soybean (*Glycine max*)], which contributed 0.4 to 14.4%. The competitive ability can be attributed to the support offered by maize plants, which improves leaf

display of the twining legumes to offset the shading effect of maize. However, the aggressive twining and trailing habit of the mucuna was observed to suppress the growth of intercropped maize in India (Singh and Relwani, 1978). Mucuna planted at the same time with maize reduced the DM yield of silage maize by 50% at 16 WAP (Maasdorp and Titterton, 1997). Versteeg et al. (1998a) observed that mucuna planted earlier than 5 wk after planting maize smothered the young maize plants by its aggressive development, resulting in serious grain yield losses. Planting of either mucuna or lablab at 4, 6, or 8 wk after planting maize was shown to have no effect on maize grain yield in four sites in Zimbabwe having an annual rainfall range of 650 to 1000 mm (Muza, 1998).

Although the DM yields of mucuna and lablab when in-row intercropped with maize were lower (2.0 and 1.7 t ha^{-1}) than when grown as sole crops (4 and 9 t ha^{-1}), the proportion of leaf and pod under the shaded conditions of the intercrops was shown to be higher (35.4 and 33.6%) than in sole crops (29.6 and 23.7%) for mucuna and lablab, respectively (Maasdorp and Titterton, 1997). The increased proportion of leaf and pods indicates the suitability of top shoot growth as a protein supplement.

Lablab is fairly drought resistant and regrows well even in the early part of the dry season following an earlier cut (Mangawu et al., 1994, cited in Maasdorp and Titterton, 1997; Weber, 1996). Mucuna tolerates low soil fertility, acidic soils, and drought conditions (Hairiah et al., 1991; Burle et al., 1992; Weber, 1996), properties which indicates its potential for surviving and producing biomass during the drier part of the year. In Brazil (Burle, 1992), when mucuna and lablab were grown at the end of the rainy season, they survived a dry season of 4 mo (Ca. 10 mm mean monthly rainfall). They produced an average of 2.4 and 1.1 t DM ha^{-1}, respectively, and continued growing

when the rains returned. In reviewing the challenges for research and development of legume-based technologies for the African savannas, Weber (1996) concluded that mucuna and lablab are among the species adapted to cropping systems in sub-Saharan Africa. Further, they are shade and drought tolerant and can be relay cropped into maize-based cropping systems to provide, from residual moisture, additional benefits to the maize crops. Delayed planting, defoliating shoot growth for livestock feed, and planting these legumes between the maize rows may reduce the competitiveness of these twining legumes, while providing forage of good quality.

When used as a cover crop, mucuna has a nematocidal effect (McSorley et al., 1994) as well as the ability to smother weeds (Fujii et al., 1992; Becker and Johnson, 1998; Versteeg et al., 1998a), particularly broad leaf weeds (Hepperly et al., 1992). It is also reported that the use of lablab as a green manure/cover crop has the potential to control weeds (Weber, 1996; Becker and Johnson, 1998) including *Striga hermonthica* (Weber, 1996), a serious weed in cereal-based cropping systems in eastern Africa. In West Africa, the ability of mucuna to control a local weed, cogongrass (*Imperata cylindrica*), seemed to have a major influence on its adoption (Versteeg et al., 1998a), indicating that farmer adoption of cover crop/green manure technology may not only be based on agronomic yield, but other factors/uses may also be important (Becker et al., 1995).

Replenishing Soil Fertility

Low soil fertility, particularly N and P deficiencies, is recognized as one of the major biophysical causes for declining per capita food production in sub-Saharan Africa (Sanchez et al., 1997). Nutrient balance studies in this region (Stoorvogel et al., 1993) have shown that on average 22 kg N, 2.5 kg P, and 15 kg K are lost annually and losses can be as high as 112 kg N, 3 kg P, and 70 kg K in the intensely cultivated highlands of

eastern Africa (Van den Bosch et al., 1998). These losses are much higher than the estimated inorganic fertilizer use in Africa of 5 to 10 kg (FAO, 1995; Heisey and Mwangi, 1996), emphasizing the need for soil fertility replenishment. Sustainable crop production in many soils of sub-Saharan Africa requires P inputs because the soils are either derived from parent material with low levels of P or have been depleted of plant-available P through continuous cropping with insufficient P inputs (Sanchez et al., 1997). The Oxisol soils that are widespread in this region have a major chemical constraint of high P fixation (Deckers et al., 1994). The low native soil P, high P fixation by soils with high Fe and Al concentration, and nutrient depleting effects of long-term cropping without additions of adequate external inputs have contributed to P deficiencies in many tropical soils (Jama et al., 1997).

Phosphorus can be replenished either immediately with high, one-time P application in soils with high P-sorption capacity, or gradually with moderate seasonal applications at rates sufficient to increase P availability in soils with low to moderate P-sorption capacity (Buresh et al., 1997). The combination of P and N replenishment can have synergism. The elimination of P deficiency can enhance N_2 fixation by legumes (Giller et al., 1997) and the integrated use of P fertilizers with organic materials to supply N can potentially enhance P availability through the addition of P and reduction of the P-sorption capacity of the soil by organic anions (Palm et al., 1997). Application of organic materials may increase crop-available P either directly by the process of decomposition and release of P from the biomass or indirectly by the production of organic acids (products of decomposition) that chelate Fe or Al, reducing P fixation (Nziguheba et al., 1998). However, the amount of P that can be added through organic materials is restricted by the

limited supply of organic material at the farm level. Palm et al. (1997) showed that whereas lablab and mucuna contain sufficient N in 2 or 3 t of leafy material to match the requirement of a 2-t crop of maize, they cannot meet the P requirements and must be supplemented by inorganic P in areas where P is deficient. Jama et al. (1997), working in western Kenya, indicated that it was economically attractive to integrate triple superphosphate (TSP) with organic materials having high N to P ratios, the organic material provides the required N for the crop and TSP meets the additional requirement for P.

Judicious application of inorganic fertilizers is recognized as an indispensable means of overcoming soil fertility decline and decreasing food production per capita (Mokwunye and Hammond, 1992). Although inorganic fertilizers are the most effective amendments to maintain soil fertility or alleviate nutrient deficiencies, their high cost, inaccessibility, and generalized recommendations resulting in low, erratic, and unprofitable crop responses limit their use, particularly on smallholder farms in sub-Saharan Africa (Vlek, 1993; Nandwa and Bekunda, 1998).

It has also been shown that on the poorly buffered Kaolinitic soils found in many areas in the tropics, including sub-Saharan Africa, continuous use of fertilizer alone cannot sustain crop yield and maintain soil fertility in the long-term because of soil acidification, loss of soil organic matter, and soil compaction (Juo et al., 1995a; 1995b). Kang (1993), working on an Alfisol soil in Nigeria, reported a soil pH decline from 6.2 to 5.1 during 10 yr of continuous cropping with maize, sweet potatoes (*Impomea batatas*), and cowpeas, manual tillage, and annual application of 160 to 200 kg N ha^{-1} as urea. On a similar soil in Nigeria, continuous cropping of maize with no stover returned to the soil and

application of 120 kg N as urea, 26 kg P, and 30 kg K ha^{-1}, during 13 yr under no tillage resulted in a steady decrease in pH from about 6 to 4.5 in the 0- to 15-cm surface soil (Juo et al., 1995b). Several other examples of acidification and the decline of soil organic matter and exchangeable nutrients in sub-Saharan Africa are given in a review by Franzluebbers et al. (1998).

Because the issue of low soil fertility is widespread in the tropics, many studies have been undertaken on the topic, particularly related to the use of organic manures as an alternative to high cost inorganic fertilizers. This review is confined to the use of mucuna and lablab with only a few studies on other species discussed for comparative purposes.

Effects of Mucuna and Lablab Green Manures on Soil and Crop

Introduction

Recently there has been a resurgence of interest in leguminous green manure/cover crops in many parts of the tropics where the use of commercial inorganic N fertilizers is not economically feasible. It is estimated that N_2 fixation ranging from 0 to 250 kg N ha^{-1} with a median of 110 kg N ha^{-1} can be achieved from annual legumes with growth periods of 100 to 150 d (Giller and Wilson, 1991; Sanginga et al., 1996a; Ibewiro et al., 2000b). The contributions of legume residues to soil improvement and crop production depend largely on the amount of biomass produced (Sanginga et al., 1996a), chemical composition (Palm and Sanchez, 1991; Tian et al., 1992; and Constantinides and Fowness, 1994), and method of application (Mafongoya and Nair 1997). The decomposition and nutrient release by these residues are also affected by both climatic and adaphic factors, including the biological activity and availability of nutrients in the soil (Myers et al., 1994; Mugendi and Nair, 1997).

Potential use of mucuna and lablab green manures

Hairiah and Van Noordwijk (1989) reported that in a growth period of 14 wk on an acid soil in Onne, Nigeria, mucuna contributed 110 kg N ha^{-1} compared to *Desmodium*, *Centrosema*, *Pueraria,* and *Vigna,* which contributed 26 to 60 kg N ha^{-1}. In Brazzaville, Congo (Mandimba, 1995), mucuna green manure increased the grain yield of maize up to 56% (to a total of 3.6 t ha^{-1}) compared to a control that did not receive any N fertilizer (2.3 t ha^{-1}). This was comparable to the yields of maize fertilized with 100 kg N ha^{-1} (3.7 t ha^{-1}) and maize grain yields following green manures of pigeon pea (*Cajanus cajan*) (3.3 t ha^{-1}) and sun hemp (*Crotolaria juncea*) (3.4 t ha^{-1}). Reviewing the potential of improved fallows and green manure in Rwanda, Drechsel et al. (1996) reported contrasting results in which they indicated that green manuring is a risky enterprise due to the highly variable biomass production that in some cases did not compensate for loss of crop yields and additional labor inputs during green manuring. They concluded that due to acute land shortage, farmers were reluctant to allocate land to fallows with the exception of fields already out of production. Based on survey information, Mousolff and Farber (1995), working in Honduras, estimated that use of mucuna as a cover crop combined with a fifth of the recommended inorganic fertilizer increased maize grain yield from 0.7 to 2 t ha^{-1} and reduced cost per hectare by 22%.

When mucuna was fertilized with P and K and grown in a derived savanna in West Africa, it accumulated about 310 kg N ha^{-1} in 12 wk as a sole crop and 166 kg N ha^{-1} when intercropped in maize (Sanginga et al., 1996a). Sanginga et al. (1996a) also indicated that mucuna derived 70% of its N from atmospheric N_2, representing 167 kg N ha^{-1} per 12 wk in the field. Mucuna intercropped in maize obtained a greater proportion

of its N (74%) from fixation than did mucuna planted alone (66%), suggesting that competition for soil N influences the proportion of N fixed by mucuna. A preceding sole crop of mucuna resulted in a grain yield of subsequent maize equivalent to that obtained from 120 kg ha^{-1} of inorganic N fertilizer (Sanginga et al., 1996a). In an on-farm study in a derived savanna of West Africa, Versteeg et al. (1998a) indicated that when mucuna was used as an annual fallow cover crop, it produced 6 to 12 t ha^{-1} of DM, and improved subsequent maize grain yields by 70% compared to yields from continuously cropped maize.

Relay-cropped mucuna in the derived savanna of West Africa increased the succeeding maize growth parameters (height, leaf area, dry matter production, ear-leaf N concentration) and grain yield compared to maize succeeding fallow regrowth (Ile et al., 1996), but these responses were lower than when mucuna fallow was combined with 40 kg N as urea, suggesting the need for additional N fertilization in combination with green-manure N. In field experiments on a moist savannah of West Africa, Akobundu et al. (2000) found that after one growing season, mucuna reduced speargrass [*Imperata cylindrica* (L.) Raeuschel] shoot density and dry matter, reduced labor required for subsequent maize, and significantly increased grain yield of the subsequent maize crop by 65 to 129% compared to maize following natural fallow, depending on mucuna species.

In a greenhouse experiment, incorporation of lablab green manure significantly increased soil NH_4^+ concentration and sorghum DM production, but no residual effect was observed in a second crop sown 40 d after harvesting the first crop (Stamford et al., 1994). Incorporation of lablab green manure reduced the soil C:N ratio, and increased

DM yield of subsequent forage maize (18.9 - 21.1 t ha^{-1}) compared to when native vegetation was incorporated (10.5 t ha^{-1}) (Crespo, 1996). When lablab was incorporated into a Vertisol in Australia, it improved both soil physical (aggregate stability) and chemical properties, reduced soil compaction, and increased exchangeable cations, whereas surface mulching only improved friability of surface soil (Hulugalle et al., 1996).

Working in a derived savanna of West Africa, Carsky et al. (1999) evaluated improved fallows using mucuna and lablab in which the residue was left on the surface at one site and most residue was burned early in the season at the second site. The mean N fertilizer replacement value from legume rotation was 14 kg N ha^{-1} in the site where all the residue was left on the ground compared to 6 kg N ha^{-1} where most of the residue was burned early in the dry season with no N applied to the maize test crop. Maize grain yields were 365 (residue on surface) and 235 (residue burned) kg ha^{-1} higher than natural fallow, respectively. Mucuna and lablab grown as rotations with maize-bean intercrop for two seasons in sub-humid highlands of East Africa (Wortmann et al., 2000) produced a legume biomass yield of 6.35 and 4.67 Mg ha^{-1} (means of 2 yr) and average P yield of 10.2 and 8.5 kg ha^{-1}, respectively. These resulted in 2-yr averages for maize biomass yield of 7.66 and 9.78 Mg ha^{-1} and maize grain yield of 2.63 and 3.22 Mg ha^{-1}, following mucuna and lablab respectively. The two-year average bean plant yields were 1.31 and 1.43 Mg ha^{-1}, and bean grain yields were 0.51 and 0.49 Mg ha^{-1}, respectively.

In evaluating the P requirement and nodulation of legumes in a derived savanna of West Africa, Sanginga et al. (1996b) found that legumes grown in soil from degraded fields responded more to P application than those grown in soil from manured fields.

This P response was greater for mucuna than lablab: however, the proportion of N derived from atmospheric N was greater for lablab than for mucuna. In a greenhouse experiment to assess the effect of seed size and P fertilization on growth of 12 herbaceous and shrub legume species, Kolawole and Kang (1997) found that P fertilization increased above-ground biomass, root DM biomass, nodulation, and concentrations of N, P, K, Ca, and Mg of mucuna and lablab. Regardless of fertilization level, element (N, P, K, Ca and Mg) concentrations were higher in mucuna than in lablab.

In areas where land is scarce such as in smallholder farms in western Kenya, the intercropping/relay cropping of green manures in cereals may be the only feasible means of generating organic inputs. In such cases, management of green manures to minimize competition with maize while maximizing the residual benefit in yield is critical. Further investigations are needed to evaluate the performance of these legumes in relay-intercrop systems under the sub-humid tropical conditions of the highlands of eastern Africa. Research is also needed on the residual effect and whether incorporation of green manure for two consecutive years is better than 1 yr of application. This information will be useful for smallholder farmers who may want to alternate the growing of legume green manures with preferred grain legumes.

Effect of Root and Shoot Stubble on Soil and Crop Responses

The contribution of roots to the nutrient and organic matter of the soil is believed to be important for soil fertility maintenance and carbon sequestration, as the below-ground biomass forms a substantial proportion of the total biomass in an ecosystem. It is estimated that roots may be the source of 30 to 60% of the C in the soil organic pool (Heal et al., 1997). Root tissues are continuously sloughed off and replaced, and these sloughed-off tissues, along with senescent and dead roots, constitute a significant avenue

of organic matter (and nutrients) addition to the soil ecosystem. It is estimated that nodulated legume roots contain < 15 kg N ha^{-1} (Kumar Rao and Dart, 1987; Bergersen et al., 1989; Ibewiro et al., 1998) to between 30 and 50 kg N ha^{-1} (Chapman and Myers, 1987; Unkovich et al., 1994; Tian and King, 1998). This amount of root N represents < 15% of total plant N (Peoples et al., 1995).

On an acid soil, 6-wk-old mucuna had a shallow root system (within 15 cm) and a shoot:root ratio of 6.7:1 (Hairiah et al., 1992). Roots contributed only 2 kg N ha^{-1} compared to above-ground biomass that contributed 21 kg N ha^{-1}. In the same trial, perennial species *Pueraria phaseoloides* and *Centrosema pubescens* had shoot:root ratios of 2.4:1 and 19.5:1 and roots contributed 150 and 30 kg N ha^{-1}, respectively.

In a pot experiment to evaluate the biomass and chemical composition of selected leguminous cover crops (Tian and Kang, 1998), roots contributed about one third of total plant biomass. Fertilizer application favored the accumulation of biomass in shoots, and the effect was stronger in low than in high fertility soil. On average, the root and nodule contribution of mucuna and lablab were 31 and 37% of total plant biomass, respectively. Kiflewahid and Mosimanyana (1992) found that the contribution of lablab leaves, stems, and roots to the whole dry biomass was 47, 46.6, and 6.4%, respectively. Carsky et al. (1999) showed that mucuna and lablab grown as improved fallows had root to shoot proportion of 2 to 3 and 8%, respectively, but they cautioned that their estimates of root DM may have been low because sampling was done only to a depth of 30 cm and not all the fine roots were recovered. Their data do indicate, however, that lablab had more root biomass than mucuna.

Although Muza (1998) reported that mucuna roots contained lower N concentration (1.38%) compared to above-ground biomass (1.96%), Tian and Kang (1998) found that roots of mucuna and lablab contained higher N concentration (2.62 and 2.44%) compared to shoots (1.66 and 2.09%, respectively). The lignin concentrations in the roots of mucuna and lablab were higher (24.5 and 19.6%, respectively) than in the shoot (7.2 and 6.0%, respectively) (Tian and Kang, 1998), but the roots contained lower polyphenol concentrations (0.63 and 0.26%, respectively) than shoots (3.54 and 1.4%, respectively). The higher lignin concentration in roots suggests that, in combination with shoot stubble, the remaining biomass after removal of the top canopy may be of low quality.

Quantities of soil N greater than 100 kg ha^{-1} have been reported under lucerne despite removal of large amounts of shoot by grazing animals or as hay (Gault et al., 1995). Russell and Fillery (1994), using ^{15}N techniques with lupins, found that below-ground N may be almost three times greater than calculated from N contained in recoverable root material because the contribution of fine roots and slough off are not accounted for. Peoples et al. (1995) concluded that if this finding is applicable to a range of other legumes, then determinations of the amount of N returned to the soil, based on recoverable roots, have been greatly underestimated.

Smyth et al. (1991) observed lower yields and N accumulation by maize when mucuna roots were incorporated into the soil compared to whole biomass incorporation and attributed this reduction to the removal of the N in above-ground biomass. In comparing N release from four legume species [alfalfa, arrowleaf clover (*Trifolium vesiculosum*), cowpea, and soybean], Frankenberger and Abdelmagid (1985) observed that the different plant components released N in the order foliage > roots > stems and that roots with

higher lignin concentration had slower N release than those with lower lignin concentration. Reid et al. (1987, in Smyth et al., 1991) found an increase in maize grain yield of 0.8 t ha^{-1} when mucuna roots were incorporated relative to a zero-N treatment. Oikeh et al. (1998) working in either low or high fertility sites in a moist tropical savanna, showed that independent of the differences in fertility, N uptake and N partitioned into grain, stover, and cob were 20% higher after legume-maize rotation than after maize intercropping even though the legume tops were removed from fields.

Ibewiro et al. (1998) studied the N contribution of mucuna, lablab, cogongrass and maize roots, shoots, and whole-plant biomass to succeeding maize. They showed that although N contribution from mucuna and lablab roots was only 3 and 4% of the total N, their incorporation resulted in maize grain yield that was 38 and 89%, respectively, of the yield obtained when whole residue was incorporated. This was attributed to the low quality of roots that may have improved the synchronization of N release with N uptake of the succeeding maize crop. These results suggest that incorporation of low quality root and stem stubble after defoliating topgrowth for livestock feed may enhance N contribution to succeeding maize in low-external input, continuous cropping systems, as well as provide quality fodder for livestock.

The dense cover formed by creeping legumes such as mucuna leads to self shading and senescence resulting in a mat of fallen leaves (Van Noordwijk and Purnomosidi, 1992). Van Noordwijk and Purnomosidi (1992) reported a total N input from mucuna litter in a 12-wk growth period of 42 kg ha^{-1} from 1.5 t ha^{-1} DM. Litter quantity exceeded the live biomass measured at the end of the growth period.

Significant increases in maize yields following mucuna even when mucuna was burned to ease land preparation (Vine, 1953) supports the hypothesis that below-ground parts may contribute significant N to subsequent maize. Despite the availability of data on the contribution of whole-plant biomass incorporation, more information is needed on the contribution of below-ground biomass plus stem stubble and litter to succeeding maize.

Manure Effects on Soil Fertility Improvement

Livestock play a key role in farming systems where farmers rely on organic matter recycling for maintaining soil fertility. Cycling of biomass through livestock and the use of manure and urine to fertilize the soil is an important linkage between livestock and soil fertility maintenance (Powell and Valentine, 1998). Thus cattle manure is an integral component of soil fertility management in many areas of the tropics and its importance as a source of nutrients for crop production is widely recognized (Bationo and Mokwunye, 1991; Powell and Williams, 1993). The quantity and quality of manures available on smallholder farms are the major factors limiting its contribution.

Crop responses to manure application may be due to N, P, cations such as Ca and Mg or to physical effects of additional soil organic matter on water infiltration and retention (Mugwira and Murwira, 1997). Powell and Williams (1995) showed that the use of 20 t ha^{-1} manure (as-is basis) increased soil pH, soil organic matter, total-N, and available P after one season of application. However the responses to manure application are highly variable due to differences in the chemical composition of the manures and the rates and frequency of manure application. The chemical composition of manures differs because of variation in animal diet [i.e. lignin:neutral detergent fiber (NDF), lignin:nitrogen (N), and polyphenol:N] (Somda et al., 1995) and manure storage. Poor storage conditions

may result in ammonia losses through volatilization (Murwira, 1995) and leaching of nitrate (Cahn et al., 1993).

Proper management of crop residues, forage, and manure can have positive impact on the nutrient dynamics of low-input farming systems (Swift et al., 1989). Up to 95% of total nutrients consumed by livestock are excreted. Nitrogen is excreted in both feces and urine, while P is excreted almost exclusively in feces (Ternouth, 1995). The proportion and forms of fecal N are highly influenced by animal diet (Powell et al., 1994; Somda et al., 1995) and to a lesser extent on how manure is collected, stored, or decomposed. Lower concentration of organic matter, N, and P in the feed, results in lower quantity and quality of manure (Powell and Saleem, 1987). High concentration of polyphenolic compounds in feed increases the amount of fecal N and decreases the amount of urinary N (Powell et al., 1994; and Somda et al., 1995). Feeds with high lignin, tannins, and related phenolic compounds may improve N cycling, by shifting N excretion from urine to feces and by lowering mineralization rates, thus increasing the availability potential of N to crops (Powell et al., 1994). It has also been shown that there is a high correlation between the concentration of feed lignin ($r^2 = 0.97$) and feed polyphenol ($r^2 = 0.85$) with the concentration of neutral-detergent insoluble - N in feces (Somda et al., 1995).

The manure that is applied to the soil decomposes and releases nutrients faster than herbaceous biomass (Somda et al., 1995). Murwira and Kirchmann (1993) conducted a laboratory incubation study which showed that aerobically decomposed dry manure may be an unsatisfactory source of N because amounts of N mineralized after 8 wk were very low when communal-area and feedlot manures were soil incubated (1.3 and 2.1%, respectively). They suggested that even though the C and N mineralization values were

low, manures could have other beneficial effects such as increasing the base status and improvement of water holding capacity of the soil.

Despite the importance of animal manure in sustaining crop productivity, the availability of sufficient amounts to permit adequate food production and improvement of soil quality, and availability of feed to support the livestock that produce the manure, are important management issues that need to be addressed. In smallholder farming systems where pressure on land is high, the amounts of manure available may not be sufficient to permit adequate grain yield. Williams et al. (1995) estimated that 9 to 21 cattle are required per hectare of pearl millet (*Pennisetum glaucum*) to replenish the 22 to 38 kg N and 2 to 6 kg P ha^{-1} harvested in grain and crop residues. The amount of natural pasture required to support livestock for the purpose of manuring crop land, calculated as rangeland:crop land ratio, is estimated to range between 10 and 40:1 (Fernandez et al., 1995; and McIntire and Powell, 1995). Manure application rates need to be evaluated to estimate the amount of manure required to offset nutrient harvests from grain and cereal crop residues. Evaluation of the trade offs in applying plant material directly to soil versus feeding it to animals and applying their manure to soil is also required to assist farmers in managing green legume manures and other feeds and livestock to improve soil management.

Integrated Nutrient Management

Land intensification on diminishing farm sizes as a consequence of population pressure has resulted in the more sustainable bush-fallow systems being replaced by nutrient-depleting, continuous cropping systems. Continuous cultivation, even when limited amounts of inorganic fertilizers are used, often leads to rapid decline in soil organic matter, pH, and nutrients (Juo et al., 1995a; 1995b), leading to negative nutrient

balances (Stoorvogel et al., 1993; Smaling et al., 1996; 1997; Van den Bosch et al., 1998). Previous studies have shown that inorganic fertilizers alone cannot sustain crop yields on poorly buffered Kaolinitic soil in the tropics due to factors such as soil acidification, compaction, and loss of soil organic matter (Juo et al., 1995a). Thus the application of organic materials is needed not only to replenish soil nutrients but also to improve soil physical, chemical, and biological properties.

Integrated Nutrient Management (INM), which seeks to maximize the complementary effects of mineral and organic nutrient sources is emerging as an important approach in improving soil productivity of smallholder farming systems (Jenssen, 1993; Smaling et al., 1996; Palm et al., 1997; Fanzlaebbers et al., 1998). The INM concept is based on the premise that the decline in soil productivity can be attributed in part to the negative nutrient budgets (the amount of nutrients removed compared to the amount of nutrients being put into the system) in most agricultural production systems in sub-Saharan Africa (Smaling and Braun, 1996). Thus, under continuous cropping, recycling of nutrients from organic sources alone may not be sufficient to sustain crop yield. Nutrients exported from the soil through harvested biomass and lost from the soil through various processes such as soil erosion (Lal, 1989; 1995; Swift et al., 1994a), leaching (Cahn et al., 1993), and denitrification (Lensi et al., 1992) must be replaced with nutrients from external sources.

Organic residues such as crop stover and animal manures are often used as alternatives to chemical fertilizers. Long-term experiments on a Kaolinitic Alfisol in West Africa have shown that with continuous maize cropping under a no-tillage system, retention of residue as mulch resulted in a slower decline in soil organic matter, and higher CEC, pH,

exchangeable Mg, and crop yield compared to when residue had been removed (Juo et al., 1995b, 1996). These results contrast with those reported by Palm et al. (1997), who found that incorporation of maize stover decreased soil available N with consequent reduction in maize grain yields, at least temporarily. These temporary negative effects can be offset by combining low quality crop residues with inorganic fertilizers (Paustian et al., 1992) or high quality organic materials with N concentration more than 20 g kg^{-1} (Smith et al., 1993).

In eastern Africa, a long-term experiment on a fine-textured Alfisol at Kabete, Kenya, showed that a combination of farmyard manure and inorganic fertilizer resulted in higher maize grain yield than either farmyard manure or inorganic fertilizer alone (Swift et al., 1994b). However, farmyard manure cannot meet nutrient demand over large areas because of limited availability, low nutrient concentration, and the high labor demand for processing and application. Other long-term experiments conducted in sub-Saharan Africa have shown that a combination of inorganic fertilizers and organic manures slowed the decline in soil organic matter after continuous cropping compared to when inorganic fertilizers were used alone or when no inputs were used (Swift et al., 1994b; Kapkiyai et al., 1999). The combination of a high-quality organic material, tithonia (*Tithonia diversifolia*) leaves, and inorganic P in a pot experiment and subsequent field studies (Gachengo et al., 1999) resulted in greater maize biomass and P uptake than from equal amounts of nutrients added from inorganic fertilizers. Studies in Zimbabwe on N mineralization from poor quality manures have shown that decomposition of these manures can lead to N immobilization and that N availability can be increased by supplementing with inorganic sources of N (Murwira and Kirchmann, 1993).

Palm (1995) found that when organic materials (animal manures, leguminous tree biomass, and green manures) were applied in modest amounts, i.e., 2 to 5 t DM ha^{-1}, and contained sufficient N to match nutrient demand for a 2-t crop of maize, the P requirement was not met and inorganic P was needed in areas where P is deficient. On-farm research conducted in northwestern Kenya (KARI, 2000), showed that a combination of half the recommended rate of inorganic fertilizer (30 kg P_20_5 + 30 kg N ha^{-1}) with half the recommended rate of farm yard manure or compost (5 t ha^{-1}), produced maize grain yield comparable to that obtained when either inorganic fertilizer or organic manures were used alone at recommended rates. Akobundu et al. (2000) showed that applying a low fertilizer rate (30 kg ha^{-1} N, P, and K) with mucuna residue, significantly increased maize grain yield in a moist savanna of West Africa. In reviewing results on the combined use of organic and inorganic nutrient sources in sub-Saharan Africa, Palm et al. (1997) concluded that high and sustained crop yields can be obtained with judicious use of organic residues combined with inorganic fertilizers. They attributed this advantage to enhanced synchrony of nutrient release and demand by the recipient crop, increased nutrient-use efficiency, and residual effects of soil organic matter associated with combined nutrient additions compared to inorganic fertilizers applied alone.

Residue Quality

Residue quality can be defined as the intrinsic characteristics or the chemical constituents which affect residue decomposition in the soil (Swift, 1989). The quality of organic residues has a significant effect on their ability to improve soil fertility both in the short term through their effects on nutrient availability and in the long-term by their effect on soil organic matter. The short-term effect on nutrient availability occurs via nutrient release during decomposition or indirectly through decomposition products

(organic ions). Low quality residue materials have characteristics which inhibit decomposition including high lignin or polyphenol concentration or low N concentration. Low quality litter/residue limit the transfer of organically bound N to the pools of mineral N available for plant growth (Constantinides and Fowness, 1994; Handayanto et al., 1994). The N concentration and C/N ratio are major determinants of the ability of organic residues to supply nutrients (Kachaka et al., 1993; Myers et al., 1994), however, there are other modifying factors.

Lignin, which is a recalcitrant substance (Spain and Le Feuvre, 1987), results in slow mineralization of lignin-bound carbon and N (Vanlauwe et al., 1996). This is because lignin intertwines with the cell wall and physically protects cellulose and other cell wall constituents from degradation (Cheson, 1997). It is the lowest quality carbon constituent, providing little or no energy to decomposers until the late stages of decomposition.

Polyphenol is a general term for compounds that have a hydroxyl group bonded to an aromatic ring. They include a range of compounds differing in size, complexity, and reactivity such as tannins, coumarins, and flavonoids. The condensed and hydrolyzable tannins are the most important in terms of decomposition and nutrient release dynamics. Although soluble polyphenols can serve as carbon substrate, many of them act as bactericides (Scalbert, 1991; Jones et al., 1994) and can therefore slow down decomposition by lowering the activity of microorganisms and enzymes. Phenolic compounds also bind mineralized N in nitro- and nitroso- forms in soil humus, making it unavailable (Azhar et al., 1986) thus reducing the availability of N for soil microbial population (Reed, 1995). Although the total soluble phenolics include a variety of compounds, consistent and significant negative correlations have been obtained between

total polyphenols obtained by the Folin-Denis method and N mineralization (Palm, 1995). The correlations may be improved if the extracts are analyzed for condensed tannins, the major group of polyphenols that bind proteins, or by doing assays that assess the protein-binding capacity (Waterman and Mole, 1994). The protein-binding capacity of polyphenols has been shown to greatly slow down decomposition (Palm and Sanchez, 1991; Handayanto et al., 1994).

In estimating how release of mineral N was affected by chemical composition, Constantinides and Fowness (1994), incubated soil with fresh leaves and with litter from 12 species commonly used in agroforestry systems. Their results showed that decomposition of fresh legume leaves resulted in net N accumulation whereas litter had net N depletion. The difference between the N concentrations in green leaves and leaf litter can be explained by the process of nutrient resorption during senescence, when leaf proteins and other nitrogenous compounds are hydrolyzed and the products transported into perennial tissue before leaves fall off the plant (Norby and Cotrufo, 1998).

Palm and Sanchez (1991) found a negative correlation between net N mineralization and polyphenol concentration or the polyphenol:N ratio. Kachaka et al. (1993) reported a significant linear relationship between N mineralization and lignin:N ratio ($r^2 = 0.996$) or the (lignin + polyphenol):N ratio ($r^2 = 0.981$) of prunings of four agroforestry species. According to Constantinides and Fowness (1994), the N concentration and C:N ratio are the most important residue quality characteristics that influence N release patterns. Abdel-Magid (1992) found that the N content in lablab plant tissue (foliage or foliage + stem) had no significant correlation with cumulative amount of N mineralized in a laboratory incubated soil, but there was a significant correlation between the C:N ratio

and the percentage of N mineralized. Working with mucuna and lablab as cover crops in a derived savanna of West Africa, Ibewiro et al. (2000a) showed that the initial (lignin + lignin):N ratio, N concentration, lignin:N ratio, polyphenol:N ratio, C:N ratio and lignin concentration of these cover crop residues explained the largest proportion of the variation in decomposition rate constants.

Palm et al. (1997) reported that residue N concentration ranging from 18 to 22 g kg^{-1} is the critical range for transition from net immobilization to net mineralization. Based on this criterion the commonly used cereal crop residues and cattle manure of low quality fall below the critical value (Palm et al., 1997). However, not all residues with high N values exhibit net mineralization. Lignin concentration of > 150 g kg^{-1} and polyphenol concentration of > 30 to 40 g kg^{-1} could slow N release and result in net immobilization (Palm, 1995). However there is no agreement in the literature on whether C:N, lignin:N, polyphenol:N, or (lignin + polyphenol):N has more influence on N release patterns (Vanlauwe et al., 1997).

Studying the impact of residue quality on C and N mineralization of leaf and root residues of three agroforestry species, Vanlauwe et al. (1996) found that leucaena (*Leucaena leucocephala*) and *Dactyladenia barteri* roots contained more lignin and less N than their leaves, whereas the lignin and N concentration of *Fleminga macrophylla* leaves and roots were not different. Tian and King (1998) showed that roots of herbaceous legumes (including mucuna and lablab) contained higher lignin concentration (200 g kg^{-1}) compared to shoots (60-100 g kg^{-1}), but polyphenol concentration in shoots was higher than in roots. Although the negative relationship of lignin:N, polyphenol:N, (lignin + polyphenol):N ratios to mineralization of N have been shown (Palm and Sachez,

1991; Tian et al., 1992; Constantinides and Fowness, 1994), more information on the relationship between root and stem stubble quality and N mineralization of green manure legumes is needed. The ultimate aim of studying residue quality indices is to identify robust indices that provide improved prediction of nutrient release. This will allow for cross-site comparisons and synthesis of results from a broad range of studies to model the effects of residue application on long-term soil fertility changes.

Synchrony Between Mineralized N and N Uptake

The efficiency of transferring N from a legume green manure to the succeeding crop depends on synchronizing the N release from the legume residue with the demand of the recipient crop. This is particularly important in high rainfall climates with high potential for N leaching. The plant species and management practices have a great influence on the success of this synchronization, and N mineralization is also affected by moisture, temperature, and soil factors such as texture, mineralogy, acidity, biological activity, and the presence of other nutrients (Myers et al., 1994). The inorganic nutrients released by mineralization may be immobilized by the soil biota, taken up by plants, or lost as a result of leaching, denitrification, or volatilization, or they may remain in the soil. The size of the inorganic pool of nutrients depends upon the balance of various processes that add to the pool (mineralization) and those that subtract (immobilization, plant uptake, and losses). With respect to synchrony of N, the most important processes are mineralization-immobilization, plant uptake, denitrification, volatilization, and leaching. Improved synchrony implies that there is less excess mineral nutrient in the soil, and thus the opportunity for loss is reduced.

Uptake of N and other nutrients by maize continues until near maturity, but the highest demand for N is at the start of reproductive stage (R1) when grain filling is initiated to R6

at physiological maturity (Karlen et al., 1988). The fraction of total N added that is taken up by the crop is known as the N recovery value (NIV). The reported NIV values for most organic residues are in the range 10 to 30% by the first crop (Giller and Cadisch, 1995; Palm, 1995; Mafongoya and Nair, 1997) and between 2 and 10% by the second crop (Mafongoya and Nair, 1997). Giller and Cadisch (1995) reported that approximately 20% of the N from high quality green manure residue is recovered by the first crop.

Factors influencing the synchrony and therefore NIV from organic manures by annual crops include type of species, biomass quality, and method and time of application (Tian et al., 1992; Mafongoya et al., 1997b). Incorporation of the residue improves N recovery compared to surface placement (Mafongoya and Nair, 1997), and this has been attributed to elimination of N losses through ammonia volatilization (Glasner and Palm, 1995).

An important question that needs to be answered is: can synchrony be enhanced through managing residue quality? In an attempt to answer this question, Myers et al. (1994) concluded that the answer is a cautious yes. This is based on the few studies reported in the literature where results support the concept of using residue quality to achieve synchrony. Most of these studies have reported on the synchrony of above-ground leafy materials (Handayanto et al., 1994; Myers et al., 1994; Palm, 1995, Handayanto et al., 1997) and little information is available on the synchrony of N release and demand when root residue or root and low quality stem stubble is incorporated for the subsequent maize crop.

Previous studies have indicated that residues of intermediate quality may result in nutrient release patterns in synchrony with crop nutrient demand (Handayanto et al.,

1994; Mafongoya et al., 1997a). Myers et al. (1994) found that a mixture of straw and *Gliricidia sepium* residue mineralized N at an intermediate rate, and that the rate gradually increased coinciding with the period when growth demand by maize was highest. In a laboratory incubation experiment, Frankenberger and Abdel-Majid (1985) compared N release from residues of four legume species (alfalfa, Egyptian clover, cowpea, and soybean). Different plant components released N in the order foliage > roots > stems. When these parts were combined, the N mineralization pattern was intermediate between that of foliage and stems. Also an interesting result was obtained from soybean and Egyptian clover. Soybean initially released N more rapidly than Egyptian clover in the first 3 wk. After Week 3, the rate of release was faster from clover, so that by 14 wk the amounts were equal. Soybean, that had greater root lignin concentration, released nutrients more slowly over the entire 20-wk study period. However contrasting results were obtained from a 70-d incubation period by Nnadi and Haque (1988) in which there was no evidence of N mineralization from several different legume roots. The mixing of residues of different quality may result in significant interactions involving physical protection of recalcitrant substrates at later stages of decomposition (Mafongoya et al., 1997b) or by the protein-binding capacity of polyphenols (Handayanto et al., 1997). Additionally, the mechanisms that alter the physical environment, such as increasing moisture availability under mulching or increasing soil organic matter (Tian et al., 1993), may play a role in these interactions.

Constantinides and Fowness (1994), Myers et al. (1994), and Palm et al. (1997) hypothesized that plant residues which initially immobilize and subsequently release N slowly could enhance N uptake by plants. Hairiah and Van Noordwijk (1989 reported in

Van Noordwijk and Purnomosidi, 1992) found that N uptake by maize following mucuna was 147 kg ha^{-1} higher than the control crop, while the N content of live biomass incorporated was only 71 kg ha^{-1}. They attributed this to the large amount of litter fall during the growth period, a quantity that exceeded the live biomass measured at the end of the growth period (Van Noordwijk and Purnomosidi, 1992). The research reported in this dissertation hypothesizes that utilization of the high quality top growth of green manures as livestock feed and incorporating the remaining intermediate quality stubble and root will increase NIV and enhance the synchrony between N release and uptake and thus provide better yield than when no fertilizer is applied.

Mixed Crop-Livestock Farming

The integration of crops and livestock, particularly dairy cattle, is one of the best avenues in which both soil-fertility improvement and increased productivity from livestock can be achieved on smallholder farms. These mixed farming systems involving complementary interactions between crops and livestock, such as using traction and manure for cropping, and feeding crop residues and other cropland forages to livestock, are increasing in importance in many areas in the tropics (Powell and Williams, 1995). The animals are also a source of income, which can be invested in crop production apart from meeting social and cultural obligations. It is estimated that 74% of the cattle in sub-Saharan Africa are associated with smallholder mixed crop-livestock farming (Brumby, 1989). Under these systems, three dairy production alternatives can be distinguished, namely zero grazing, free grazing, and a combination of the two (semi-zero grazing) (Nyambati, 1997). The first two systems are the most common due to small farm sizes. Decreasing farm sizes has led to an increased intensification of land use, with consequent

need for efficient cycling of nutrients among crops, animals, and soil if the productivity of these low-input systems is to be sustained (Mohamed-Saleem, 1998).

Although there could be competition for crop residues between livestock feeding and soil fertility improvement, returning crop residues to the soil, particularly stover may not be the best option. Long-term studies in the sub-humid highlands of eastern Africa have shown that maize stover retention results in reduction in yields compared to a control where no external input was applied, whereas application of farm yard manure improved crop productivity (Kapkiyai et al., 1998), suggesting that it could be advantageous to feed crop residues to livestock and apply the resultant manure to the soil. It has also been shown that nutrient release from manure is faster and appears to be more synchronous with crop nutrient demand than the nutrient release patterns of low quality plant biomass applied to soils (Somda et al., 1995).

The main feeds in these systems include the purposely-grown fodders such as napiergrass (*Pennisetum purpureum* K. Schum), crop residues, natural weed fallow, and roadside grazing. The full integration of crops and livestock is not without risk, however. Poor livestock performance can occur due to confinement to small grazing areas during the cropping season to avoid crop damage. This in turn increases the risk of overgrazing and environmental degradation through the process of soil erosion. Excessive grazing of stover during the dry season has also contributed to removal of nutrients as feed from cropland without adequate replacement, leading to negative nutrient balances (Smaling et al., 1997).

Napiergrass is the major fodder preferred in these systems because of its high yield potential and drought tolerance, making it suitable as a cut-and-carry fodder. Napiergrass

alone cannot support high levels of livestock productivity, particularly dairy cattle (Anindo and Potter, 1986). Often during the dry season napiergrass is harvested at an advanced stage of maturity and it is low in nutritive value (Muia at al., 2001). The conventional methods of improving napiergrass quality through fertilization (Sollenberger and Jones, 1989) or supplementation using concentrates (Anindo and Potter, 1986) are limited because most smallholder farmers cannot afford these inputs. The growing of forage legumes as rotations or improved fallows to specifically increase livestock productivity is increasing (Tarawali and Mohamed-Saleem, 1995; Weber, 1996).

Potential Use of Napiergrass Fodder

Background Information (Botany, Origin, and Characteristics)

Napiergrass, also known as elephantgrass, is the most popular perennial fodder in the intensively managed smallholder crop-livestock mixed farming production systems. The grass, which is native to eastern and central Africa (Boonman, 1993), was named napier after Colonel Napier who advocated its use for commercial livestock production (Boonman, 1997). The name elephantgrass is probably associated with the African elephant (*Loxodanta africana*), which has a special preference for napiergrass. There are both giant (tall) and dwarf types. The tall napiergrass is robust, growing to 4 m in height and having up to 20 nodes (Henderson and Preston, 1977). This type resembles sugarcane in habit and adaptation and forms bamboo-like stems when mature. Napiergrass is propagated vegetatively because seeds have low genetic stability and viability (Humpreys, 1994). The dwarf 'Mott' napiergrass bred at the Coastal Plains Research Station in Tifton, Georgia, has maximum height of 1.5 m (Hanna and Monson, 1988). Unlike the tall napiergrass, the dwarf type is very leafy and non-flowering. In

East Africa and particularly in Kenya, there are a number of tall cultivars which have been selected and tested over a wide range of environments (Goldson, 1977). The most common cultivars grown in Kenya are Bana, French Cameroon, and Clone 13. Napiergrass grows well from sea level at the hot humid coast to altitudes of over 2100 m, but frost appears to limit its cultivation above this altitude (Skerman and Riveros, 1990).

Dry Matter Yield

Napiergrass produces greater dry matter yields than the other tropical grasses (Skerman and Riveros, 1990). In Kenya, dry matter yields vary between 10 and 40 t DM ha^{-1} depending on soil fertility, climate, and management (Schreuder et al., 1993). These DM yields contrast with those of rhodesgrass (*Chloris gayana*) and kikuyugrass (*Pennisetum clandestinum*), popular ley pasture grasses in Kenya, which yield between 5 and 15 t DM ha^{-1} (Boonman, 1993). Exceptionally high DM yield of up to 85 tons DM ha^{-1} have been reported elsewhere when high rates of N fertilizer were applied to napiergrass (Skerman and Riveros, 1990). Despite its impressive performance in the southeastern USA as a grazing fodder (Sollenberger and Jones, 1989), dwarf napiergrass has not been adopted by small holder dairy farmers due to its relatively low DM yields (Sotomayor et al., 1997) and its high susceptibility to the fungal snow mold disease, *Cowdria sphaenoides*, under Kenyan conditions (Boonman, 1997). Smallholder farmers therefore prefer the giant napiergrass, which is well suited for the intensive "cut and carry" feeding system.

Nutritive Value

Napiergrass has been a subject of extensive continuing research, not only in East Africa but elsewhere. Most of the initial studies tended to concentrate on its agronomy, chemical composition, and in vitro digestibility (Ware-Austin, 1963; Odhiambo, 1974;

Mugerwa and Ogwang, 1976; Goldson, 1977; Snijders et al., 1992; Anindo and Potter, 1994). Animal performance on napiergrass has only been evaluated in recent years, and emphasis on these studies has been on protein supplementation to dairy cows feeding on napiergrass as a basal feed (Anindo and Potter, 1986; 1994; Muinga et al., 1992; 1993; 1995; Mukisira et al., 1995; Abdulrazak et al., 1997; Kariuki et al., 1998; Muia et al., 1999; 2000a; 2000b; 2001).

The crude protein concentration of napiergrass is lower during the dry season, but it remains relatively constant throughout the year compared to ley pastures (Ware-Austin, 1963). The nutritive value of napiergrass is affected by the stage at which it is cut (Odhiambo, 1974; Skerman and Riveros, 1990; Anindo and Potter, 1994; Muia et al., 1999; 2001). Anindo and Potter (1994) showed that crude protein concentration varied from 70 to 148 g kg^{-1} and digestibility of 8-wk regrowth was 560 to 720 g kg^{-1} for dry-season and wet- season forages, respectively. They also found an intake of 2.5 and 2.65 kg DM per 100 kg^{-1} of animal live weight for the dry and wet season forages. Muia et al. (2001) found that the CP concentration decreased from 82 g kg^{-1} in 10-wk-old 1.3-m-tall napiergrass to 53 g kg^{-1} in 15-wk-old 2 m tall napiergrass herbage, while the neutral detergent fiber (NDF) and lignin concentrations increased from 542 and 37 g kg^{-1} to 634 and 52 g kg^{-1}, respectively. The intake of CP (15 vs. 11 g kg^{-1} $W^{0.75}$) was higher for Friesian steers fed the less mature forage. Likewise concentrations of rumen ammonia were higher for steers fed the 10-wk-old material.

Legume Supplementation

Use of legumes to supplement cattle diets has continued to receive attention from livestock scientists, particularly in the tropics where low quality roughages form the bulk of the feed. Supplementation of low quality basal roughage diets with legume forage

increases essential nutrients available to rumen microbes, increases rate of passage of both particulate and liquid matter phases, and may increase degradation, intake, and consequently animal performance (Norton and Poppi, 1995; Osuji and Odenyo, 1997; Nsahlai et al., 1998). Legume forage contains protein, minerals, and vitamins essential for growth of rumen microbes that degrade roughages prior to gastric and intestinal digestion by animals. The effect of legume supplementation on digestibility of basal feed is based on the fact that digestion of cell wall constituents of the basal diet are enhanced by providing a readily fermentable source of N so that rumen ammonia levels are maintained at an optimum level for cellulose digestion.

There is a wide variation in response to legume from no change in intake to 100% increase in intake (Poppi and Norton, 1995). Though the data indicate that a 20 to 50% inclusion of legume in the diet results in a 10 to 45% increase in intake, the response varies with quality of the basal diet. The positive effects of legume/protein supplementation to low quality basal diets, including napiergrass are well documented in the literature (Muinga et al., 1992; 1993; 1995; Abdulrazak et al., 1997; Muia et al., 2000a; 2001).

Studies done in sub-Saharan Africa at the International Livestock Research Institute (ILRI) have shown that supplementation with graded levels of lablab increased microbial N supply, rumen degradation, particulate passage, and intake and liveweight gain of crossbred calves (Abule et al., 1995). Nsahlai et al. (1998) using sheep found that supplementation with forage legumes (lablab and *Sesbania sesban*) to low quality teff (*Eragrotis tef*) diets increased rate of degradation of teff by 50 to 142%, increased the fractional rate of passage of particles, intake, and increased fecal N. Increasing levels of

lablab in basal diet of maize stover (lablab w/w of 70:30 vs 50:50) increased the amount of readily degradable DM, organic matter, intake, and reproductive performance of goats (Makembe and Ndlovu, 1996), a response which was attributed to increased opportunity for lablab selection. Legume (*Calliandra calothyrsus* and *Macrotyloma axillare*) supplementation increased feed intake, N intake, fecal production, and fecal-N concentration of steers compared to those fed only on a basal diet of barley (*Hordeum vulgare*) straw (Delve et al., 2001).

In an experiment to evaluate the effects of forage type and level of concentrate supplementation, cows fed on a maize-lablab, forage-based diet consumed more organic matter, and had a higher apparent digestibility of organic matter than those consuming oat-vetch, forage-based diet (Khalili et al., 1994). Forage type did not affect daily milk yield, milk fat concentration or total solids in milk, except for milk protein concentration.

Forage Yield and Nutritive Value of Mucuna and Lablab

Ravindran (1988), working in Sri Lanka, evaluated mucuna at four growth stages and found the optimum harvesting time to be around 90 d after planting, at about the onset of flowering. At this time the dry matter yield was 3.1 t ha^{-1}, CP concentration was 206 g kg^{-1}, and in vitro organic matter digestibility (IVOMD) was 554 g kg^{-1}. Similar CP results have been reported by Singh and Relwani (1978) and Adjorlolo et al. (2001), indicating its potential as protein supplement to low quality roughages. In an experiment using sheep to determine the nutritive value of mucuna forage at flowering stage (3 mo after planting), Adjorlolo et al. (2001) showed that mucuna whole plant forage had CP, NDF, and lignin concentrations of 200, 544, and 96 g kg^{-1} respectively, and that mucuna forage supplementation increased the CP digestibility, in sacco degradation rate, and

particle outflow rate of both DM and NDF of sodium hydroxide-treated rice (*Oryza sativa*) straw.

There is a wide variation in the dry matter yield and CP concentration of lablab forage depending on location and stage of harvesting. In Australia, Wood (1983) reported that lablab produced herbage yield of 8.6 t ha^{-1} at flowering which was comprised of 3.6 t ha^{-1} leaf containing 231 g kg^{-1} CP and 5 t ha^{-1} of stem containing 69 g kg^{-1} CP. In the mid-south of the USA, lablab at full bloom stage produced a DM yield of 5.2 t ha^{-1} and contained 146, 471, and 352 g kg^{-1} of CP, NDF, and acid detergent fiber (ADF), respectively (Fribourg et al., 1984). Kiflewahid and Mosimanyana (1987) from Botswana reported average yields of 1.23 to 1.44 t DM ha^{-1} on smallholder dairy farms, and CP concentration of 161 g CP kg^{-1} when lablab was planted and harvested along with maize and sorghum. In Zimbabwe, sun-dried lablab at 8 wk growth (pre-anthesis) contained 250, 370, 89, 7.2, and 1.1 g kg^{-1} of CP, NDF, acid detergent lignin (ADL), Ca, and P, respectively, with a DM degradation of 842 g kg^{-1} (Mupangwa et al., 1997). Abule et al. (1995) showed that CP, NDF, Ca, and P concentrations of sun-dried lablab hay were 186, 420, 14, and 1.9 g kg^{-1}, respectively. Maasdorp and Titterton (1997) reported a dry matter digestibility (DMD) of mucuna and lablab at early green pod stage when maximum biomass occurred (16 and 18 WAP, respectively) of 500 and 588 g kg^{-1} respectively. At this time the CP concentration was 182 and 164 g kg^{-1} for mucuna and lablab, respectively. Lablab hay at 50% flowering stage had IVOMD of 600 g kg^{-1} (Nsahlai et al., 1998).

Seeds of lablab had a CP concentration of 249 g kg^{-1}, with well balanced amino-acids for humans (Chau et al., 1998). Mucuna and lablab sampled at 112 d after planting

(DAP) had lower N concentration (25.4 and 24.5 g kg^{-1}, respectively) than when sampled at 91 DAP when N concentration was 33 and 38.3 g kg^{-1}, respectively (Carsky et al., 1999). In a more recent study to evaluate the effect of variable harvest dates on biomass and quality, Agyemang et al. (2000) found that lablab hay harvested at 100, 114, 128, and 142 DAP had biomass yield of 1.28, 1.97, 2.04, and 1.99 t DM ha^{-1}, respectively, CP concentration of 138, 175, 144 and 131 g kg^{-1} DM, respectively, and NDF concentration of 503, 546, 572, and 576 g kg^{-1} DM, respectively. The hay harvested at 114 DAP had the highest CP concentration, fastest rate of degradation, and about 50% rumen degradable protein.

Antinutritive Factors

Although mucuna seed has a high protein concentration and its quality is comparable to that of soybean (Ravindran and Ravindran, 1988), it contains a toxic chemical [3, 4-dihydroxyphenyl alanine (Levodopa, or L-Dopa)] (Lorenzetti et al., 1998; Siddhuraju and Becker, 2001). Evaluating 36 accessions, Lorenzetti et al. (1998) found L-Dopa concentration in the seeds to range from 22 to 62 g kg^{-1} of DM. Lorenzetti et al. (1998) found that the stippled seed accessions had significantly lower L-Dopa concentration than the black, speckled, or white, but Siddhuraju and Becker (2001) found contradicting results where the white variety had higher L-Dopa concentration (49.6 g kg^{-1}) compared to the black variety (43.9 g kg^{-1}). The concentration has also been shown to vary with latitude and seeds grown within 10^0 of the equator contained significantly higher concentrations.

L-Dopa can cause toxic effects to humans (Infante et al., 1990) if consumed at levels above 1.5 g d^{-1} (Lorenzetti et al., 1998). It has been reported that the oxidation products of L-Dopa conjugate with SH group of proteins (cystein) forming a protein bound 5-S-

cysteinnyldopa cross links, leading to polymerization of proteins (Takasaki and Kawakishi, 1997). A procedure to prepare detoxified mucuna flour is available (Versteeg et al., 1998b), but this may demand extra labor. Mucuna seed was extensively used in the southern USA as part of a ration for cows at the beginning of the last century (Tracy and Coe, 1918) and no toxic effects were observed, suggesting that the L-Dopa in mucuna forage may have minimal detrimental effects to ruminant animals.

Mucuna and lablab contain other anti-nutritional factors such as polyphenols, tannins, trypsin inhibitor activity, cyanogenic glycosides, and hemaglutanating activities (Rajaram and Jonardhanan, 1991). Tannins are naturally occurring plant polyphenols that form strong complexes with proteins. They are usually subdivided into two groups: hydrolysable tannins (water soluble) and proathocyanidins (condensed tannins) (Reed, 1995). Tannins in forage legumes have both negative and positive effects on their nutritive value. Tannins in high concentrations reduce intake, digestibility of proteins and carbohydrates, and animal performance (Reed et al., 1990; Tanner et al., 1990). Tannins in low to moderate concentrations, especially condensed tannins, prevent bloat and increase the flow of non-ammonia N and essential amino acids from the rumen (Woodward and Reed, 1997). The presence of condensed tannins is reported to reduce N degradation in the rumen through the formation of tannin-protein complexes which are stable at neutral rumen pH, but do cleave at the low gastric pH (2.5-3.5) of the abomasum and relatively high pH (8-9) of the distal small intestines (Salawu et al., 1997).

Dry Matter Intake and Animal Performance

The dry matter intake (DMI) of feed eaten is an important factor controlling ruminant production. Obeid et al. (1992) observed that DMI of maize-mucuna silage was lower compared to that from pure maize silage. Pachauri and Upandhayaya (1982) found an

increase in live-weight gain of goats fed hay from mucuna fodder. A higher ADG of 0.38 kg was obtained from cattle feeding on maize-mucuna silage compared to 0.25 kg from cattle on pure maize silage, but the gain was lower than those for maize-soybean (0.68 kg) and maize-*Crotalaria juncea* (0.7 kg) mixtures (Obeid et al., 1992). A short-term observational study in Nigeria showed that milk production from cows consuming silage consisting of 75% maize forage and 25% mucuna was 8.22 kg head^{-1} d^{-1}compared to 7.5 for those consuming silage made from elephantgrass alone (Umoh, 1975). Supplementation with mucuna forage harvested at flowering to sheep feeding on rice straw was shown to marginally increase DMD and OMD, and significantly increase degradation rate of both DM and NDF, and also increase particle outflow rate (Adjorlolo et al., 2001).

Graham et al. (1986) indicated that steers grazing lablab at a stocking rate of 1.7 steers ha^{-1} gained 50 to 60 kg liveweight during 86 d of grazing. They also found that when buffelgrass (*Cenchrus ciliaris)* was combined with lablab in varying proportions, liveweight gains were directly related to the amount of lablab available, but no further increase in gain resulted when lablab was more than 67% of the diet. McLeod et al. (1990) reported a higher voluntary intake of lablab hay by Hereford steers compared to that of grass hay and that the intake of the leaf fraction was higher than that of the stem fraction. Lablab supplementation to calves or cows fed tef straw increased the rate of degradation of tef straw, decreased mean retention time, and total DMI increased with increasing supplementation (Abule et al., 1995). A diet containing 50:50 maize stover:lablab compared to a diet of 70:30 maize stover: lablab fed to goats had higher intake (55 vs. 53 g kg$^{0.75}$), ADG (22.2 vs. 6.3 g d^{-1}) and milk yield (884 vs. 434 g d^{-1}),

indicating the potential of lablab in improving animal performance when supplemented to maize stover-based diets (Makembe and Ndlovu, 1996). In a field experiment (Milera et al., 1989), fresh lablab forage (30%) and guineagrass silage (70%) supplementation to crossbred cows grazed for 4 h d^{-1} significantly increased milk production (10.7 kg cow^{-1} d^{-1}) compared to when guineagrass was supplemented alone (9.2 kg cow^{-1} d^{-1}). Based on farmers' evaluation using forage yield, animal responses, and milk quality of cows fed lablab forages as ranking criteria (ranked on a scale of 1-4), Agyemang et al. (2000) concluded that forage harvested at 114 and 128 DAP had the best utilization rank score.

Although information on chemical composition is available, the use of mucuna and lablab as feed for cattle has not been studied in detail and information is scanty, particularly on their effect as supplement for lactating cows feeding on low quality fodder.

Based on the soil fertility and fodder quantity and quality constraints facing smallholder farmers in western Kenya and the previous research described in this literature review, a series of experiments was designed. The objectives were to 1) quantify the N contribution from mucuna and lablab residue incorporation to succeeding maize when all biomass is incorporated and when part of the residue is removed as livestock feed, 2) determine the effect of alternative cropping systems (legume relay intercrop), defoliation regime, and number of years (1 yr vs. 2 yr) of residue incorporation on soil fertility as measured through yields of a subsequent test crop of maize and bean, and 3) evaluate fodder production and nutritive value of legumes in alternative cropping systems and assess their value as a supplement to lactating cows

during the dry season. The results of these studies are described in the chapters that follow.

CHAPTER 3
NITROGEN CONTRIBUTION FROM RELAY-CROPPED MUCUNA AND LABLAB TO MAIZE IN NORTHWESTERN KENYA

Introduction

Low soil fertility is a major constraint to crop production in smallholder farming systems in northwestern Kenya. High population pressure leads to continuous cultivation and when little or no fertilizer is used soils become depleted of nutrients, with N and P the most limiting (Smaling et al., 1997). Although soil fertility can be improved with inorganic fertilizers, they are not widely used by smallholder farmers due to lack of financial resources. The integrated use of inorganic fertilizers and organic residues has been shown to be a useful alternative for increasing crop productivity in these regions (Palm et al., 1997). Jama et al. (1997), working in western Kenya, indicated that it was economically attractive to integrate inorganic P fertilizer (triple super phosphate) with organic materials having a high N-to-P ratio. Herbaceous legumes are examples of this type of material and they can be used in association or rotation with crops in green manure/cover cropping systems (Ibewiro et al., 2000a).

When organic residues are incorporated into the soil, they release N during decomposition, however for effective decomposition, the release of nutrients should be synchronized with the demand of the recipient crop (Myers et al., 1994). Most studies evaluating synchrony of N release have used above-ground leafy materials (Handayanto et al., 1994; Myers et al., 1994; Palm, 1995). Little information is available on the synchrony of N release and demand when root residue or root and low quality stem

stubble are incorporated for the subsequent maize crop. Previous studies have indicated that residues of intermediate quality may result in nutrient release patterns in synchrony with crop nutrient demand (Handayanto et al., 1994; 1995; 1997; Mafongoya et al., 1997a; 1997b). Myers et al. (1994) found that a mixture of straw and *Gliricidia sepium* residue mineralized N at an intermediate rate, and that the rate gradually increased coinciding with the period when growth demand by maize was highest, showing that the release of N from plant residues can be regulated through the manipulation of quality (Handayanto et al., 1997).

Decomposition and N release of organic residues in the soil are influenced by biomass yield (Sanginga et al., 1996a), chemical composition (Palm and Sanchez, 1992; Tian et al., 1992), and by abiotic factors such as climate and soil conditions (Mugendi et al., 1997). Several studies have shown that residue concentrations of N, lignin, and polyphenols, and the ratios of these constituents are useful indices of residue quality and affect decomposition and N release (Vanlauwe et al., 1997; Mafongoya et al., 1998).

Mucuna (*Mucuna pruriens* (L.) DC. var. *Utilis* (Wright) Bruck) and lablab (*Lablab purpureus* (L.) Sweet cv. Rongai) are promising legume green manures that have been successfully used in cover cropping systems with maize (*Zea mays* L.) in many parts of the tropics. They have been shown to contribute N (Ibewiro et al., 2000a), increasing the yields of subsequent maize (Versteeg et al., 1998a; Ibewiro et al., 2000a; Tian et al., 2000). In a rotational cropping system in the sub-humid highlands of East Africa, Fischler (1996) showed that preceding mucuna or lablab increased the maize grain yield by 50 or 40%, respectively. Working in a derived savanna of West Africa, Ibewiro et al. (2000a) found that relative to the controls, mucuna and lablab residues decomposed

rapidly, releasing 50 and 64%, respectively, of their N by 28 d after planting of maize and increased dry matter and N uptake of subsequent maize.

Although use of green manures has been reported in Africa (Balasubramanian and Blaise, 1993; Drechsel et al., 1996; Manyong et al., 1996; Snapp et al., 1998), the adoption of herbaceous legumes there is generally low (Thomas and Sumberg, 1995; Drechsel et al., 1996). Adoption of green manures has been much more rapid when the legumes had uses in addition to soil fertility improvement (Versteeg et al., 1998a). One such use is as a livestock feed (Abule et al, 1995; Agyemang et al., 2000, Adjorlolo et al., 2001), but there has been little research evaluating multiple uses of legumes for improvement of soil fertility and livestock diets.

In evaluating the potential of herbaceous legumes for relay-cropping systems with maize and beans in the sub-humid highlands of northwestern Kenya, a clearer understanding is needed of legume biomass yield and the chemical attributes of herbage that influence residue decomposition, N release, and uptake by maize. The specific objectives of this study were to 1) characterize the chemical composition of mucuna and lablab, 2) quantify the N contribution from incorporated mucuna and lablab residue to succeeding maize when either all biomass is incorporated or part of the residue is removed as livestock feed, and 3) relate residue chemical composition of mucuna and lablab with mineral N in the soil, N uptake, and grain yield of the succeeding maize intercrop.

Materials and Methods

Experimental Site

The experiment was conducted in western Kenya at the Kenya Agricultural Research Institute's National Agricultural Research Centre, Kitale (1^0 N and 35^0 E, altitude 1860 m), Kenya during the 1999 and 2000 growing seasons. Located in the sub-humid highlands, the area has a unimodal rainfall pattern lasting from mid-March to mid-November. This pattern allows for one late maturing hybrid maize and two short-duration crops of common bean (*Phaseolus vulgaris* L.) intercropped with maize. Maize and the first crop of beans are planted in April, and the second crop of beans is planted in August. In this study, maize and bean were planted in April 1999, but mucuna and lablab substituted for the second crop of beans in August 1999. The legumes grew through the dry season until soil incorporation in March 2000. Data reported for maize and bean are those for the season following that incorporation, i.e., April to November 2000.

The rainfall during the experimental period was 1100 mm and the mean monthly minimum and maximum temperatures were 12 and 24^0C, respectively. The soils are classified as humic Ferrolsols based on the FAO/UNESCO system (FAO – UNESCO, 1994) and are equivalent to a Kandiudalfic Eutaudox in the USDA soil taxonomy system (Soil Survey Staff, 1991). These are deep, highly weathered, and well-drained loam soils that are dark red to dark reddish brown in color with low activity clay and moderately acid topsoil. The topsoil (0-20 cm) had the following properties; pH (1:2.5 H_2O), 5.4; organic C, 14.2 g kg^{-1}; total N, 1.3 g kg^{-1}; extractable P (modified Olsen), 9.7 mg kg^{-1}; and texture, clay loam with 39% clay, 41% sand, and 20% silt.

Treatments and Cropping Systems

Seven treatments were evaluated. Four treatments consisted of the two legumes (mucuna and lablab) intercropped with maize and the legumes were either undefoliated with their herbage incorporated into the soil before subsequent maize or defoliated to a 10-cm stubble with topgrowth removed for livestock feed and the remaining residue incorporated. The three control treatments were the maize-bean-bean system receiving 1) inorganic N fertilizer (30 kg N ha^{-1}), 2) no N fertilizer, and 3) cattle manure at half the local recommended rate of 5 t ha^{-1} (supplying approximately 65 kg N and 18 kg P ha^{-1}). The treatments were laid out in a randomized complete block design replicated three times. Experimental plots were 4.5 by 6 m with a 1-m border around each plot.

The experiment was initiated at the beginning of the growing season in April 1999. Maize was planted at an inter- and intra-row spacing of 75 by 30 cm, respectively, using two seeds per hill of Kitale hybrid 614D maize grown in the region. The maize seedlings were thinned to one plant per hill 4 wk after planting (WAP) to give a plant population of 44,440 plants ha^{-1}. At planting, triple super phosphate fertilizer (0-46-0) was applied in the same hill as for maize at a rate of 13 kg P ha^{-1} to all treatments except for cattle manure. The first crop of common bean was planted simultaneously with maize at onset of rains in April. An improved bean variety GLP2 (Rosecoco), commonly planted by farmers in the region, was used. The second crop of beans and the legume green manures were relay cropped in maize in August, 135 d after maize planting. Before planting of the second bean crop or the legume intercrop (after harvesting the first crop of beans), the maize was weeded and all leaves below the ear were removed to minimize shading. The common bean, mucuna, and lablab were planted between maize rows at an intra-row spacing of 30 cm using three seeds per hill. They were thinned to two plants per hill 4

WAP. All the plots were hand weeded twice before harvesting the first crop of beans. The plots were manually weeded once after the August planting of legumes. Stalk borer (*Chilo* spp), a common pest of maize, was controlled by application of Beta-cyfluthrin (Bulldock). Beta-cyfluthrin, a synthetic pyrethroid insecticide, was applied in granular form into the whorl of each plant at a rate of 7 kg ha^{-1} at 4 and 8 wk after germination.

Green Manure Defoliation Management and Sampling

After harvesting maize in mid-November 1999, all stover was removed in accordance with the farmers' practice. Mucuna and lablab were left to continue growing until land preparation for the 2000 growing season in mid-March. The legumes were sampled in mid-March (30 WAP) before the residue was incorporated. The biomass production was assessed in terms of litter fall, above-ground biomass (leaf and stem), and root. For plots of the defoliated treatment, legume herbage was cut to a stubble of 10 cm. Prior to clipping the entire plot, two representative 0.5-m^2 quadrats were sampled. Herbage above 10 cm was composited across the two sites per plot and separated into weeds (grass and broadleaf), legume leaf, and legume stem fractions. Fractions were dried, weighed, and ground for laboratory analysis. In these same quadrats, all material below 10 cm was removed at soil level, composited across the two sites per plot, and separated into weed, live legume leaf, live legume stem, and litter fractions. Fresh weights of each fraction were taken, fractions were subsampled, and the remainder was returned to the two sampling sites. The subsample was weighed fresh, dried, weighed again, and then ground for analysis.

Undefoliated treatment plots were sampled at the same time. Again two representative 0.5-m^2 quadrats were sampled. In this case, all material was removed at soil level, composited, and separated into weed, live legume leaf, live legume stem, and litter

fractions. Fresh weights were taken, fractions were subsampled and the subsample weighed, and the remainder was returned to the quadrat. The subsample was dried, weighed, and ground for analysis.

Within each quadrat of all legume treatments, a root sample was taken. A soil core from a 0.5-m^2 area was removed to a depth of 20 cm. All visible roots were removed from the soil and washed with water on top of a 0.5-mm sieve to remove all soil and then rinsed with distilled water. The roots were dried at 70^0C for 48 h and weighed before grinding for analysis. Weed biomass yield was determined from two quadrats and samples for chemical analysis were taken as described above.

Soil Mineral N Sampling

Soil samples were taken from all seven treatments to determine soil mineral N before residue incorporation (BI) and at six dates after planting maize and bean in April 2000 to monitor mineral-N release in relation to the maize growth phase. Sampling dates were 4, 8, 10, 15, 21, and 27 WAP (at maize harvest). At each sampling date eight 10-cm cores were taken per plot to a depth of 20 cm. The soil from the eight sampling points per plot was composited, thoroughly mixed, and then subsampled and packed into polyethylene bags. The samples were kept in a cooler box with ice and transported immediately to the laboratory for analysis. They were extracted with 2*N* KCl. The extracts were analyzed for NH_4^+ and NO_3^- following the method outlined by Anderson and Ingram (1993). The NH_4^+ and NO_3^- were calculated to elemental N and then summed to give soil mineral N. Soil nitrate was estimated in kg ha^{-1} using the measured bulk density of 1.25 g cm^{-3} for the 0 to 20-cm depth.

Maize N Uptake Sampling

For determination of maize DM yield and N uptake, six representative maize plants were harvested (cut at soil surface without harvesting roots) from the two rows next to each outer border row at 2, 4, 8, 10, 15, 21, and 27 WAP (at harvest) in 2000. To minimize gap effects, care was exercised to ensure that two consecutive plants were not removed. At each sampling date, plant subsamples were taken for DM and N concentration determinations. The samples were washed with water (where necessary) and oven dried at 60^0C to constant weight to determine DM. The samples were ground to pass a 1-mm sieve and kept in airtight plastic bags in a cool, dry place until ready for chemical analysis.

Grain and Stover/Straw Dry Matter Yield of maize and Beans

The first crop of common bean was harvested at the end of July and the second crop of common bean and the maize were harvested in mid-November. Maize and bean were harvested from the two center rows of every plot. The first and last two hills of each row were not harvested. The size of the sampling unit was 1.5 by 5.4-m (8.1 m^2). Grain yield at 13.5% moisture concentration and stover/straw DM yields were recorded.

Chemical Analyses

Legume fractions from below 10 cm of defoliated plots and all fractions from undefoliated plots were analyzed for N, P, K, lignin, and polyphenol. Total N, P, and K were determined using the Kjeldahl digestion with concentrated sulphuric acid followed by colorimetric determination of N and P and flame photometric determination of K (Anderson and Ingram, 1993). Neutral detergent fiber and lignin were determined using the methods of Van Soest et al. (1991). Total polyphenols were extracted using 50% aqueous methanol with a plant to extract ratio of 0.1/50 mL and phenols analyzed

colorimetrically using Folin-Ciocalteu reagent (Anderson and Ingram, 1993). The soil samples were analyzed for soil pH in water (soil:water ratio of 1:2.5), total N, NO_3^-, NH_4^+, P, K, organic carbon, and soil particle size using procedures outlined by Anderson and Ingram (1993).

Statistical Analyses

The general linear models procedure of SAS was used to test treatment effects on plant and soil responses (SAS, 2001). For response variables pertaining only to the four legume treatments, the model included effects of legume, defoliation, and their interaction. For response variables pertaining to all seven treatments in the study, a first analysis tested the effects of legume, defoliation, and their interaction, and this was followed by single degree of freedom contrasts that compared the legume treatments (individually or in groups) with the controls. Relationships between residue chemical composition and soil mineral N were determined using regression analysis in the regression procedure of SAS (SAS, 2001). Differences referred to in the text are significant at $P \leq 0.10$, unless otherwise indicated.

Results and Discussion

Legume Residue Biomass

Defoliation reduced leaf, stem, and total legume residue as well as the whole residue incorporated (Table 3-1). Legume leaf biomass was greater for undefoliated than defoliated treatments by a factor of five for mucuna and 26 for lablab. Stem biomass also was greater for undefoliated than defoliated treatments, but only by a factor of three. There were no differences between legume species for either leaf or stem biomass although there was a trend toward greater leaf mass for mucuna than lablab ($P = 0.147$).

Table 3-1. Residue biomass of various fractions of mucuna and lablab, weeds, and whole residue when legumes were relay cropped in maize.

Fraction	Treatments†				Effect			
	UD-M	D-M	UD-L	D-L	Legume (L)	Defoliation (D)	L x D	SE
Legume	---------- t ha^{-1} ----------				---------- P Values ----------			
Leaf	1.07	0.22	0.78	0.03	0.147	0.002	0.741	0.14
Stem	0.75	0.27	0.91	0.31	0.475	0.006	0.663	0.10
Litter	0.12	0.13	0.17	0.19	0.188	0.723	0.859	0.02
Roots	0.11	0.07	0.15	0.17	0.108	0.776	0.406	0.02
Total legume	2.05	0.69	2.0	0.70	0.943	0.005	0.934	0.25
Weeds	0.60	1.10	0.59	0.80	0.621	0.275	0.636	0.13
Whole residue	2.65	1.79	2.60	1.50	0.662	0.043	0.765	0.23
Shoot : Root ratio	16.9	11.1	13.5	3.2	0.038	0.009	0.333	1.74
Leaf : Stem ratio	1.43	0.85	0.82	0.14	0.002	0.003	0.679	0.15

† UD-M = Undefoliated mucuna, D-M = Defoliated mucuna, UD-L = Undefoliated lablab, D-L = Defoliated lablab

Legume litter and roots averaged 0.15 and 0.13 t ha^{-1}, respectively, and were not affected by treatment. Total legume biomass incorporated into the soil prior to planting maize was nearly identical for the two species, but was approximately three times greater for undefoliated than for defoliated treatments (Table 3-1).

Leaf:stem ratio and shoot:root ratio of incorporated biomass were greatest for undefoliated mucuna (UD-M) and least for defoliated lablab (D-L), the response of the latter treatment was due in large part to very low leaf biomass. The presence of legumes in the cropping system reduced weed growth from 2.2 t ha^{-1} in the unfertilized natural fallow control to an average of 0.8 t ha^{-1} in the legume intercrop treatments, a response similar to that described by Becker and Johnson (1998). The grass weeds comprised mainly couchgrass (*Digitaria scalaraum*) and the broadleaf weeds were black jack (*Bidens pilosa*), wondering jew (*Commelina bengalensis*), and Gallant soldier (*Galinsoga parviflora*).

When grown as monocrops and planted at the beginning of the growing season (April) in a side experiment at this location, mucuna and lablab produced greater than 5 t DM ha^{-1} compared to about 2 t ha^{-1} when relay cropped in maize and planted in August. This level of yield reduction is consistent with previous reports when mucuna and lablab were grown in association with cereal crops (Fischler, 1996; Sanginga et al., 1996a; Wortmann et al., 2000) and can be attributed primarily to a shift in the season of growth to include the dry season. In addition, germination of mucuna was slow and uneven and the lablab seedlings were susceptible to aphid (*Aphis craccivora*) damage and leaf rust (Anthracnose, caused by *Colletotrichum spp*.) when planting occurred during August when rainfall was quite high. The ability of these legumes to remain alive and grow

during the dry season when intercropped with maize is important. Although biomass yields were only 2 t ha^{-1}, the great majority of this material was living at time of incorporation resulting in residue that was less affected by weathering and leaching losses of nutrients than would be the case if litter was the primary fraction being incorporated.

Chemical Composition of Legume Biomass

Leaf N concentration was affected by a legume species by defoliation regime interaction (P = 0.05; Table 3-2). Legume species had no effect on leaf N of undefoliated treatments (P = 0.444), but defoliated mucuna (D-M) leaf N was greater than that of D-L (P = 0.016). Likewise there was no effect of defoliation on mucuna leaf N, but leaf N of undefoliated lablab (UD-L) was greater than D-L. Litter N concentration was not affected by treatment and was approximately 10 g kg^{-1} less than for leaves, except for D-L where the difference was only 1.3 g kg^{-1}. The lower N concentration of litter than leaf can be explained by the process of nutrient resorption during senescence, when leaf proteins are hydrolyzed and products transported to other parts before leaf fall (Norby and Contrufo, 1998).

There also was interaction of legume species and defoliation regime for stem N concentration (P = 0.043). Stem N concentration of undefoliated treatments was not affected by legume species (P = 0.657), but D-M stem (16.2 g kg^{-1}) contained higher (P = 0.003) N concentration than D-L (10.2 g kg^{-1}). Defoliation reduced lablab stem N concentration (P = 0.034), but had no effect on mucuna stem (P = 0.227). Mucuna roots had greater (P = 0.039) N concentration than lablab. The N concentration of mucuna and lablab fractions in the current study were generally lower than those reported by Ibewiro

Table 3-2. Nitrogen, lignin, and polyphenol concentration of various residue fractions of mucuna and lablab relay cropped in maize.

Fraction	Treatments†				Effects			
	UD-M	D-M	UD-L	D-L	Legume (L)	Defoliation (D)	L x D	SE
Nitrogen	---------- g kg^{-1} ----------				---------- P values ----------			
Leaf	22.1	25.1	24.6	16.7	0.224	0.308	0.050	1.32
Stem	14.5	16.2	13.8	10.2	0.016	0.344	0.043	0.79
Litter	12.1	13.2	13.7	15.4	0.121	0.234	0.758	0.52
Roots	13.4	13.3	11.6	11.3	0.039	0.754	0.858	0.54
Lignin								
Leaf	52	57	35	99	0.302	0.028	0.056	8.64
Stem	77	96	89	109	0.019	0.004	0.921	4.00
Roots	132	121	108	108	0.018	0.454	0.489	3.90
Polyphenol								
Leaf	45	55	27	15	< 0.001	0.778	0.01	5.15
Stem	36	37	13	8	0.004	0.876	0.495	4.53
Roots	23	27	6	5	0.010	0.913	0.607	3.47

† UD-M = Undefoliated mucuna, D-M = Defoliated mucuna, UD-L = Undefoliated lablab, D-L = Defoliated lablab

et al. (2000a). This could be due to differences in environmental conditions prevailing during plant growth, which can result in biomass of differing quality (Handayanto et al., 1995), and the stage at which the residue was sampled. Biomass in our study was sampled at the end of the dry season (30 WAP) when some leaves had been lost as litter and the above-ground herbage was comprised of older leaves and stems.

There was an interaction effect of legume and defoliation regime on leaf lignin concentration ($P = 0.056$). Defoliation increased lablab leaf lignin concentration ($P = 0.007$), but had no effect on mucuna leaf ($P = 0.743$). Defoliated lablab leaf had greater ($P = 0.021$) lignin concentration than D-M, but there was no difference ($P = 0.386$) between undefoliated treatments. Mucuna stem contained less ($P = 0.019$) lignin than lablab stem, and defoliation increased lignin concentration of the stem fraction of both legumes ($P = 0.004$) (Table 3-2). Mucuna roots contained higher lignin concentration than lablab ($P = 0.018$), but defoliation did not affect root lignin concentration. In agreement with literature (Tian and King, 1998), roots had higher lignin concentration than other residues. The lignin concentration in mucuna and lablab residues was below 150 g kg^{-1}, a concentration above which decomposition and N release is thought to be impaired (Palm et al., 2001) due to lignin protection of cell wall constituents from microbial attack (Cheson, 1997).

Relatively large differences in polyphenol concentration occurred between species (Table 3-2). All mucuna fractions had higher ($P < 0.01$) polyphenol concentration than those of lablab. Polyphenol concentration ranged from 5 g kg^{-1} in D-L roots to 55 g kg^{-1} in D-M leaves and concentrations in the plants were generally in the order: leaf > stem > roots. There was legume by defoliation treatment interaction ($P = 0.01$) for leaf

polyphenol concentration. Interaction occurred because the magnitude of the species difference was greater for defoliated than undefoliated leaf. The legumes contained higher concentrations of polyphenol than those reported by Ibewiro et al. (2000a), but these were within the range reported for agroforestry species by Constantinides and Fowness (1994) and were above concentrations (> 4 g kg^{-1}) at which decomposition is reduced (Palm et al., 2001).

Mucuna stem contained higher (P = 0.033) P concentration than lablab stem, and defoliation reduced P concentration of stems of both legumes (P = 0.049) (Table 3-3). Root P concentration was affected only by legume species and was lower for lablab (0.85 g kg^{-1}) than mucuna (1.35). Legume species effects on K concentration were significant for leaf, litter, and root fractions. Lablab leaf and stem had greater K concentration than mucuna, but the opposite was true for roots (Table 3-3). Defoliation had no effect on K concentration of any fraction. The P concentration of mucuna and lablab above-ground residue was similar to that reported from the sub-humid highlands of eastern Africa (Wortmann et al., 2000) and was close to the critical range for net P mineralization of between 2 and 3 g kg^{-1} reported by Singh et al. (1992), suggesting a net P mineralization due to the application of green manure residue.

Nutrient Mass Incorporated

Defoliation reduced the N content in legume leaf (P = 0.002), stem (P = 0.009), and total legume (P = 0.001) fractions, and in the whole residue (P = 0.018) that was incorporated (Table 3-4). Nitrogen contribution from UD-M and UD-L treatments was similar (49 and 47 kg N ha^{-1}, respectively), but that of D-M was higher (P=0.089) than

Table 3-3. Phosphorus and potassium concentrations of various residue fractions of mucuna and lablab relay cropped in maize.

Fraction	Treatments†				Effects			SE
	UD-M	D-M	UD-L	D-L	Legume (L)	Defoliation (D)	L x D	
	---------- g kg^{-1} ----------				---------- P values ----------			
Phosphorus								
Leaf	1.6	1.5	1.8	0.9	0.427	0.119	0.217	0.15
Stem	2.4	1.5	1.4	0.7	0.033	0.049	0.850	0.22
Litter	0.8	0.7	0.8	0.7	0.780	0.194	0.414	0.03
Roots	1.5	1.2	0.9	0.8	0.009	0.281	0.534	0.10
Potassium								
Leaf	6.7	8.4	15.9	12.5	0.007	0.674	0.138	1.23
Stem	13.4	14.5	16.5	15.0	0.170	0.474	0.312	0.52
Litter	5.6	5.7	10.6	13.0	0.001	0.305	0.318	1.04
Roots	10.8	11.7	9.4	9.2	0.046	0.728	0.506	0.43

† UD-M = Undefoliated mucuna, D-M = Defoliated mucuna, UD-L = Undefoliated lablab, D-L = Defoliated lablab

Table 3-4. Nitrogen contribution of various residue fractions of mucuna and lablab relay cropped in maize.

Fraction	Treatments†				Effects			
	UD-M	D-M	UD-L	D-L	Legume (L)	Defoliation (D)	L x D	SE
Legume	---------- kg ha^{-1} ----------				---------- P values ----------			
Leaf	26.1	5.6	19.0	0.5	0.092	0.002	0.565	3.59
Stem	8.8	4.2	12.4	3.2	0.609	0.009	0.260	1.45
Litter	1.5	1.7	2.3	2.9	0.133	0.547	0.764	0.28
Roots	1.5	1.0	1.8	1.8	0.270	0.622	0.547	0.22
Total legume	37.9	12.5	35.5	8.4	0.499	0.001	0.845	4.68
Weeds	10.7	19.5	11.7	13.1	0.577	0.316	0.450	2.02
Whole residue	48.6	32.3	47.2	21.5	0.385	0.018	0.496	4.61

† UD-M = Undefoliated mucuna, D-M = Defoliated mucuna, UD-L = Undefoliated lablab, D-L = Defoliated lablab

D-L. The natural weed fallow control contributed 40 kg N ha^{-1}. Defoliated mucuna and lablab treatments contributed 66 and 45% as much N as the undefoliated treatments, respectively. For UD-M and UD-L, the leaf fraction contributed the greatest amount of N (68 and 54% of the total legume, respectively) and root contributed the least (4 and 5%, respectively). In the D-L treatment, stem contributed 38% compared to only 6% from leaves, while for D-M the contributions of stem and leaf were about the same (35 and 44%, respectively).

Defoliation reduced the P and K contribution of leaf, stem, and total legume fractions, but nutrient contribution from the whole residue was reduced only for P (Table 3-5). The green manures contributed low amounts of P, ranging from 0.5 (D-L) to 3.5 kg ha^{-1} (UD-M). The K contribution ranged from 7.4 (D-M) to 31.7 kg ha^{-1} (UD-L).

Soil Mineral N

The bulk of the inorganic N found in the soil at all sampling periods was in the form of NO_3^--N. The NO_3^--N fraction was three times that of NH_4^+-N. Mineral N in the 0- to 20-cm soil depth at the beginning of the season before residue incorporation ranged from 16 kg ha^{-1} in the inorganic N plot to 20 kg ha^{-1} in UD-M plots, with a mean of 18 kg ha^{-1} (Figure 3-1). Throughout the period from planting through 27 WAP, there were no differences among treatments in soil mineral N at any sampling date. The mean amount of soil inorganic N across all treatments decreased progressively until 8 WAP. The soil inorganic N marginally increased between 8 and 21 WAP (grain filling stage) and decreased at harvest (27 WAP). Regression of soil inorganic N averaged across all treatments over time showed a cubic response (Figure 3-1).

Table 3-5. Phosphorus and K content of various residue fractions of mucuna and lablab relay cropped in maize.

Fraction	Treatments†				Effects			
	UD-M	D-M	UD-L	D-L	Legume (L)	Defoliation (D)	L x D	SE
Phosphorus	---------- kg ha^{-1} ----------				----------P values ----------			
Leaf	1.8	0.3	1.5	0.1	0.262	0.006	0.712	0.28
Stem	1.5	0.4	1.4	0.2	0.830	0.040	0.796	0.26
Litter	0.1	0.1	0.1	0.1	0.180	0.884	0.907	0.01
Roots	0.2	0.1	0.1	0.1	0.969	0.327	0.483	0.02
Total legume	3.5	0.9	3.1	0.5	0.547	0.006	0.970	0.51
Weeds	1.1	1.6	1.1	1.1	0.568	0.501	0.572	0.17
Whole residue	4.6	2.5	4.2	1.6	0.479	0.036	0.766	0.55
Potassium								
Leaf	7.8	1.8	13.1	0.4	0.574	0.012	0.296	2.00
Stem	8.1	4.1	15.3	4.6	0.204	0.031	0.267	1.84
Litter	0.7	0.7	1.8	2.4	0.026	0.528	0.571	0.29
Roots	1.2	0.8	1.4	1.5	0.224	0.605	0.503	0.16
Total legume	17.8	7.4	31.7	8.9	0.156	0.013	0.238	3.61
Weeds	18.3	31.9	16.5	20.9	0.497	0.349	0.621	3.81
Whole residue	36.1	39.3	48.2	29.8	0.901	0.467	0.312	4.56

† UD-M = Undefoliated mucuna, D-M = Defoliated mucuna, UD-L = Undefoliated lablab, D-L = Defoliated lablab

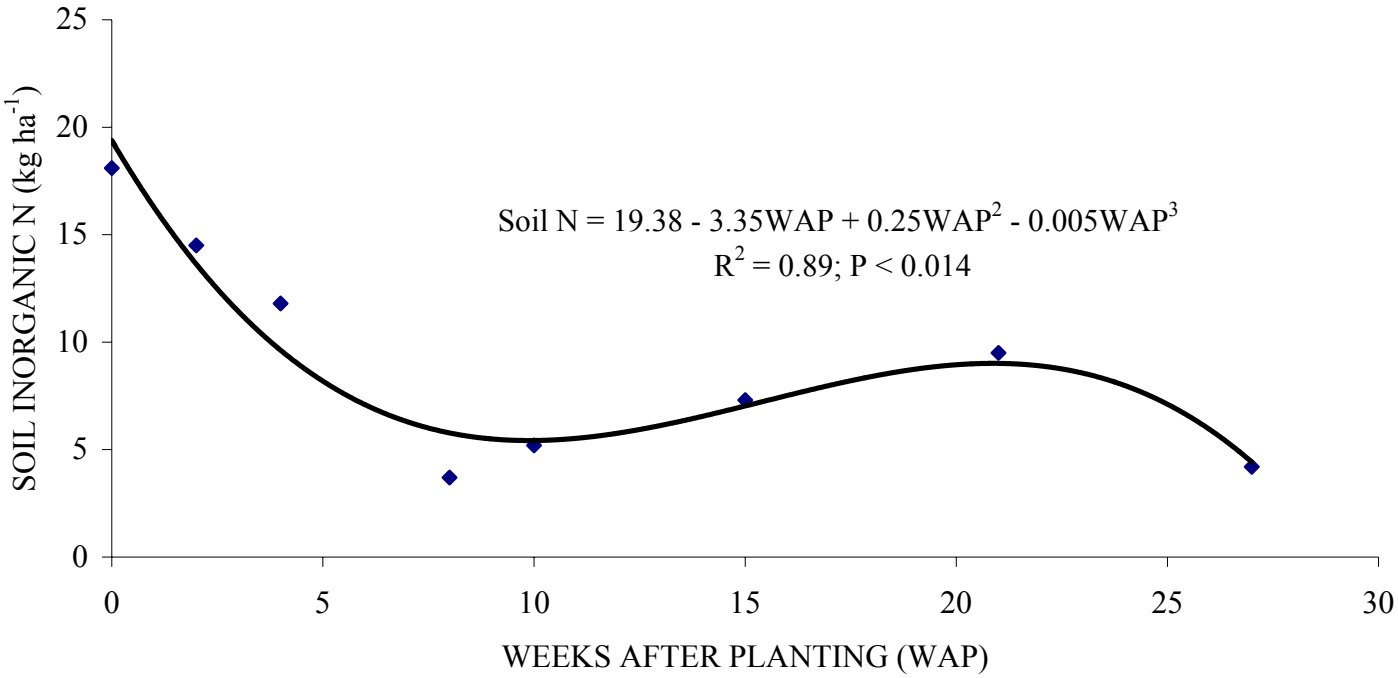


Figure 3-1. Mean inorganic N in the soil at different time periods.

Maize Yield and N Uptake

There was an interaction of legume by defoliation for above-ground maize biomass yield ($P = 0.037$) at 4 WAP (Table 3-6). Undefoliated mucuna tended to yield greater ($P = 0.11$) maize biomass than UD-L, but there were no differences ($P = 0.492$) between the defoliated treatments. Defoliation had no effect ($P > 0.457$) on maize biomass yield for either legume. Undefoliated mucuna yielded ($P = 0.093$) more maize biomass than the natural fallow control. At 8 WAP, defoliation of legumes resulted in lower ($P = 0.015$) maize biomass yield. All legume residue treatments (UD-M, D-M, UD-L, and D-L) yielded more ($P < 0.001$, $P < 0.001$, $P = 0.024$, and $P = 0.092$, respectively) maize biomass than the natural fallow control at 8 WAP. At 10 WAP, lablab plots yielded higher ($P= 0.076$) maize biomass than mucuna plots, and defoliation of both legumes reduced ($P = 0.046$) yield. The yield under UD-L was greater ($P < 0.001$) than the natural fallow control. By 15 WAP, the legume and defoliation effects and their interaction were not significant, however, maize biomass yield was higher under UD-M ($P = 0.073$), D-M ($P = 0.081$), and UD-L ($P = 0.099$) than the natural fallow control. Mucuna plots tended ($P = 0.110$) to outyield those of lablab and there were no defoliation effects at 21 WAP, but UD-M (0.034) and D-M ($P = 0.10$) outyielded the natural fallow control. No treatment effects were significant for maize DM yield at 27 WAP.

Nitrogen uptake by maize following mucuna treatments was greater ($P < 0.001$) than lablab at 4 WAP, but defoliation effects were not significant (Table 3-7). At 8 WAP, legume defoliation reduced ($P = 0.016$) N uptake by maize, however, N uptake by

Table 3-6. Total above-ground maize biomass yield at different sampling dates.

Treatment[†]	Weeks after planting					
	4	8	10	15	21	27
	kg ha^{-1}					
UD-M	130	2030	3260	7180	15680	17310
D-M	110	1690	3060	7140	16990	16700
UD-L	100	1980	4100	7060	14600	17970
D-L	100	1610	3180	6450	15370	16800
N fertilizer	110	1600	2980	7550	16790	19800
Natural fallow	100	1400	2790	5830	13060	16310
Cattle manure	110	1750	3350	7890	15720	17840
Effects[±]	P values					
Legume (L)	0.002	0.539	0.076	0.442	0.110	0.796
Defoliation (D)	0.530	0.011	0.046	0.533	0.842	0.550
L x D	0.037	0.849	0.159	0.587	0.484	0.851
SE	5.30	74.2	179.7	208.1	838.5	632.9

[†] UD-M = Undefoliated mucuna, D-M = Defoliated mucuna, UD-L = Undefoliated lablab, D-L = Defoliated lablab

[±] Significant contrasts of legume treatments vs. control treatments are reported in the text.

maize in all legume residue treatments was higher ($P < 0.02$) than the natural fallow control. At 10 WAP, immediately after the period when the N demand by maize is highest (Karlen et al., 1988), the interaction of legume and defoliation effects was significant ($P = 0.072$). Defoliation of lablab reduced ($P = 0.039$) N uptake by maize, but did not affect ($P = 0.478$) N uptake under mucuna treatments. The N uptake was highest in the UD-L treatment and this was greater ($P = 0.002$) than UD-M. Relative to the natural fallow control, UD-L, and D-M resulted in higher ($P = 0.001$ and $P = 0.036$, respectively) N uptake. By 15 WAP, the effects of legume, defoliation, and their interaction were not significant, although analysis using single degree of freedom contrasts revealed that the defoliation of lablab reduced ($P = 0.085$) N uptake by maize. Both UD-L ($P = 0.028$) and UD-M ($P= 0.090$) achieved higher uptake than the natural fallow control. Treatment effects were not significant at 21 WAP and 27 WAP (at harvest), but UD-M achieved higher ($P = 0.062$) N uptake than the natural fallow control at 21 WAP.

Defoliated lablab was associated with low N uptake and recovery rates at all time periods. This is likely due to two reasons. First, the defoliation of lablab at 10 cm considerably reduced the biomass left for incorporation of this upright growing legume (Table 3-1). Also, lablab biomass was comprised of a higher proportion of stem than leaf (Table 3-1), and the stem had a higher lignin concentration than mucuna stem (Table 3-2), suggesting that D-L biomass was very low in quality. In contrast, defoliation of mucuna rarely had a significant effect on subsequent maize responses relative to UD-M.

Table 3-7. Nitrogen taken up by maize at different sampling dates.

	Weeks after planting					
Treatment[†]	4	8	10	15	21	27
	---------- kg ha^{-1} ----------					
UD-M	5	47	52	73	190	163
D-M	4	40	63	64	162	169
UD-L	3	44	82	81	132	171
D-L	4	38	57	60	111	151
N fertilizer	4	36	63	76	126	172
Weed fallow	4	32	40	49	113	143
Cattle manure	4	41	55	68	134	159
Effects[±]	---------- P values ----------					
Legume (L)	< 0.001	0.331	0.208	0.852	0.154	0.778
Defoliation (D)	0.608	0.016	0.432	0.211	0.496	0.701
L x D	0.088	0.622	0.072	0.572	0.915	0.499
SE	0.23	1.55	4.84	4.68	15.9	8.84

[†] UD-M = Undefoliated mucuna, D-M = Defoliated mucuna, UD-L = Undefoliated lablab, D-L = Defoliated lablab
[±] Significant contrasts of legume treatments vs. control treatments are reported in the text.

Relationships Between Residue Quality Parameters and Soil Mineral N

There were weak, but significant, negative correlations between soil mineral N and lignin ($r = -0.61$, $P = 0.04$), lignin-to-N ratio ($r = -0.66$, $P = 0.02$) and (polyphenol + lignin)-to-N ratio ($r = -0.54$, $P = 0.07$), and a positive correlation with residue N concentration ($r = 0.6$, $P = 0.05$) at 4 WAP (Figures 3-2 and 3-3). The significance of these relationships only at 4 WAP, and not in other time periods, could in part be explained by the fact that at 4 WAP N uptake by maize was low and thus the soil mineral N reflected more closely the amount of N mineralized from the residue. In agreement with results of Meentemeyer (1978), these data indicate that lignin is an important quality component determining the rate of decomposition and in part agrees with the observation by Melillo et al. (1989) that the lignin-to N ratio predicts the early stage of decomposition. The negative relationship is in agreement with previous studies that have demonstrated an inverse relationship between N release and lignin, lignin-to-N ratio, and (lignin + polyphenol)-to-N ratio (Palm and Sanchez, 1991; Oglesby and Fowness, 1992; Kachaka et al., 1993; Handayanto et al., 1994; Constantinides and Fowness, 1994; Vanlauwe et al., 1996; Ibewiro et al., 2000a) under laboratory incubations or litter bag decomposition studies. The positive relationship between N concentration and soil mineral N at 4WAP was in agreement with previous report of Constantinides and Fowness (1994) in which the initial N explained most of the variation in N accumulation or depletion from the soil when fresh leaves or litter from commonly used agroforestry species were incorporated.

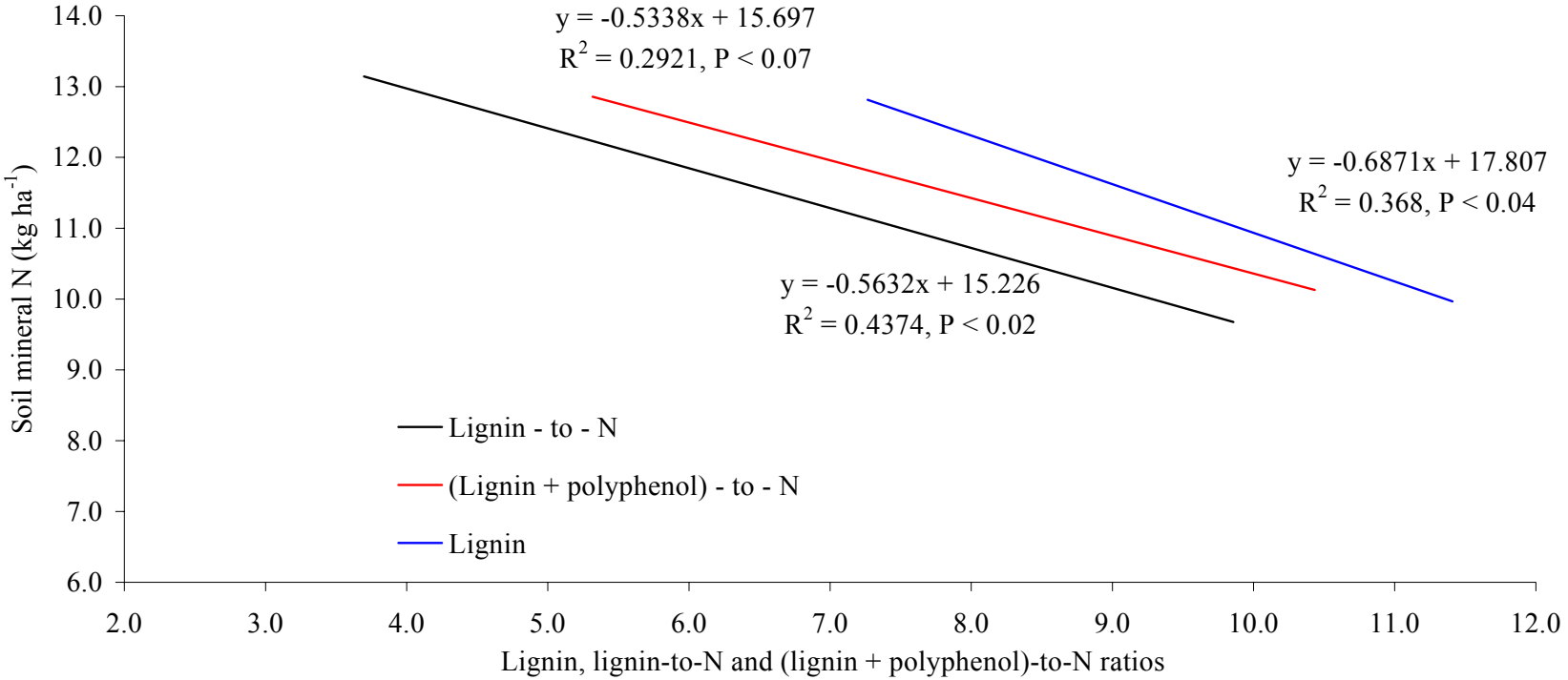


Figure 3-2. Relationships between soil mineral N and residue lignin, lignin-to-N ratio, and (lignin + polyphenol)-to-N ratio at 4 WAP.

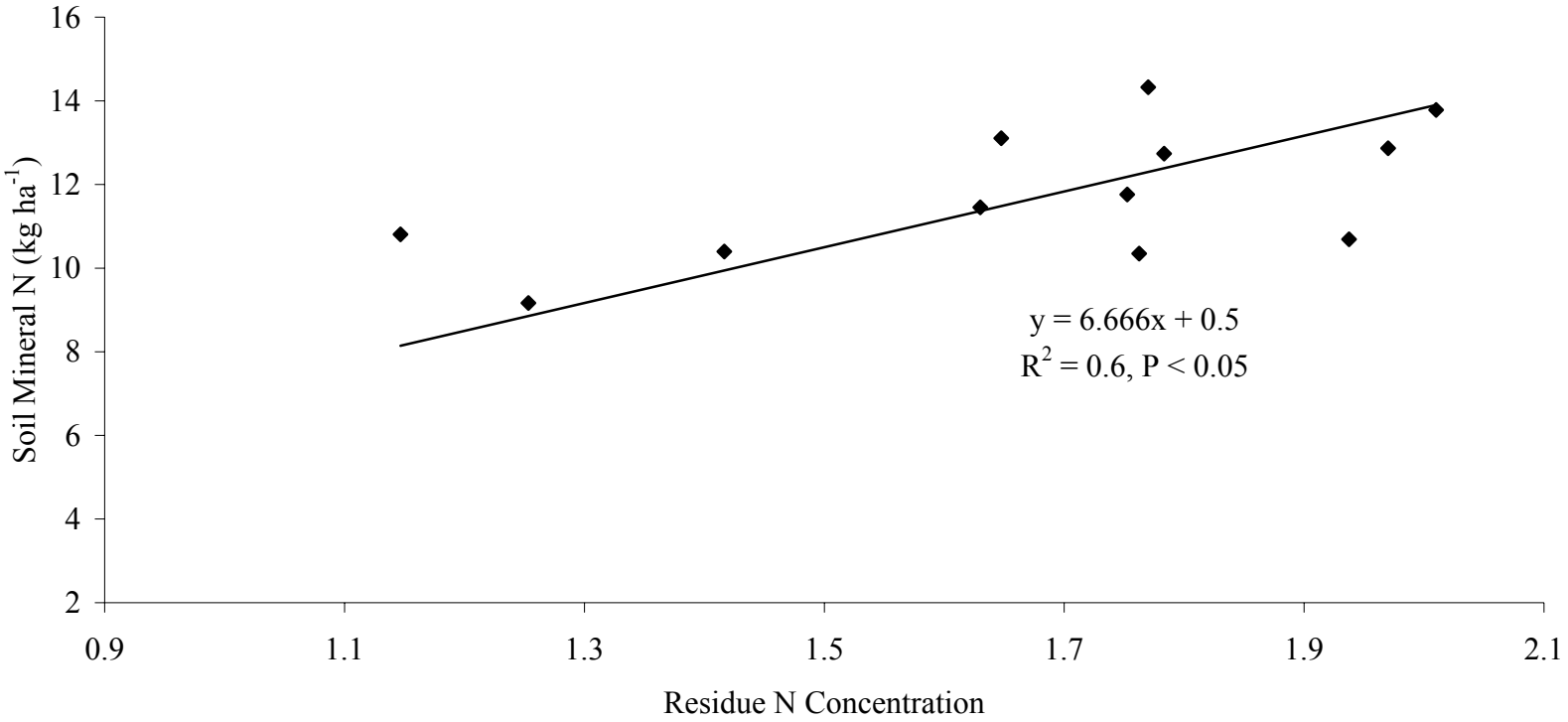


Figure 3-3. Relationship between residue N concentration and soil mineral N at 4 WAP.

The material used in this study had a lignin:N ratio within a narrow range of 3.7 to 9.9. This limited range and the wide variability of mineral N in the soil under field conditions explains why we found only a weak correlation between lignin:N and N release in the soil. Our results agree with those of Palm and Sanchez (1991) who used fresh legume leaves with a narrow range, but contrasts those of Constantinides and Fowness (1994) who used a wide range of materials. The low correlations could also be explained by losses of inorganic N in the soil due to leaching (Cahn et al., 1993) and denitrification (Lensi et al., 1992) of nitrate under the high rainfall of the subhumid tropics, by volatilization (Costa et al., 1990), and to some extent from the uptake of N by maize. This relationship provides a practically useful function for estimating N release from residue quality under northwestern Kenya conditions and could be used in modeling studies which evaluate the effects of organic inputs on long-term soil fertility changes.

Apparent N Recovery

No treatment effects were detected on N recovery by maize (Table 3-8). Nitrogen recovery was lowest at 4 WAP (< 3%). At 8 WAP, when the demand for N by maize was greater, the recovery ranged from 12% for the inorganic N control to 27% for the UD-L treatment. The mean N recovery rates across all time periods were in the range of 21% for cattle manure to 52% for the UD-L treatment (Table 8), but no significant differences were detected. The N recovery by D-M averaged 45% compared to 35% for the UD-M. Nitrogen recovery achieved by UD-L was similar to that from the inorganic N and was about twice that obtained by D-L. The cattle manure treatment had the lowest, but most consistent N recovery rate. The apparent N recovery by subsequent maize is similar to that reported by Tian et al. (2000) for legume cover crops in a derived savanna of West Africa.

The high N accumulation in the natural weed fallow may have reduced the responses to legume biomass incorporation. Additionally across all treatments, the weeding of maize during the period of maize growth and incorporating weeds could have contributed N to the system that was not quantified in our study.

The relatively high N recovery found in our study could, in part be explained by unaccounted N from the fine roots. Roots slough off and litter decomposes during the dry season and this material was not accounted for in the DM quantified just before land preparation, but it did contribute to the soil inorganic N taken up by the maize. Similar observations were made by Van Noordwijk and Purnomosidi (1992) who found a higher litter DM biomass during the growth period than live biomass measured at the end of the growth period. Also Hairiah and van Noordwijk (1989), referenced in van Noordwijk and Purnomosidi (1992), found that N uptake by maize following mucuna was 147 kg ha^{-1} higher than control crop while the N content of live biomass incorporated into the soil was only 71 kg ha^{-1}.

For lablab residue treatments, some seeds dehisced and were incorporated into the soil but were not accounted for in the biomass recorded. Thus, these factors in addition to the time that elapsed between sampling/incorporating green manure residues and the planting of maize (21 d) as well as differences in rainfall amounts received prior to each sampling date, could partly explain the high variability observed in the N recovery data. On average, the N recovery was comparable to that obtained from inorganic fertilizer application (30-50%) reported from tropical cropping systems (Baligar and Bennet, 1986).

Table 3-8. Nitrogen recovery by maize at various sampling dates.

Treatment†	Weeks after planting‡						
	4	8	10	15	21	27	Mean
	----------%----------						
UD-M	2	26	21	41	84	34	35
D-M	2	24	73	54	51	66	45
UD-L	-1	27	111	72	27	77	52
D-L	2	30	76	56	-12	16	28
N Fertilizer	1	12	60	92	45	98	51
Cattle manure	1	13	22	29	33	24	21
Effects	---------- P Values ----------						
Legume (L)	0.278	0.667	0.275	0.621	0.125	0.955	0.657
Defoliation (D)	0.199	0.981	0.848	0.960	0.668	0.813	0.759
L x D	0.405	0.742	0.305	0.661	0.879	0.456	0.355
SE	1.06	3.09	18.8	12.3	31.1	29.4	7.93

† UD-M = Undefoliated mucuna, D-M = Defoliated mucuna, UD-L = Undefoliated lablab, D-L = Defoliated lablab

Bean and Lablab Grain Yield

The effects of legume, defoliation regime, and their interaction on bean grain and straw yields were not significant (Table 3-9), however mucuna plots tended (P = 0.135) to yield greater bean grain yield than lablab. Yield of the second crop of beans was low (102 kg ha^{-1}) compared to both the first crop (648 kg ha^{-1}) and the average grain yield of relay-cropped lablab (364 kg ha^{-1}). The bean straw yield was not affected by treatment. Bean yields reported from the highlands of east Africa are generally between 0.2 to 1 t ha^{-1} without fertilization (Giller et al., 1998; Wortmann et al., 2000), but yields above 1 t ha^{-1} have been reported for some varieties (Wortmann et al., 1996). Bean yields in our study were at the lower end of this range, probably due to low soil fertility (Giller et al., 1998) and the occurrence of bean root rot, a major disease problem in western Kenya (Otsyula et al., 1999). The lower bean grain yield following lablab compared to mucuna could be due to greater competition from maize (under UD-L) and the susceptibility of lablab to leaf rust disease, a disease that could have also affected bean growth for this treatment.

The lablab grain yield was consistent with those (200-450 kg ha^{-1}) reported in the literature (Weber, 1996) and was greater than the second bean crop grain yield, suggesting that the opportunity cost of foregoing the second crop of beans to plant lablab is low. In addition there is an added advantage of producing biomass that could be used either as supplemental feed or for improving soil fertility. Thus relay cropping of legume green manures has the advantage of growing the first crop of beans plus producing additional organic material instead of a second bean crop, the yield of which is usually low.

Table 3-9. Maize and bean grain and stover/straw yield for the 2000 growing season.

Treatment[†]	Beans		Maize	
	Grain	Straw	Grain	Stover
	------- kg ha^{-1} --------		--------- t ha^{-1} ---------	
UD-M	684	541	5.1	5.8
D-M	620	546	6.2	5.3
UD-L	546	498	7.4	6.7
D-L	481	455	5.7	4.3
Controls				
N Fertilizer	716	602	7.8	7.1
Natural fallow	715	621	4.8	4.6
Cattle manure	772	620	6.8	8.5
Effects	---------- P Values ----------			
Legume (L)	0.135	0.415	0.424	0.858
Defoliation (D)	0.456	0.812	0.753	0.334
L x D	0.998	0.769	0.215	0.587
SE	40.7	35.4	0.44	0.54

[†] UD-M = Undefoliated mucuna, D-M = Defoliated mucuna, UD-L = Undefoliated lablab, D-L = Defoliated lablab.

Maize Grain Yield

Despite relatively large numerical differences among legume treatment means, no differences in maize grain yield were detected (Table 3-9). For the green manure treatments, UD-L resulted in the maize grain yields closest to those of the N fertilizer control. Maize grain yield under UD-L was higher ($P = 0.089$) compared to the natural weed fallow where no inorganic N was applied. Yields following D-M were at least as great as for UD-M, whereas the trend was the opposite for lablab. The inorganic N control outyielded ($P = 0.053$) the natural fallow, and cattle manure tended ($P = 0.180$) to yield higher than the natural fallow.

Maize grain yield from the natural weed fallow in our study at NARC-Kitale, Kenya (Chapter 4) was higher than those reported from farmers' fields (Chapter 5). This is not unexpected because similar yields (average of 2 yr of 4.4 t ha^{-1}) have been reported from the highlands of eastern Africa when no external inputs were applied (Cheminingwa and Nyabundi, 1994). This could be attributed to the higher fertility in the experiment station and the N contribution from the natural weed biomass (Nguimbo and Balasubramanian, 1992; Carsky et al., 1999; Muhr et al., 1999c). The modest trend toward greater maize yield following incorporation of lablab residue compared to mucuna concurs with the results of Wortmann et al. (2000) and is in agreement with our observation of a trend toward enhanced N uptake following lablab residue, which was of lower quality (lower N and higher lignin concentration) than mucuna.

The high N-uptake by maize under the D-M treatment was reflected in the N recovery and maize grain yield obtained from this treatment compared. Our hypothesis was that utilization of the high quality upper canopy of green manure legumes as livestock feed

and soil incorporating the remaining intermediate quality stubble and root will enhance synchrony between N release and uptake by succeeding maize. The reduction of the percentage DM contribution of leaves in the D-M and the higher lignin concentration of mucuna roots and stems than leaves resulted in a reduction of biomass quality after defoliation. Thus the trend toward increased efficiency of N uptake and grain yield by maize under this treatment may be explained by this reduction in quality (Myers et al., 1994). This observation is in agreement with literature on the effect of residue quality on N release and uptake by the recipient crop. Residue of intermediate quality has been shown to increase the efficiency of N uptake compared to very high or low quality residues (Handayanto et al., 1997). Biomass of very high quality (high N and low lignin/polyphenol concentration) releases N faster than it can be taken up by the recipient crop while very low quality biomass (low N and high lignin/polyphenol concentration) releases N too slowly to meet the demand by the recipient crop (Myers et al., 1994).

Conclusions

Under the conditions of northwestern Kenya, undefoliated relay-cropped mucuna and lablab produced 2 t ha^{-1} of dry matter (Table 3-1), contributing 38 and 36 kg N ha^{-1}, respectively (Table 3-4). Green manure treatments resulted in average maize grain yield advantages of 0.85 and 1.75 t ha^{-1}, respectively, compared to the natural weed fallow (Table 3-9). Assuming that approximately 20% of the N from high quality residue is recovered by the first crop (Giller and Cadisch, 1995), the yield advantages are much higher than estimates of 500 kg ha^{-1} from similar biomass yields (Giller et al., 1997). There is also an added long-term advantage of reducing the soil organic matter decline (Kapkiyai et al., 1999). Given that maize and bean production are not sacrificed to grow mucuna and lablab biomass, planting the intercrop and defoliating part of the biomass as

livestock feed could be an attractive option for farmers. Therefore even though green manures grown as relay intercrops have lower N contribution potential than if grown as a sole crop, these systems are more likely to be adopted than sole-crop plantings because the green manure does not prohibit the main crop of beans and may also increase both livestock productivity and soil fertility over time.

Even a low maize grain response may be of interest to farmers who have limited access to commercial fertilizers. These farmers are more likely to adopt a legume plant that can produce some feed for their livestock or food for the household. Lablab may be preferred to mucuna because it can provide grain before it is incorporated or part of its biomass can be used as livestock feed. Based on our results of N uptake and maize and bean yield response, even after defoliation, it can be concluded that both mucuna and lablab could be included in the design and development of sustainable green manure intercropping systems in the sub-humid highlands of eastern Africa, including those in northwestern Kenya.

CHAPTER 4
PRODUCTIVITY OF MAIZE-BEAN INTERCROP RELAY CROPPED WITH MUCUNA AND LABLAB GREEN MANURES

Introduction

Declining soil fertility as a result of nutrient depletion is a major constraint to crop production in many areas of the tropics, and in Africa it is recognized as the fundamental biophysical cause of declining per capita food production (Sanchez et al., 1996). Most agricultural production in western Kenya is from smallholder farmers who practice mixed crop-livestock farming where maize (*Zea mays* L.) and dairy are the major enterprises. On average, these farmers cultivate less than 2 ha, and 74% of them do not use any inorganic fertilizer. Those who use fertilizer, apply it at rates far below those recommended for optimum crop production (Muriuki, 1998). Participatory rural appraisals (PRAs) carried out in the NARC-Kitale regional research mandate area indicated that crop yields and livestock productivity were low. This was attributed mainly to continuous cultivation of crops or grazing of livestock without the addition of adequate external nutrient inputs, leading to soil nutrient depletion (Smaling et al., 1997). The use of legumes could play an important role in improving productivity and sustainability of these smallholder production systems.

Increased interest in the management of nutrients and organic matter in relation to sustainability of agricultural systems has resulted in consistent research effort on the use of green manures. Herbaceous legume cover crops can provide an alternative to the use of inorganic fertilizers for crops (Tian et al., 2000) and use of commercial feed

supplements for livestock. Legume residues provide organic matter to the soil (Hulugalle et al., 1996; Tian et al., 1999), nutrients, especially N (Carsky et al., 1999; Ibewiro et al,. 2000; Tian et al., 2000), and improvement in soil physical properties (Lal et al., 1995; Tian et al., 1999). Adoption of legume green manures on smallholder farms however, depends not only on their contribution to soil fertility improvement, but also their potential for other uses such as weed suppression, human food, and feed for livestock (Becker et al., 1995; Versteeg et al., 1998a). The mulch layer formed by legume residues suppresses weed growth (Weber, 1996; Akobundu et al., 2000), controls pests and diseases (Weber, 1996), and reduces labor required for the subsequent season's crop (Akobundu et al., 2000). A number of legumes such as mucuna [*Mucuna pruriens* (L.) DC. var. *Utilis* (Wright) Bruck], lablab [*Lablab purpureus* (L.) Sweet cv. Rongai], tropical kudzu (*Pueraria phaseoloides*), and centro (*Centrosema pubescens*) have shown promise in the tropics (Ibewiro et al., 2000a; Tian et al., 2000; Wortmann et al., 2000). Annual dry matter yields of these legumes range from 2 to 8 t ha^{-1} and N accumulation from 30 to 300 kg ha^{-1} (Hairiah and Van Noordwijk, 1989; Ibewiro et al., 2000a; Tian et al., 2000). Despite the availability of data on the yield and contribution of above-ground legume biomass to succeeding cereal crops, information is still limited on the contribution of roots and stubble biomass when part of the residue is harvested for fodder.

Since 1995, the concept of green manure/cover crops has been introduced to northwestern Kenya by the KARI/RF on-farm project whose broad objective was to develop organic manure-based, low cost technologies for improved soil management on smallholder farms. Screening work conducted for 3 yr indicated that mucuna and lablab

were the most promising green manure legumes that could be relay cropped into the maize-bean cropping system. The current study was part of an effort to integrate process research with participatory on-farm research to alleviate the nutrient depletion problem on smallholder farms. The objectives were to: 1) quantify the effects of relay-cropped legumes on yield of a subsequent maize-bean intercrop when part of the legume residue was harvested for fodder or all of it remained on site and was soil incorporated before maize planting, and 2) to determine the effect of number of years of residue use on soil fertility as measured through a subsequent test maize-bean intercrop.

Materials and Methods

Experimental Site

The research was conducted from 1999 to 2001 at the National Agricultural Research Center (NARC) at Kitale in northwestern Kenya (1^0 01'N and 35^0 00'E; 1860 m). The center is in agro-ecological zone Upper Midlands 4, as described by Jaetzold and Schmidt (1983). The experimental site was a field that has been under continuous cultivation of maize for at least the last 10 yr. The soils are classified as humic Ferrolsols based on FAO/UNESCO system (FAO - UNESC, 1994) equivalent to Kandiudalfic Eutaudox in the USDA soil Taxonomy system (Soil Survey Staff, 1994). These are deep, highly weathered and well-drained, clay loam soils that are dark red to dark reddish brown in color with low activity clay and moderately acid topsoil (Jaetzold and Schmidt, 1983). Both N and P are limiting for crop growth (Smaling et al., 1997). The top soil (0-20 cm) had the following properties; pH (1:2.5 H_2O), 5.4; organic C, 14.2 g kg^{-1}; total N, 1.3 g kg^{-1}; extractable P (modified Olsen), 9.7 mg kg^{-1}; and is clay loam with 39% clay, 41% sand, and 20% silt. Rainfall is distributed in one growing season with an annual total (30-yr average) of 1143 mm. The growing season is from mid-March to mid-November.

The rainfall is relatively evenly distributed during April through November with peaks in May and August. The dry season is from December to March.

Experimental Treatments and Layout

There were 15 treatments, including three controls, replicated three times in a randomized complete block design. Twelve treatments originated from a 2 x 3 x 2 factorial that included two legume cropping systems, three crop sequences (number of years of residue application), and two legume defoliation treatments (Table 4-1). The two legume cropping systems were 1) maize + bean (both planted in April) + mucuna (planted in August), and 2) maize + bean (both planted in April) + lablab (planted in August). The three crop sequences were defined based on whether the legume was planted in the first year only, in the second year only, or in both the first and second years. Plots planted to mucuna or lablab only in the first year (August 1999) were planted to the maize-common bean intercrop in Year 2 (2000). Plots planted to mucuna or lablab in Year 2 (August 2000) only were planted to maize-common bean intercrop in Year 1 (1999). The two legume defoliation treatments were 1) herbage above 10 cm removed at season end, and 2) undefoliated. The three control treatments were 1) inorganic N fertilizer (30 kg N ha^{-1}), 2) no N fertilization, and 3) 5 t ha^{-1} cattle manure (supplying approximately 65 kg N and 18 kg P ha^{-1}). No inorganic N was applied to any plots other than the inorganic control. At maize planting, 13 kg P ha^{-1} was applied in the same hill as for maize to all plots, except the cattle manure treatment. In the third year of the experiment, all plots were planted to a maize-bean intercrop.

Experimental plots were 4.5 by 6 m with a 1-m border on all sides. The experiment was planted at the beginning of the rainy season in April 1999. The maize was planted at an inter- and intra-row spacing of 75 by 30 cm, respectively, using two seeds per hill of

hybrid 614D maize. The maize seedlings were thinned to one plant per hill 4 wk after planting (WAP) to give a plant population of 44,440 plants ha^{-1}. An improved bean cultivar (GLP2; Rose coco), commonly planted by farmers in the region, was used. The first crop of common bean was planted simultaneously with maize at onset of rains in April. The second crop of beans or green legume manures was relay cropped in maize in August, 135 d after the April planting. Before planting the second bean crop or the legume intercrop (after harvesting the first crop of beans), the maize was weeded and all leaves below the ear were removed to minimize shading. The common bean, mucuna, and lablab were planted between the maize rows at an intra-row spacing of 30 cm using three seeds per hill, which were thinned to two plants per hill 4 WAP. All the plots were hand weeded twice before harvesting the first crop of beans. The plots were manually weeded once after the August planting of legumes. Stalk borer (*Chilo* spp.), a common pest of maize, was controlled by application of Beta-cyfluthrin (Bulldock), a synthetic pyrethroid insecticide in granular form into the whorl of each plant, at the rate of 7 kg ha^{-1} at 4 wk and 8 wk after germination.

Herbage Yield and Chemical Composition

After harvesting maize, maize stover was removed in accordance with farmer practice, and mucuna and lablab were left to continue growing. For plots that were defoliated, the legumes were cut to a stubble of 10 cm in March before land preparation. The production of legume residue biomass was assessed in terms of litter fall, above-ground biomass (leaf and stem), and root mass from two 0.5-m^2 quadrats per plot at 30 WAP (mid-March). To measure root mass, soil from the 0.5-m^2 areas was removed to a depth of 20 cm. All visible roots were separated from the soil, washed with water on top of a 0.5-mm sieve to remove remaining soil, and rinsed with distilled water. The samples of

shoots and roots were oven dried at 60^0C for 48 h, weighed, and ground for determination of N concentration. Nitrogen concentration of the plant samples was determined using the Kjeldahl digestion with concentrated sulphuric acid followed by colorimetric determination of N (Anderson and Ingram, 1993). Nitrogen accumulated in the harvested biomass and litter fall was calculated by multiplying biomass N concentration and quantity.

Grain and Stover/Straw Dry Matter Yield of Maize and Beans

The first crop of common bean each year was harvested at the end of July and the second crop of common bean and the maize were harvested in mid-November. Maize and bean were harvested from the two center rows of every plot. The first and last two hills of each row were not harvested. The size of the sampling unit was 1.5 by 5.4-m (8.1 m^2). Maize cobs were separated manually from the stover and threshed to separate grain. Maize grain yield at 13.5% moisture concentration and stover DM yield were recorded. Common bean grain and straw DM yields were also measured from the same sampling unit.

Statistical Analyses

To assess the effect of legume cropping system, defoliation regime, and cropping sequence (number of years of residue application), and their interactions on biomass yield, chemical composition, and nutrient accumulation, the above and below-ground legume fraction data were analyzed using the general linear model (GLM) procedure of SAS (SAS, 2001). The maize and bean data were also analyzed using the same procedure. Single degree of freedom contrasts were used to compare controls with green manure treatments. Treatments were considered different at $P < 0.10$.

Table 4-1. Outline of treatment arrangement showing crop combinations, cropping system sequences, and legume defoliation regime.

1999		2000		2001
Cropping System[†]	Legume Defoliation[‡]	Cropping System	Legume Defoliation	
Z/B/M	No	Z/B/M	No	Z/B
Z/B/M	Yes	Z/B/M	Yes	Z/B
Z/B/B	-	Z/B/M	No	Z/B
Z/B/B	-	Z/B/M	Yes	Z/B
Z/B/M	No	Z/B/B	-	Z/B
Z/B/M	Yes	Z/B/B	-	Z/B
Z/B/L	No	Z/B/L	No	Z/B
Z/B/L	Yes	Z/B/L	Yes	Z/B
Z/B/B	-	Z/B/L	No	Z/B
Z/B/B	-	Z/B/L	Yes	Z/B
Z/B/L	No	Z/B/B	-	Z/B
Z/B/L	Yes	Z/B/B	-	Z/B
Z/B/B (IN)[§]	-	Z/B/B (IN)	-	Z/B
Z/B/B (No IN)[§]	-	Z/B/B (No IN)	-	Z/B
Z/B/B (CM)[§]	-	Z/B/B (CM)	-	Z/B

[†] Crops are represented as Z = maize, B = common bean, M = mucuna, and L = lablab
[‡] Defoliation regime indicated as no = no defoliation occurring and yes = mucuna or lablab herbage above 10 cm removed at season end as fodder, and a dash (-) indicates absence of forage legume
[§] Control treatments abbreviated as maize and beans IN = Inorganic N fertilized, No IN = No inorganic N applied, and CM = cattle manure applied

Results and Discussion

The results and discussion are organized to address three research questions: 1) was there an effect of one year of residue application?, 2) was there a lesser effect of 1 yr versus 2 yr of residue application?, and 3) were there long-term residual effects of residue application? In evaluating the effect of one year of residue application, legume, common bean, and maize data were used from plots where legume residue was incorporated in the first year only (March 2000) or in the second year only (March 2001). The comparison of 1 yr versus two consecutive years of residue application was made using 2001 maize and bean data from plots where legume residue was incorporated only in the second year (March 2001) and plots where legume residue was incorporated in both years (March 2000 and 2001). The long-term residual effects of residue application on common bean and maize yields were evaluated using 2001 maize and bean data from plots where legume residue was incorporated in March 2000, but not 2001.

Effect of One Year of Residue Application

Legume Biomass Yield

Years of legume biomass data are those when the residue was incorporated (e.g. 2000 data are for legume planted in August 1999 and incorporated in March 2000). There was a significant interaction ($P = 0.005$) between legume and year for legume leaf, litter, and total residue (Table 4-2). Thus data were analyzed and presented by year. During the 2000 season, there was a trend ($P = 0.157$) toward greater legume leaf mass for mucuna, but in the second year mucuna did produce higher ($P < 0.001$) leaf mass than lablab. Defoliation resulted in leaf mass reduction ($P < 0.001$) in both seasons.

Type of legume had no effect ($P = 0.598$), but defoliation reduced ($P < 0.001$) stem mass. Stem biomass was higher ($P = 0.008$) during the 2001 season than 2000.

Interaction of legume and year for litter biomass occurred because the legume effect approached significance (P = 0.108) during the 2000 season, but mucuna produced higher (P = 0.013) litter mass than lablab during the 2001 season. Defoliation had no effect (P = 0.858) on litter mass. Neither legume, defoliation, nor their interaction had an effect on root mass, however, root mass during the 2001 season was greater (P = 0.024) than during 2000.

The legume by year interaction for total residue biomass was significant (P = 0.004). There was no difference (P = 0.944) between mucuna and lablab in residue mass during the 2000 season, but mucuna produced greater (P = 0.001) residue mass during 2001. Defoliation reduced (P < 0.001) total residue mass of both legumes in both seasons.

Nitrogen Concentration

Both the legume by defoliation and legume by year interactions for leaf N concentration were significant (P = 0.028, P = 0.031, respectively) (Table 4-3). Defoliation of lablab reduced (P = 0.066) leaf N concentration, but it had no effect (P = 0.821) on mucuna. During the 2001 season, lablab tended (P = 0.106) to contain higher leaf N concentration than mucuna, but there was no difference (P = 0.274) between the legumes during the 2000 season.

The interaction of legume by defoliation for stem N concentration was significant (P = 0.005). Defoliation of lablab reduced (P = 0.001) stem N concentration, but it did not affect (P = 0.718) mucuna. Both UD-M and D-M stems contained higher (P = 0.061, P < 0.001, respectively) N concentration than UDL and DL, respectively. Stem N concentration was higher (P = 0.058) during the 2001 season than the 2000 season. Lablab litter fraction contained higher (P = 0.004) N concentration than mucuna.

Table 4-2. Effects of legume and defoliation on residue biomass of mucuna and lablab relay cropped in maize for 1 yr.

	Leaf	Stem	Litter	Roots	Total Legume Residue
Treatments	---------- t ha^{-1} ----------				
2000 season					
UD-M[†]	1.07	0.75	0.12	0.11	2.05
D-M	0.22	0.27	0.13	0.07	0.69
UD-L	0.78	0.91	0.17	0.15	2.00
D-L	0.03	0.31	0.19	0.17	0.70
2001 season					
UD-M	1.69	1.52	1.53	0.27	5.01
D-M	0.73	0.88	1.33	0.27	3.21
UD-L	0.76	1.74	0.17	0.31	2.89
D-L	0.13	0.68	0.18	0.25	1.15
Effects	---------- P values ----------				
Legume (L)	< 0.001	0.598	0.030	0.257	0.003
Defoliation regime (D)	< 0.001	< 0.001	0.858	0.528	< 0.001
L x D	0.194	0.209	0.804	0.916	0.928
Year (Y)	0.034	0.008	0.021	0.024	0.003
L x Y	0.005	0.666	0.020	0.404	0.004
D x Y	0.966	0.149	0.810	0.751	0.467
L x D x Y	0.485	0.474	0.828	0.404	0.999
SE	0.11	0.11	0.15	0.02	0.31

[†] UD-M = Undefolated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab

Table 4-3. Residue N concentration of mucuna and lablab relay cropped in maize.

	Leaf	Stem	Litter	Roots	Total Legume Residue
Treatments	---------- g kg^{-1} ----------				
2000 season					
UD-M[†]	22.1	14.5	12.1	13.4	18.9
D-M	25.1	16.2	13.2	13.3	18.2
UD-L	24.6	13.8	13.7	11.6	17.5
D-L	16.7	10.2	15.4	11.3	12.3
2001 season					
UD-M	36.8	18.9	8.0	17.5	21.8
D-M	35.7	17.4	8.1	18.4	18.9
UD-L	43.2	15.0	13.0	13.7	21.5
D-L	39.1	11.0	15.4	12.4	15.3
Effects	---------- P values ----------				
Legume (L)	0.624	< 0.001	0.004	< 0.001	0.104
Defoliation regime (D)	0.082	0.006	0.215	0.682	0.031
L x D	0.028	0.005	0.463	0.256	0.213
Year (Y)	0.020	0.058	0.197	0.095	0.205
L x Y	0.031	0.114	0.087	0.010	0.551
D x Y	0.754	0.143	0.947	0.961	0.581
L x D x Y	0.299	0.218	0.681	0.373	0.910
SE	2.10	0.66	0.74	0.57	0.87

[†] UD-M = Undefolated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab

The interaction of legume by year for root N concentration was significant (P = 0.010) because mucuna N was affected by year to a greater extent than lablab. Mucuna root N concentration was greater (P < 0.10) than lablab during both years. The N concentration of total residue tended to be greater for mucuna than lablab (P = 0.104) and defoliation reduced (P = 0.031) N concentration of total residue. In summary, mucuna stem and root biomass generally had greater N concentrations than for lablab, while the reverse was true for litter. Trends toward greater N concentration in mucuna vs. lablab total residue and for undefoliated vs. defoliated plots were mainly a result of greater leaf mass for mucuna and for undefoliated residue and the high N concentration of the leaf fraction.

Nitrogen Content

There was a significant interaction of legume by year (P = 0.003) and defoliation by year (P = 0.059) for N content in the leaf fraction (Table 4-4). Mucuna accumulated greater (P < 0.001) N in the leaf than lablab during the 2001 season, but only tended (P = 0.183) to have greater N during the 2000 season. Interaction of defoliation and year occurred because the magnitude of the defoliation effect was greater in 2001 than 2000.

Nitrogen content in the stem fraction was affected by both the interactions of legume by year (P = 0.059) and defoliation by year (P = 0.031). Nitrogen content in mucuna stem was higher (P = 0.060) than lablab during the 2001 season, but was not different (P = 0.665) during 2000. Defoliation reduced (P < 0.004) N content in the stem fraction in both years. The interaction of legume by year for N yield in the litter was significant (P = 0.014). Lablab accumulated more (P = 0.067) N in the litter during 2000 due to the higher N concentration in this fraction but mucuna accumulated more N in the litter during the 2001 season, probably due to higher litter biomass as a result of a later sampling date (2 wk later). Root N content was greater (P = 0.011) during the 2001

season than 2000, but it was not affected by treatment. The interaction between legume and year for total residue N yield was significant ($P = 0.001$). Nitrogen content of mucuna total residue was greater ($P < 0.001$) than lablab during the 2001 season, but there was no difference ($P = 0.553$) in 2000. Defoliation reduced ($P < 0.001$) the residue N content of both legumes in both seasons.

Bean Grain and Straw Yield

There was no year by treatment interaction, therefore the average bean and straw yields across the 2 yr are presented (Table 4-5). Bean grain yields were higher ($P = 0.015$) after mucuna than lablab, but legume defoliation had no effect ($P = 0.571$). The year effect was significant ($P = 0.014$) for bean grain yield. The mean bean grain yield under legume residue treatments during the 2000 growing season (583 kg ha^{-1}) was higher than for the 2001 season (437). The year effect was also significant ($P = 0.002$) for bean straw yield. The mean straw yield under legume residue treatments during the 2000 season (510 kg ha^{-1}) was higher than during the 2001 season (330). No differences ($P > 0.10$) were detected between grain and straw yields of residue treatments compared to the controls.

Maize Grain and Stover Yield

The year by treatment interactions were not significant for both maize grain and stover yield (Table 4-6), therefore means across the two seasons are presented. The effect of legume, defoliation, and their interaction on both grain and stover yields were not significant, but there was a year effect. The mean maize grain yields under residue treatments were higher during the 2000 (6.1 t ha^{-1}) than 2001 season (5.1), but the reverse

Table 4-4. Residue N content of mucuna and lablab relay cropped in maize.

	Leaf	Stem	Litter	Roots	Total Legume Residue
Treatments	---------- kg ha^{-1} ----------				
2000 season					
UD-M[†]	26.1	8.8	1.5	1.5	37.9
D-M	5.6	4.4	1.7	1.0	12.7
UD-L	19.0	12.4	2.3	1.8	35.5
D-L	0.5	3.2	2.9	1.8	8.4
2001 season					
UD-M	61.6	28.7	12.2	4.8	107.3
D-M	26.2	15.3	11.1	4.9	57.5
UD-L	31.1	25.2	1.5	4.3	62.0
D-L	5.9	7.4	2.2	3.1	18.7
Effects	---------- P values ----------				
Legume (L)	< 0.001	0.067	0.036	0.514	< 0.001
Defoliation regime (D)	< 0.001	0.001	0.959	0.457	< 0.001
L x D	0.173	0.402	0.760	0.710	0.415
Year (Y)	0.015	0.011	0.028	0.011	0.030
L x Y	0.003	0.059	0.014	0.096	0.001
D x Y	0.059	0.031	0.874	0.782	0.096
L x D x Y	0.584	0.919	0.839	0.348	0.307
SE	4.40	2.03	1.12	0.36	7.08

[†] UD-M = Undefolated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab

Table 4-5. Grain and straw yield of common bean intercropped in maize after one year of mucuna and lablab residue incorporation. Data are means across two seasons (2000 and 2001).

Treatments	Grain	Straw
	----------kg ha^{-1} ----------	
UD-M[†]	610	460
D-M	560	450
UD-L	440	400
D-L	430	380
Controls		
Inorganic N	605	470
Natural fallow	547	465
Cattle manure	658	472
Effects	---------- P values ----------	
Legume (L)	0.015	0.155
Defoliation regime (D)	0.571	0.738
L x D	0.755	0.885
Year (Y)	0.014	0.002
L x Y	0.901	0.978
D x Y	0.515	0.937
L x D x Y	0.752	0.714
SE	30.41	27.30

[†] UD-M = Undefoliated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab

Table 4-6. Grain and stover yield of maize after one year of mucuna and lablab residue application. Data are means across two seasons (2000 and 2001).

Treatments	Grain	Stover
	---------- t ha^{-1} ----------	
UD-M†	5.2	6.9
D-M	5.5	7.1
UD-L	6.5	7.5
D-L	5.2	6.3
Controls		
Inorganic N	7.5	9.4
Natural fallow	4.4	7.0
Cattle manure	6.6	9.2
Effects	---------- P values ----------	
Legume (L)	0.425	0.997
Defoliation regime (D)	0.499	0.208
L x D	0.201	0.486
Year (Y)	0.027	0.006
L x Y	0.568	0.783
D x Y	0.858	0.916
L x D x Y	0.376	0.901
SE	0.27	0.51

† UD-M = Undefolated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab

was true for stover yield. Single degree of freedom contrasts showed that UD-L yielded more (P = 0.088) maize grain than UD-M, and defoliation of lablab reduced (P = 0.084) grain yield relative to UD-L. Defoliation of mucuna had no effect (P = 0.571) on maize grain yield. Average maize grain yield of the legume residue treatments was greater (P = 0.076) than the natural fallow control, and these differences were greater (P = 0.048) for undefoliated treatments versus the control. Defoliated mucuna tended (P = 0.166) to yield higher maize grain than the natural fallow. Similarly, N fertilizer and cattle manure yielded higher (P < 0.01) maize grain than the natural fallow control. The yields of undefoliated legume treatments were not different but tended to be lower than (P = 0.161) those obtained using cattle manure.

Effect of One versus Two Years of Consecutive Residue Application

Legume Biomass Yield

The three-way interaction of legume by defoliation by cropping sequence was significant (P = 0.062) for leaf mass (Table 4.7). Undefoliated mucuna yielded higher leaf mass than lablab on one-year residue plots (P = 0.002) and tended to yield more (P = 0.105) on two-year residue plots. Defoliated mucuna yielded higher (P < 0.001) leaf mass than D-L in both sequences. Defoliation reduced (P < 0.01) leaf mass of both legumes in both one- and two-year residue plots.

The interaction of legume, defoliation regime, and cropping sequence on stem herbage yield was also significant (P = 0.018). Stem mass of UD-L was higher (P = 0.003) than UD-M on two-year residue plots but not (P = 0.551) on one-year residue plots (Table 4-7). Stem mass of D-M was higher (P = 0.012) than D-L on two-year residue plots and tended to be higher (P = 0.140) on one-year residue plots. Defoliation of mucuna reduced (P = 0.003) stem mass on one-year residue plots but not (P = 0.267) on two-year

residue plots, however, defoliation of lablab reduced stem mass in both one- ($P = 0.036$) and two- ($P < 0.001$) year residue plots. Thus, unlike leaf mass, which was consistently greater for mucuna, stem mass tended to favor lablab for undefoliated plots and mucuna for defoliated plots.

In agreement with the literature (Van Noordwijk and Purnomisidi, 1992) mucuna had greater amounts of litter biomass than lablab ($P < 0.001$; Table 4-7). Root herbage mass was not affected by treatments, but lablab root comprised higher percentage of total biomass (10%) than mucuna (5%), in agreement with Tian and Kang (1998).

The three-way interaction of legume by defoliation by cropping sequence for total residue mass was significant ($P = 0.081$). Undefoliated mucuna yielded higher ($P = 0.058$) total residue mass than UD-L on one-year plots and tended to yield more ($P = 0.103$) on two-year plots. Defoliated mucuna yielded higher residue mass than D-L on both one- ($P = 0.011$) and two- ($P < 0.001$) year residue plots. Defoliation of mucuna decreased ($P = 0.073$) residue mass on one-year residue plots, but it did not ($P = 0.918$) affect residue mass on two-year plots. Defoliation of lablab decreased residue mass on both one- ($P = 0.033$) and two- ($P = 0.004$) year plots.

Generally mucuna yielded more total residue biomass than lablab, and defoliation reduced residue mass, except for D-M on two-year residue plots which yielded as much as UD-M. The generally higher residue biomass for mucuna vs. lablab plots was due to the greater leaf and litter biomass for mucuna treatments. The greater amounts of mucuna biomass suggest that it was more adapted to growth under shading by maize and to the dry conditions following maize harvest than lablab. The biomass yields under the

Table 4-7. Effects of cropping sequence (1 yr versus 2 consecutive yr), legume, and defoliation on residue biomass of mucuna and lablab relay cropped in maize during the 2000/2001 season.

	Leaf	Stem	Litter	Roots	Total Legume Residue
Treatments	---------- t ha^{-1} ----------				
1st-Yr legume					
UD-M[†]	1.69	1.52	1.53	0.27	5.01
D-M	0.73	0.88	1.33	0.27	3.21
UD-L	0.76	1.74	0.20	0.30	2.89
D-L	0.13	0.68	0.21	0.25	1.15
2nd-Yr legume					
UD-M	1.41	1.17	1.99	0.24	4.81
D-M	0.78	1.41	2.23	0.32	4.74
UD-L	0.96	1.94	0.06	0.34	3.31
D-L	0.12	0.57	0.15	0.22	0.96
Effects	---------- P values ----------				
Legume (L)	< 0.001	0.919	< 0.001	0.898	< 0.001
Defoliation regime (D)	< 0.001	< 0.001	0.897	0.525	< 0.001
L x D	0.669	< 0.001	0.961	0.131	0.095
Cropping sequence (CS)	0.900	0.552	0.331	0.898	0.233
L x CS	0.128	0.850	0.197	0.898	0.388
D x CS	0.669	0.227	0.657	0.898	0.382
L x D x CS	0.062	0.018	0.763	0.335	0.081
SE	0.11	0.11	0.15	0.02	0.33

[†] UD-M = Undefolated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab

intercrop were in the lower end of the range of biomass reported by Wortmann et al. (2000) from the highlands of east Africa when mucuna and lablab were grown in rotation with maize. The higher proportion of stem in lablab, and the higher lignin concentration in its stem fraction (Chapters 3 and 7) suggests that lablab residue may be of lower quality than mucuna.

Legume N Concentration

Legume and defoliation regime effects on leaf N concentration were significant (Table 4-8). Undefoliated lablab contained higher ($P < 0.004$) leaf N concentration than UD-M. Defoliation reduced lablab leaf N concentration ($P < 0.085$), but it did not affect mucuna leaf N concentration ($P > 0.552$).

Stem N concentration was affected by both legume ($P < 0.001$) and the interaction of defoliation regime by cropping sequence ($P = 0.049$). Mucuna contained higher N concentration in the stem than lablab ($P < 0.001$). Defoliation by sequence interaction effects occurred because defoliation tended to reduce stem N concentration on one-year residue plots ($P = 0.118$), but there was no effect ($P = 0.870$) on two-year plots. Mucuna litter contained lower ($P < 0.003$) N concentration than lablab, likely due to the greater initial N concentration in lablab leaf. The lower N concentration in the litter fraction than in the leaf may have been due to nutrient resorption during senescence when leaf proteins and other nitrogenous compounds are hydrolyzed and the products are transported into perennial tissue before leaf fall (Norby and Contrufo, 1998). Nitrogen concentration in mucuna roots was higher ($P < 0.001$) than in lablab concurring with Tian and Kang (1998). The N concentration in the total legume residue was not affected by legume ($P = 0.823$) and cropping sequence ($P = 0.235$), but defoliation reduced ($P = 0.008$) N concentration in the residue.

Legume N Content

The three-way interaction of legume by defoliation by cropping sequence for leaf N content was significant (P = 0.045) (Table 4-9). By virtue of greater leaf mass, undefoliated mucuna had greater (P = 0.003) N content in the leaf fraction than UD-L on one-year plots, but there was no difference (P = 0.628) on two-year plots. Defoliated mucuna had greater (P = 0.03) leaf N content than D-L on both one- and two-year plots. Defoliation reduced (P = 0.042) leaf N content of both legumes on both one- and two-year plots. The N content of the leaf fraction of D-M was on average 48% as great as that from UD-M, but the contribution from D-L was only 4% that of UD-L. Thus the impact of removing top canopy herbage for fodder on amount of residue N incorporated is much greater for lablab than mucuna.

The interaction of legume by defoliation by cropping sequence for stem N content was significant (P = 0.027). There was no difference (P > 0.127) in stem N content between UD-M and UD-L, but D-M had greater (P < 0.009) stem N content than D-L on both one- and two-year plots. Defoliation of mucuna decreased (P = 0.004) stem N content on one-year plots, but it did not affect (P = 0.349) stem N content on two-year plots. Defoliation of lablab decreased (P < 0.055) stem N content on both one- and two-year plots. Mucuna accumulated more N in the litter than lablab (P = 0.001), but defoliation did not affect (P = 0.906) N content in the litter fraction.

The three-way interaction of legume by defoliation by cropping sequence for total residue N content was significant (P = 0.054). Undefoliated mucuna had higher (P = 0.033) N content in total legume residue than UD-L in one-year plots, but there were no differences (P = 0.317) on two-year plots. Defoliated mucuna had greater N content than

Table 4-8. Effects of cropping sequence (1 yr versus 2 consecutive yr), legume, and defoliation on residue N concentration of mucuna and lablab relay cropped in maize.

	Leaf	Stem	Litter	Roots	Total Legume Residue
Treatments	---------- g kg^{-1} ----------				
1st-Yr legume					
UD-M[†]	36.8	18.9	8.0	17.5	21.8
D-M	35.7	17.4	8.1	18.4	18.9
UD-L	43.2	15.0	13.0	13.7	22.6
D-L	39.1	11.0	15.4	12.4	15.4
2nd-Yr legume					
UD-M	34.8	17.7	8.0	16.7	19.1
D-M	33.7	17.3	7.8	15.6	15.4
UD-L	45.4	13.0	15.1	13.2	22.3
D-L	36.9	12.8	12.6	11.2	13.4
Effects	---------- P values ----------				
Legume (L)	0.003	< 0.001	0.003	< 0.001	0.823
Defoliation regime (D)	0.036	0.018	0.964	0.104	0.008
L x D	0.114	0.328	0.990	0.146	0.203
Cropping sequence (CS)	0.520	0.586	0.904	0.021	0.235
L x CS	0.560	0.618	0.983	0.304	0.335
D x CS	0.577	0.049	0.399	0.191	0.717
L x D x CS	0.557	0.263	0.441	0.578	0.894
SE	1.10	0.63	0.74	0.54	0.93

[†] UD-M = Undefolated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab

Table 4-9. Effects of cropping sequence (1 yr versus 2 consecutive yr), legume, and defoliation on residue N content of mucuna and lablab relay cropped in maize.

	Leaf	Stem	Litter	Roots	Total Legume Residue
Treatments	---------- kg ha^{-1} ----------				
1st-Yr legume					
UD-M[†]	61.6	28.7	12.2	4.8	107.3
D-M	26.2	15.3	11.1	5.0	57.5
UD-L	31.1	25.2	1.5	4.3	62.0
D-L	5.9	7.4	2.2	3.1	18.7
2nd-Yr legume					
UD-M	49.2	20.7	16.2	3.9	89.9
D-M	26.2	24.4	17.4	5.0	73.0
UD-L	43.8	25.4	0.6	4.6	74.5
D-L	4.4	7.3	1.1	2.5	15.3
Effects	---------- P values ----------				
Legume (L)	< 0.001	0.005	0.001	0.086	< 0.001
Defoliation regime (D)	< 0.001	< 0.001	0.906	0.403	< 0.001
L x D	0.318	0.004	0.919	0.070	0.119
Cropping sequence (CS)	0.763	0.806	0.475	0.630	0.806
L x CS	0.109	0.961	0.290	0.867	0.696
D x CS	0.846	0.044	0.852	0.994	0.583
L x D x CS	0.045	0.027	0.826	0.404	0.054
SE	4.37	1.82	1.12	0.29	6.93

[†] UD-M = Undefolated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab

D-L on both one- (P = 0.023) and two- (P = 0.002) year plots. Defoliation of mucuna decreased residue N content relative to UD-M on one- (P = 0.005) and two- (P = 0.083) year plots. Defoliation of lablab also reduced residue N content compared to UD-L on one- (P = 0.094) and two- (P = 0.028) year plots. In agreement with previous reports (Tian et al., 2000), mucuna generally accumulated more N in the total biomass than lablab.

Bean Grain and Straw Yield

Mucuna treatments resulted in higher (P= 0.004) subsequent bean grain yield than lablab (Table 4-10), but defoliation regime had no effect (P = 0.435) on bean grain yield. Mean bean grain yield on plots after 1 yr of residue application (437 kg ha^{-1}) was not different (P > 0.830) from those where the residue had been applied for 2 yr (446), suggesting that there was no apparent advantage of 2 yr versus 1 yr of residue application. Single degree of freedom comparisons showed that mucuna treatments tended (P = 0.158) to yield higher bean grain yield than the natural fallow, and the yields under mucuna treatments were similar to those from inorganic N (P = 0.847) and cattle manure (P = 0.720). Legume species affected (P = 0.069) bean straw DM yield (Table 4-10), with mucuna plots outyielding lablab plots. Defoliation did not affect (P = 0.892) straw DM yield and neither did residue application for 2 yr years versus 1 yr (P = 0.764).

The yields of bean grain and straw yield show that mucuna residue application resulted in higher yields than lablab. The D-M treatment performed particularly well after 2 yr of incorporation suggesting that it may have more residual effects than the other treatments. Overall, there was no apparent advantage to applying residue for two consecutive years compared to one year.

Table 4-10. Effects of cropping sequence (1 yr versus 2 consecutive yr), legume, and defoliation of mucuna and lablab grain and straw yield of common bean intercropped in succeeding maize.

Treatments	Grain	Straw
	----------kg ha^{-1} ----------	
After 1 year residue		
UD-M[†]	527	379
D-M	499	357
UD-L	342	299
D-L	380	297
After 2 years residue		
UD-M	428	318
D-M	589	397
UD-L	403	359
D-L	362	290
Controls		
N fertilizer	493	338
Natural fallow	379	310
Cattle manure	544	328
Effects	---------- P values ----------	
Legume (L)	0.004	0.069
Defoliation regime (D)	0.435	0.892
L x D	0.408	0.247
Cropping sequence (CS)	0.830	0.764
L x CS	0.752	0.495
D x CS	0.501	0.757
L x D x CS	0.116	0.132
SE	25.74	13.91

[†] UD-M = Undefoliated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab

Bean yield in this study was affected by both low fertility and root rot disease caused by a complex of fungal pathogens (*Fusarium solani*, *Rhizoctonia solani*, and *Pythium spp.*), which have been observed to be severe in western Kenya where bean production is intensive (Otsyula et al., 1998). The beans yields were higher, however than those reported from the highlands of east Africa (Wortmann et al., 2000) when maize-bean intercrops were preceded by mucuna and lablab green manures.

Maize Grain and Stover Yield

There was interaction of legume, defoliation, and cropping sequence for maize grain yield ($P < 0.002$) (Table 4-11). After 1 yr of residue application, there were no differences ($P > 0.553$) between mucuna and lablab on maize grain yield. When the legume residue was applied for two consecutive years, D-M resulted in higher ($P = 0.028$) maize grain yield than D-L, but UD-L attained higher ($P < 0.006$) grain yield than UD-M, suggesting that residual effects may be greatest with D-M and UD-L.

Defoliation of both mucuna and lablab tended ($P > 0.123$) to decrease maize grain yield after 1 yr of residue application, but after 2 yr of residue application, defoliation of mucuna increased ($P = 0.053$) the grain yield compared to UD-M, but D-L resulted in a reduction ($P < 0.001$) in maize grain yield compared to UD-L. For maize grain yield, there tended to an advantage of applying the residue for 2 compared to 1 yr for D-M ($P = 0.134$), and UD-L ($P = 0.059$) but not for UD-M and D-L. The average maize grain yield for the legume treatments after the second year vs the first year of legume was 5.3 vs 5.1 t ha^{-1}, which does not suggest much overall advantage.

Single degree of freedom comparisons showed that the average legume treatment after 2 yr of incorporation (5.3 t ha^{-1}) yielded higher ($P < 0.055$) maize grain yield than the

natural fallow control (4.1 t ha^{-1}). The differences were greater ($P < 0.026$) when only the undefoliated treatments were compared to the natural fallow. Defoliated mucuna and UD-L outyielded ($P = 0.033$, and $P = 0.005$, respectively) the natural fallow, but UD-M and D-L did not. Also the inorganic N and cattle manure treatments outyielded ($P < 0.001$, and $P = 0.002$, respectively) the natural fallow. The yields from UD-L plots were similar ($P = 0.444$) to those from cattle manure, but both UD-L and D-M, which yielded the highest maize grain yields among the legume residue treatments, achieved lower ($P = 0.048$, and $P = 0.007$, respectively) yields compared to inorganic N.

The interaction of legume type, defoliation regime and years of residue application on maize stover yield was also significant ($P = 0.035$) (Table 4-11). After 2 yr of residue application, D-M resulted in higher ($P < 0.001$) maize stover yield than D-L, and there was trend ($P = 0.131$) for UD-L to outyield UD-M. Also after 2 yr of residue application, D-L reduced ($P = 0.017$) stover yield compared to UD-L, whereas D-M increased ($P =0.095$) stover DM yield relative to UD-M. There was no apparent advantage of applying residue for two consecutive years on maize stover yield, except for UD-L which achieved higher ($P = 0.032$) stover yield than after 1 yr of residue application. Relative to the controls, D-M and UD-L after 2 yr of residue application and the inorganic N and cattle manure control treatments yielded the highest stover yield, but only the inorganic N attained higher ($P < 0.039$) yields than the natural fallow.

Table 4-11. Effects of cropping sequence (1 yr versus 2 consecutive yr), legume, and defoliation of mucuna and lablab on grain and stover yield of succeeding maize.

Treatments	Grain	Stover
	---------- t ha^{-1} ----------	
After 1 year residue		
UD-M[†]	5.18	8.04
D-M	4.81	8.93
UD-L	5.59	8.29
D-L	4.69	8.23
After 2 years residue		
UD-M	4.46	8.15
D-M	6.08	11.33
UD-L	6.72	11.05
D-L	3.98	7.12
Controls		
N fertilizer	7.18	11.63
Natural fallow	4.11	9.34
Cattle manure	6.48	9.85
Effects	---------- P values ----------	
Legume (L)	0.756	0.616
Defoliation regime (D)	0.030	0.396
L x D	< 0.001	0.012
Cropping sequence (CS)	0.500	0.202
L x CS	0.740	0.403
D x CS	0.976	0.771
L x D x CS	0.002	0.035
SE	0.21	0.48

[†] UD-M = Undefolated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab

Maize grain yields were highest for D-M and UD-L among the residue treatments after 2 yr of residue application. These higher yields may possibly be attributable to the lower quality of these residues. Defoliation of mucuna reduced the proportion of leaves, which have the highest N concentration, whereas lablab residue was comprised of a higher proportion of stem which has low N and high lignin.

Long-Term Residual Effects of Residue Application

Bean Grain and Straw Yield

The residual effect of mucuna and lablab residue applied during 2000 growing season on 2001 bean grain and straw yields are reported in Table 4-12. The interaction of legume and defoliation approached significance ($P = 0.120$) because defoliation had no effect ($P = 0.966$) on mucuna plots but tended to affect ($P = 0.107$) lablab plots.

Single degree of freedom contrasts showed that the yields under UD-M were comparable ($P = 0.254$) to D-M, but UD-L yielded higher ($P = 0.098$) bean grain yield than D-L. The bean yields from legume residue treatments were not different ($P > 0.10$) than those from the three controls.

Maize Grain and Stover Yield

The effect of legume and defoliation on maize grain and stover yield from plots where the legume residue was applied the previous season were not significant (Table 13). Single degree contrasts showed that yields were higher under D-M ($P = 0.052$), UDL ($P = 0.085$), and D-L ($P = 0.005$) plots than the natural fallow, but yields under UD-M only tended ($P = 0.144$) to be higher. Also inorganic N and cattle manure treatment yields were higher ($P < 0.001$, and $P = 0.004$, respectively) than the natural fallow. The yields on D-L plot were comparable ($P = 0.450$) to the inorganic N, but D-M ($P = 0.024$), and UD-L ($P = 0.013$) plots were lower than in inorganic N plots. The yields of maize grain

suggest that D-M, UD-L, and D-L likely had higher residual effects, possibly because of the lower residue quality of these treatments (Chapter 3). These results suggest that farmers could intercrop legumes in alternating years and still realize some benefit from residue application in the year following no application, especially for residues having lower leaf:stem ratio, lower N concentration, and higher lignin concentration.

Conclusions

Legume residue incorporation increased maize grain and stover DM yield compared to the natural fallow in agreement with the literature (Akobundu et al., 2000; Ibewiro et al., 2000a; Ile et al., 1996; Tian et al., 2000). Two years of residue application resulted in a greater yield increases for D-M and UD-L treatments, suggesting that the residual effects of these treatments may be greater than those of UD-M. Previous studies (Myers et al., 1994; Handayanto et al., 1994; 1997; Mafongoya et al., 1997a; Vanlauwe et al., 1997) have shown that residues of very high quality (i.e., high N and low lignin) release nutrients quickly while those of intermediate quality release nutrients at a slower rate perhaps in better synchrony with crop demand.

Undefoliated lablab residue consisted of a higher proportion of stem than UD-M and the stem was of lower N (Table 4-3) and higher lignin concentrations (Chapter 3) than that of mucuna. Defoliation of mucuna reduced the proportion of leaves and increased the proportion of stems (Table 4-2) which contained lower N (Table 4-3) and higher lignin concentrations (Chapter 3). These differences suggest that residues of both

Table 4-12. Residual effects of mucuna and lablab residue application in March 2000 on grain and straw yield of common bean intercropped in succeeding maize in 2001.

Treatments	Grain	Straw
	----------kg ha^{-1} ----------	
UD-M[†]	437	376
D-M	433	310
UD-L	553	365
D-L	268	267
Controls		
N fertilizer	493	338
Natural fallow	379	310
Cattle manure	544	328
Effects	---------- P values ----------	
Legume (L)	0.766	0.593
Defoliation regime (D)	0.112	0.123
L x D	0.120	0.753
SE	22.7	12.1

[†] UD-M = Undefoliated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab

Table 4-13. Residual effects of mucuna and lablab residue application in March 2000 on grain and stover yield of succeeding maize in November 2001.

Treatments	Grain	Stover
	---------- t ha^{-1} ----------	
UD-M[†]	5.2	9.0
D-M	5.6	8.9
UD-L	5.5	9.1
D-L	6.6	9.5
Controls		
N fertilizer	7.2	11.6
Natural fallow	4.1	8.8
Cattle manure	6.5	9.9
Effects	---------- P values ----------	
Legume (L)	0.349	0.675
Defoliation regime (D)	0.229	0.824
L x D	0.541	0.738
SE	0.17	0.36

[†] UD-M = Undefolated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab

UD-L and D-M were of intermediate quality. The data on maize grain and stover yields suggest that UD-M may have released nutrients rapidly, thus some may have been lost before they were taken up by the long maturity maize hybrid, whereas UD-L and D-M could have released nutrients in greater synchrony with crop demand.

Thus defoliation of mucuna is thought to have increased the efficiency of N uptake (Chapter 3) and resulted in greater residual effects. Defoliation of lablab resulted in such a large biomass reduction that the beneficial effects of lowered quality could not be realized in the first year. However, D-L had the greatest second-year residual effect for maize grain yield. This may have occurred because after defoliating lablab, which has an upright growth habit, the stubble left behind is comprised of mainly the stem fraction, which contained low N and high lignin concentration (Nyambati et al., 2001). Thus this low quality residue resulted in slower decomposition and nutrient release (Handayanto et al., 1997; Vanlauwe et al., 1997; Palm et al., 2001), reducing losses and enhancing nutrient use efficiency and thus higher residual effects. Therefore our data tend to support the hypothesis that residues of intermediate quality enhance the residual effects particularly in high rainfall areas that are prone to more nutrient losses such as the highlands of northwestern Kenya.

Considering these results together with those of the on-farm (Chapter 5) and mineral N study (Chapter 3) we conclude that inclusion of green manure legumes as relay intercrop into the current maize-bean system increased subsequent maize yields. At the research station (this chapter) where the legume residue biomasses were higher, the responses were greater for both legumes than on-farm (Chapter 5). On farmers' fields, where the soil fertility is much lower, mucuna was better adapted than lablab, resulting in greater

responses to mucuna. Defoliation of mucuna reduced the residue quality and subsequently enhanced the efficiency of nutrient use and in some cases resulted in higher maize yields than undefoliated mucuna, whereas defoliation of lablab, which was of lower quality than mucuna, resulted in lesser maize yield response due to greater proportion of biomass removed (because of its upright growth habit). Residues of intermediate quality (UD-L, and D-M) resulted in higher maize yields after two consecutive years of residue application, and D-M along with D-L had the greatest residual effect following a year with no residue incorporated.

CHAPTER 5
ON-FARM PRODUCTIVITY OF RELAY-CROPPED MUCUNA AND LABLAB IN SMALLHOLDER CROP-LIVESTOCK SYSTEMS IN NORTHWESTERN KENYA

Introduction

Declining soil fertility is a major constraint to crop production in smallholder farming systems in many regions of the tropics. This is due to a number of factors including continuous cultivation, removal of crop residues, loss of nutrients through soil erosion, and overgrazing between cropping seasons (Lal, 1995; Swift et al., 1994a). These practices are often associated with decreasing farm size as a result of increasing population pressure. In northwestern Kenya, smallholder farmers practice mixed farming where livestock, particularly dairy production, and crop production are closely integrated. In these systems both low soil fertility and inadequate livestock feeds are the major constraints to production (Nyambati, 1997; Muyekho et al., 1998).

Negative nutrient balance, particularly N and P, on smallholder farms is a main factor causing food production to decline in sub-Saharan Africa despite an increasing trend in the rest of the world (Swift et al., 1994a). The potential to increase crop and livestock production in these systems is limited due to very minimal use of external nutrient sources in the form of inorganic fertilizers and feed supplements (FAO, 1995). It is estimated that the average inorganic fertilizer application in sub-Saharan Africa is less than 10 kg of fertilizer nutrients per hectare (FAO, 1995; Heisey and Mwangi, 1996; Larson and Frisvold, 1996). These levels are well below crop and soil maintenance

requirements and are likely to remain low because fertilizer is the most costly input used by smallholder farmers in Africa.

Under continuous cropping, appropriate crop rotations and the integrated use of inorganic fertilizers and organic residues can sustain crop productivity (Mitchell et al., 1991; Franzluebbers et al., 1998). Integrated nutrient management which seeks to maximize the complementary effects of inorganic fertilizers and organic nutrient sources is emerging as one of the options that hold much promise in increasing crop productivity on smallholder farms (Smaling et al., 1996; Palm et al., 1997; Franzluebbers et al., 1998). In a long-term experiment in the sub-humid highlands of eastern Africa, Kapkiyai et al. (1999) showed that improved organic residue management practices resulted in a slower rate of soil organic carbon decline and a higher particulate soil organic carbon. The soil organic matter changes were also strongly correlated with nutrient availability.

Green manure legumes, incorporated into the soil, have the potential to contribute N during decomposition (Tian et al., 2000), improve soil organic matter and soil physical properties (Hulugalle et al., 1996; Tian et al., 1999), suppress the growth of weeds (Versteeg et al., 1998a; Akobundu et al., 2000), and be a source of high quality feed (Agyemang et al., 2000; Adjorlolo et al., 2001; Chapter 3). The adoption of these legumes on smallholder farms has been very low (Thomas and Sumberg, 1995), however. The main challenge is how best to integrate herbaceous legumes into the existing farming systems.

The complementary effects of legumes on cropping have gained greater interest recently (ILCA, 1993) because of declining soil fertility. The integration of legumes into fallow periods (Muhr et al., 1999c) or as relay crops could improve their acceptability to

smallholder farmers who cannot afford to purchase external inputs such as commercial concentrates and inorganic fertilizers. Mucuna (*Mucuna pruriens*) and lablab (*Lablab purpureus*) are some of the most promising green manure legumes for cropping systems in sub-humid regions of sub-Saharan Africa (Weber, 1996; Ibewiro et al., 2000a; Tian et al., 2000), however, the use of these organic residues alone may not be sufficient to overcome both N and P deficiencies. The integration of small amounts of inorganic P and green manure legumes offers a strategy to meet both N and P requirements of crops (Jama et al., 1997; Palm et al., 1997).

Combining the use of inorganic and organic fertilizers has been shown to increase crop yield compared to use of similar N amounts from inorganic fertilizers (Murwira and Kirchmann, 1993). A better understanding of the performance of relay-cropped legumes and their effect on the subsequent cereal crop may help in adapting these legumes to cereal-based cropping systems. The current study evaluated the potential of relay cropping mucuna and lablab into the current maize-bean intercrops in comparison with the traditional natural fallow system on farmers' fields. The specific objectives were (i) to measure the agronomic effectiveness of relay-cropped mucuna and lablab residue combined with inorganic P compared to natural fallow, cattle manure, and inorganic fertilizer for subsequent maize-bean test crops, and (ii) to determine the effect of removing part of the biomass for livestock fodder on maize yield under low soil fertility on farmers' fields.

Materials and Methods

Experimental Site

A researcher-farmer managed on-farm trial was conducted at Tumaini village, 25 km north of Kitale on six farmer fields. Tumaini village is in agro-ecological zone classified as upper midland 4 with an average rainfall range of 1000 to 1200 mm (Jaetzold and Schmidt, 1983). The soils are classified as humic Ferralsols based on FAO classification (FAO-UNESCO, 1994) and are equivalent to Kandiudalfic Eustaudox in the USDA soil taxonomy system (Soil Survey Staff, 1994). These are deep, highly weathered and leached soils with low activity clay. Air-dry soil in the top 20 cm had the following characteristics; clay = 39%; sand = 41%; silt = 20%; pH (1:2.5 soil water suspension) = 5.3; exchangeable acidity = 1.4 $cmol_c\ kg^{-1}$; exchangeable Ca = 3.1 $cmol_c\ kg^{-1}$; exchangeable Mg =1.2 $cmol_c\ kg^{-1}$; exchangeable K = 0.18 $cmol_c\ kg^{-1}$; extractable P = 5.0 mg P kg^{-1}; soil organic carbon = 19 g kg^{-1}; total soil nitrogen = 1.43 g kg^{-1}; and total soil P = 0.46 g kg^{-1}. The farms were chosen because their production constraints are representative of most smallholder farms in the sub-humid highlands of northwestern Kenya. These constraints are low soil fertility and inadequacy of feeds, particularly during the dry season (Nyambati, 1997; Muyekho et al., 1998). These constraints were identified using participatory rural appraisal (PRA) methods (Chambers, 1997). Participating farmers were selected by a farmer research group, which was formed in 1997 to undertake a farmer participatory evaluation of crop/animal husbandry activities.

Pre-experimental Activities

A PRA approach was used to diagnose the production constraints, describe the farming system, and evaluate the results at the end of the experiment. The participatory research was initiated in 1997, when researchers from NARC-Kitale and local frontline

extension staff conducted a preliminary characterization and diagnosis of the farming system using PRA (Muyekho et al., 1998). This was followed by researcher-farmer managed trials focusing on animal health and inadequacy of dry season feeds. Production constraints related to soil fertility were not addressed due to the narrow focus of the initial project. The present study was a follow-up effort to address these constraints. A list of farms with severely low soil fertility were identified by a farmer research committee together with local key informants including the local extension staff. A research group comprising a multidisplinary team of researchers and extension personnel visited the farms to ascertain the fertility status and suitability of the farms to participate in the researcher-farmer managed, on-farm experiments. The final list was decided after a community meeting where the objectives of the present study were explained to the farmers. This study is part of a wider effort by the KARI/RF project to develop, with farmers, low cost manure-based technologies for improved soil management with the goal of alleviating nutrient depletion problems in resource-poor farms.

Experimental Treatments and Layout

The experiment was laid out as a randomized complete block design with seven treatments on each of the six farms, and farm was considered a replicate. Four treatments originated from a 2 X 2 factorial combination of two cropping systems and two legume defoliation treatments. The two legume cropping systems were 1) maize + bean (both planted in April) + mucuna (planted in August) and 2) maize + bean (both planted in April) + lablab (planted in August). The two legume defoliation treatments were 1) herbage above 10 cm removed at season end, and 2) undefoliated. Control treatments included 1) a natural fallow with no inorganic N, 2) inorganic N fertilized (30 kg N ha^{-1}),

and 3) cattle manure fertilized (5 t ha^{-1}, supplying approximately 65 kg N and 18 kg P ha^{-1}). Cattle manure from a large-scale farm was used to avoid confounding manure quality among farms with experimental treatment effects. No inorganic N was applied to any plots other than the inorganic control. The plot size was 6 m by 3.75 m with an inter- and intra-row spacing of 75 cm and 30 cm, respectively. The beans were planted between the rows of maize with an intra-row spacing of 30 cm. The experiment was started in March 1999 when all the plots on each farm were hand plowed. Maize and beans were inter-planted in April, at the beginning of the growing season. Inorganic P was applied in the same hill as for maize at a rate of 13 kg P ha^{-1} in all the plots except for the cattle manure plot. At 8 wk after planting, the inorganic treatment was top dressed with 30 kg N ha^{-1}. All the plots were hand weeded twice before the beans were harvested in July.

In August, the green manure treatment plots were hand plowed between maize rows, before mucuna and lablab were planted. After maize harvest in November, all the maize crop residues were removed from the plots in accordance with farmer practice, and the green manure legumes were left to continue growing during the dry season fallow period until mid–March 2000 when they were incorporated into the soil. The succeeding maize and beans were planted again in April. The same management operations were repeated before the second succeeding maize crop was planted in April 2001.

Green Manure Defoliation Management and Sampling

After harvesting maize at the end of November 1999 and 2000, mucuna and lablab were left to continue growing until land preparation time for the next growing season in mid-March 2000 and 2001 (30 wk after planting). Legumes were sampled and defoliation management instituted before the residue was incorporated. The biomass production was assessed through litter fall, above-ground legume biomass (leaf and

stem), and root. For plots that were defoliated, the legumes were cut to a stubble of 10 cm. Prior to clipping the entire plot, two representative 0.5-m^2 quadrats were sampled. The upper canopy herbage above 10 cm was composited across the two sites per plot, weighed fresh, and sub-samples were taken for dry matter yield and chemical composition determination to evaluate its potential for fodder. In these same quadrats, all material below 10 cm was removed at soil level and composited across the two sites per plot. Undefoliated plots were also sampled at two representative 0.5-m^2 quadrats per plot. In this case, all material was removed at soil level. The sampled herbage was separated into above-ground stem plus leaf and litter fractions. Fresh weights of each fraction were taken, fractions were sub-sampled, and the remainder was returned to the two sampling sites in the respective plot. The sub-sample was weighed fresh, dried in the oven at 60^0C for 48 h to constant weight, weighed again, and then ground for analysis.

Within each sampled quadrat, a root sample was taken. A soil core from 0.5-m^2 to a depth of 20 cm was carefully retrieved from the sampling area. All roots were removed, washed with clean water through a 0.5-mm sieve to remove all soil, and finally rinsed with distilled water. The roots were dried at 70^0 C for 48 h, weighed, and ground for analysis. To characterize the experimental site, soil samples were taken from all seven treatments at the start of the growing season of the initial year of the experiment in 1999. At each sampling period, soil samples were taken from six sampling points from the top 20 cm, composited, thoroughly mixed, and then sub-sampled. Cattle manure samples were taken from the large-scale farm that provided the treatment manure and from every participating farmer to characterize the quality of cattle manure available on smallholder farms. The cattle manure samples were air dried and ground for analysis.

Chemical Analysis

The top-canopy herbage above 10 cm was analyzed for dry matter (DM), ash, crude protein (CP), neutral detergent fiber (NDF), and in vitro dry matter digestibility (IVDMD). Residue biomass samples (below 10 cm in defoliated plots and all herbage to soil level in undefoliated plots) were analyzed for N, P, K, Ca, and Mg. The soil samples were analyzed for extractable P and K and for total N, P, and organic carbon, and for soil particle size. Legume biomass, N concentration, and N yield were determined for both the 1999/2000 and 2000/2001 seasons, whereas P, K, Ca, and Mg concentration and yield were determined during the 1999/2000 season only. The cattle manure samples were analyzed for N, P, K, Ca, and Mg. Total N, P, and K of plant samples were analyzed by Kjeldahl digestion with concentrated sulfuric acid (Anderson and Ingram, 1993), followed by colorimetric determination for N and P (Parkinson and Allen, 1975) and flame photometry for K (Anderson and Ingram, 1993). Calcium and Mg were determined following the procedure outlined by Anderson and Ingram (1993). The soil extractable P and K were determined using the modified Olsen method and the total soil N was determined by Kjeldahl digestion modified to include salicylic acid for the recovery of soil nitrate (Anderson and Ingram, 1993). Total soil carbon was determined by wet oxidation with acidified dichromate and external heating followed by colorimetry (Anderson and Ingram, 1993). Neutral detergent fiber was determined according to the method of Van Soest et al. (1991). The IVDMD was determined using the Tilley and Terry (1963) method.

Statistical Analysis

The general linear models procedure of SAS was used to test treatment effects on plant and soil responses (SAS, 2001). For response variables pertaining only to the four

legume treatments, the model included effects of legume, defoliation, and their interaction. For response variables pertaining to all seven treatments in the study, a first analysis tested the effects of legume, defoliation, and their interaction, and it was followed by single degree of freedom contrasts that compared the legume treatments (individually or in groups) with the controls. To account for other variation in farmer resources and management, maize and bean grain yields were analyzed using the researcher and farmer oriented criteria of stability analysis (Hildebrand, 1984; 1996). In this approach the variations in physical or biological environments are expressed as an index based on yield of all treatments on each farm. The calculated environmental index reflects all the favorable and unfavorable factors found on farms including soil fertility status and farmer management that affect response of the technology being tested. Using regression analysis, the yield response of each treatment is related to different environments.

Farmer Evaluation

The potential acceptability of the legumes by farmers for enhancing soil fertility and the dry season feed supply was assessed in a participatory evaluation. The farmer evaluation was done by the six participating farmers using a ranking matrix in the third year of the experiment after 2 yr of residue incorporation. The farmers were asked to discuss as a group and decide the criteria to be used to evaluate the four legume treatments. The farmers' criteria were used to make a matrix which served as an instrument for farmers to decide which legume was better for each criterion. The matrix was also used to rank the seven experimental treatments on their farms for soil fertility improvement potential (effect on maize grain yield).

Results and Discussion

Farmers' Resource Endowment and Priority Setting

The average farm size of smallholder farms in the study area was less than 2 ha and most farmers have mixed systems in which crops and dairy production are closely integrated. The most important crops grown include: maize, beans, vegetables, bananas (*Musa cavendishii*), finger millet [*Eleusine coracana* (L.) Gaertn], cassava (*Manihot esculenta* Crantz), sweet potatoes (*Impomea batatas*), and fruit trees. The cropping system is characterized by continuous cropping as a result of land intensification due to population pressure. One maize crop is grown per year and it is intercropped with common bean in April. In August after harvesting the first crop of beans, a second crop of beans or sweet potatoes is sometimes relay-cropped in maize. Vegetables (mainly *Brassica spp.*) are planted in October near the rivers for hand irrigation during the dry season from December to late March. Declining soil fertility is the major constraint to crop productivity. Maize, beans, milk, and sweet potatoes are the main foods consumed at home.

Livestock are an important enterprise of the farming system. They are a source of income, food, manure, and traction. The livestock feeding system may be described as semi-zero grazing where crop residues and homestead and roadside grazing play an important role. The commonly used feeds are natural pasture grazing, maize stover, napiergrass [*Pennisetum purpureum* (Schum.) cv. Bana], bean straw, sweet potato vines, weeds, and banana pseudostems. Maize stover is also used as a source of fuelwood and construction of farm structures. Inadequacy of feeds and livestock diseases are the major constraints to livestock production. The feed shortage constraint is particularly critical

during the dry season. There are few improved pastures and there is a general lack of knowledge concerning fodder legumes and fodder shrubs.

Labor for farming activities is predominantly provided by the household members. Labor for growing of finger millet, bean, and vegetable production is mainly provided by women. Men are involved in livestock feeding, maize production, and in cash crop production, such as the growing of vegetables during the dry season. Generally women and children provide most of the labor for farm activities.

The use of inorganic fertilizers is limited. Manure is an important and highly valued output of livestock. The manure is collected near the homestead where the cattle are enclosed at night. There is no deliberate effort to store the manure properly, and it is left in the open until needed. Apart from the relay cropping of sweet potatoes in maize after harvesting a first crop of beans, there is no other form of improved fallows.

Soil and Cattle Manure Characteristics

Soil samples from various plots indicated that soils are moderately acidic, with fair amounts of exchangeable bases, and marginally available P. The soils were deficient in N. The N concentration of farmers' cattle manures ranged from 6.2 to 13.8 g kg^{-1} (Table 5-1). Phosphorus concentration did not fluctuate much between farms, but there was a wide variation in the concentrations of K, Ca, and Mg of the manures. On average the nutrient concentrations (N, P, K, Ca, and Mg) in farmers' manure were lower compared to the large-scale farm manure used in the experiment and were in the range reported from smallholder farms in the central highlands of Kenya (Lekasi, 1998). The difference in organic C and N between the smallholder farmer and commercial farm manure could be due to differences in diet (Somda et al., 1995), methods of collection and storage (Probert et al., 1995), degree of decomposition, and handling conditions of the manures

(Murwira, 1995). Farmers' manures were contaminated with undecomposed crop residues and soil, because they were either left in the 'boma' (night enclosure for cattle) for several days before collection or were stored on bare ground.

Table 5-1. Nutrient concentration of cattle manures from smallholder farms and a large-scale farm used in the experiment.

Farmer	Nutrient				
	N	P	Ca	Mg	K
	---------- g kg^{-1} ----------				
Teresa	11.1	2.08	7.0	1.89	14.2
Khaukha	13.5	2.93	10.9	4.01	13.4
Baraza	13.8	2.82	11.5	3.32	9.2
Simiyu	13.2	2.32	10.5	1.54	7.5
Nasambu	6.2	1.17	4.7	0.94	6.9
Kufwafwa	11.6	1.78	8.3	3.86	9.6
Small farm mean	11.6	2.18	8.8	2.59	7.8
Large-scale farm	17.2	3.69	17.3	6.22	14.6

Herbage Mass and Nutritive Value of Top Canopy Herbage

During the 1999/2000 growing season, top-canopy herbage mass of lablab was higher than mucuna, but in the 2000/2001 season mucuna yielded more biomass (Table 5-2). On average, defoliation of top canopy herbage provided 0.9 t DM ha^{-1} yr^{-1}. The top canopy herbage (leaf + stem) of mucuna contained higher (P = 0.007) CP and lower (P = 0.001) NDF concentrations than lablab in 1999/2000 (Table 5-2), but there was no difference in IVDMD between the two legumes. Crude protein concentration of mucuna top canopy herbage tended (P = 0.217) to be greater than lablab in 2000/2001 season. The CP concentration of lablab top-canopy herbage was higher and the NDF concentration was lower than that reported for above-ground whole plant herbage harvested at 142 d after planting (DAP) (Agyemang et al., 2000). The CP and NDF concentrations of mucuna top canopy herbage were comparable to above-ground mucuna herbage harvested at 90 DAP (Adjorlolo et al., 2001). These results suggest that the top-canopy herbage is a potential dry season protein supplement.

Legume Residue Biomass

Residue biomass during the 1999/2000 growing season was greater than during the 2000/2001 season (Figures 5-1 and 5-2). In both seasons, UD-M produced more (P < 0.001) biomass (2.3 t ha^{-1}, mean of two seasons) than UD-L (0.8 t ha^{-1}). Defoliation reduced (P < 0.01) total residue during 1999/2000 season, but it did not affect (P = 0.373) it during the 2000/2001 season. In the 999/2000 growing season, D-M and D-L supplied 39 and 57%, respectively, as much total residue as from undefoliated treatments. In the 2000/2001 growing season, D-M supplied 79% of the biomass supplied by UD-M, whereas both lablab treatments yielded low but similar amounts of biomass, due to in part

to greater litter production by the D-L treatment. The low biomass achieved by lablab in both seasons suggest that lablab may be less tolerant to low soil fertility in addition to the shading conditions under maize (Marsdorp and Titterton, 1997) and that lablab was less tolerant to drought than mucuna (Burle et al., 1992), which continued to grow throughout the dry season. In both seasons, mucuna produced more root biomass than lablab in agreement with Kolawole and Kang (1997). Mucuna shed more leaves during the 2000/2001 growing season than lablab probably due to sampling which occurred 2 wk later than during the 1999/2000 season.

Table 5-2. Biomass and nutritive value of the top-canopy (above a 10-cm stubble) herbage of mucuna and lablab relay cropped in maize on farmers' fields in Tumaini at Kitale, Kenya. Means are across farms (n = 6).

Biomass constituent	Treatments[1]			
	Mucuna	Lablab	SE	P value
Herbage mass	----------t ha^{-1}----------			
1999/2000	1.18	1.47	0.18	0.293
2000/2001	0.67	0.30	0.09	0.106
Nutritive value	----------g kg^{-1} ----------			
1999/2000				
CP	175	118	11.5	0.007
Ash	94	73	4.3	0.022
NDF	374	520	43.4	0.001
IVDMD	659	691	18.4	0.442
2000/2001				
CP	179	147	16.2	0.217

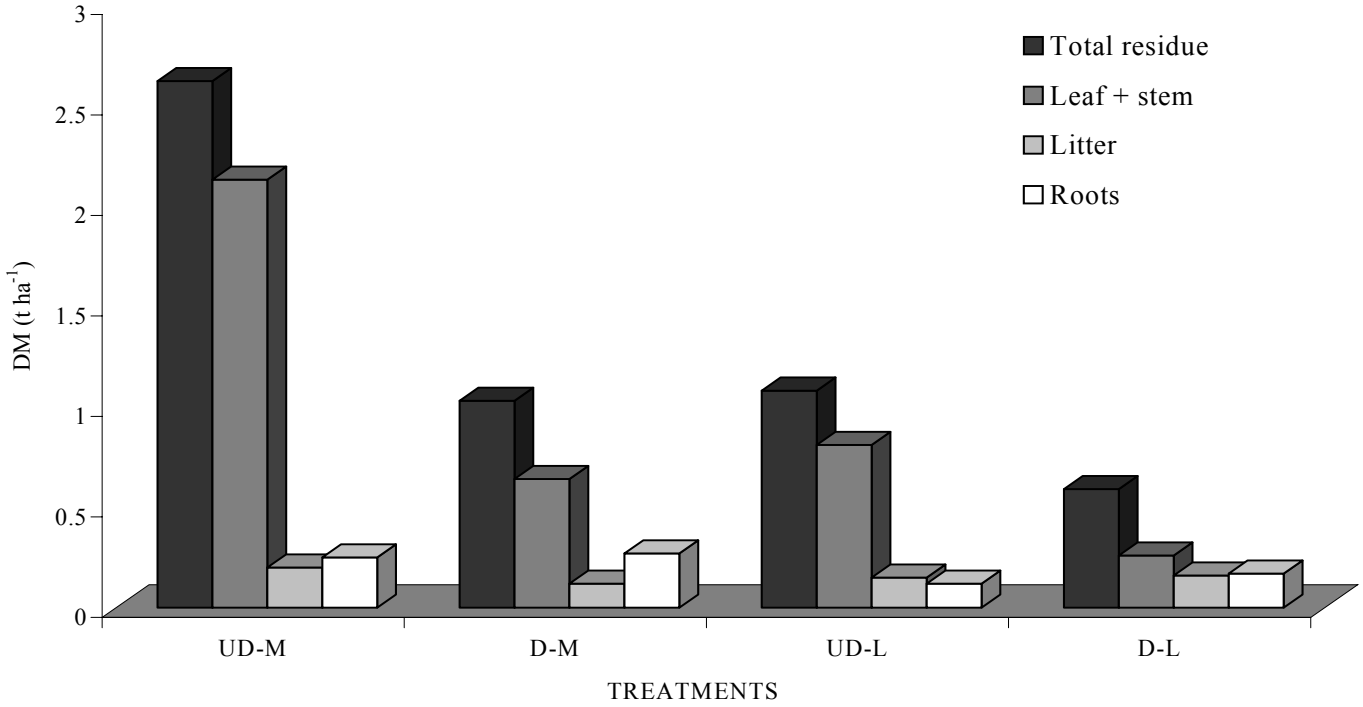


Figure 5-1. Mass of various residue fractions of mucuna and lablab relay cropped in maize on farmers' fields during the 1999/2000 growing season. Treatments are undefoliated mucuna (UD-M), defoliated mucuna (D-M), undefoliated lablab (UD-L), and defoliated lablab (D-L). P values for legume, defoliation, and legume x defoliation effects, respectively are as follows: total residue, < 0.001, < 0.001, and 0.003; leaf + stem, < 0.001, < 0.001, and 0.003; litter, 0.879, 0.693, and 0.347; roots, < 0.001, 0.585, and 0.212.

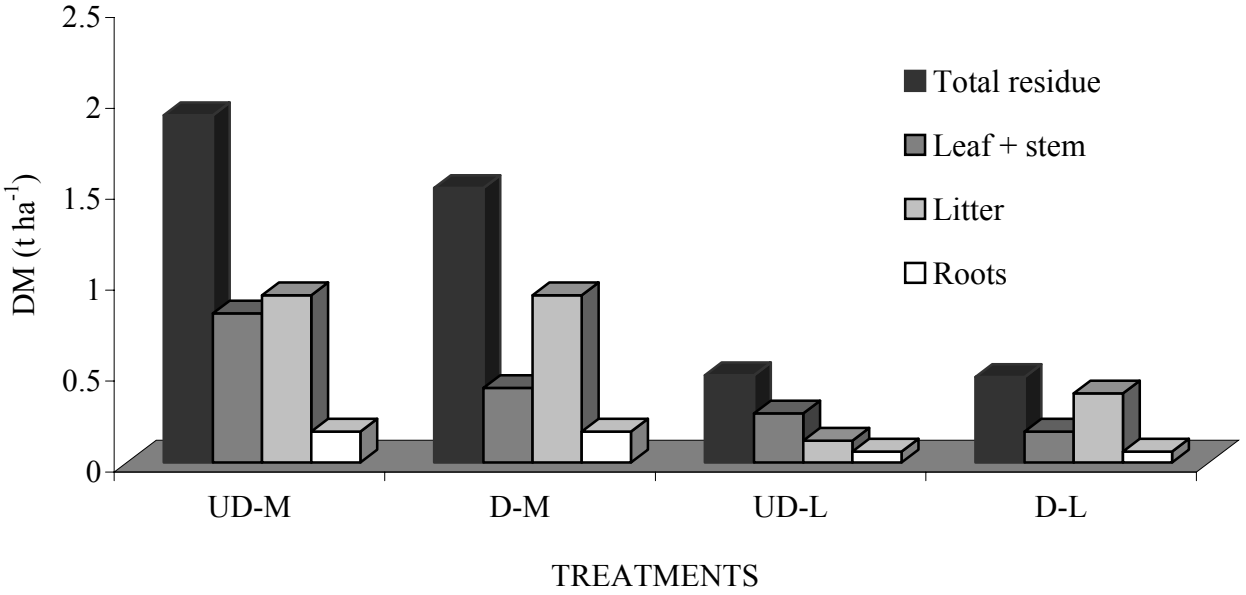


Figure 5-2. Mass of various residue fractions of mucuna and lablab relay cropped in maize on farmers' fields during the 2000/2001 growing season. Treatments are undefoliated mucuna (UD-M), defoliated mucuna (D-M), undefoliated lablab (UD-L), and defoliated lablab (D-L). P values for legume, defoliation, and legume x defoliation effects, respectively are as follows: total residue, < 0.001, 0.373, and 0.351; leaf + stem, 0.001, 0.015, and 0.111; litter, 0.004, 0.412, and 0.431; roots, < 0.001, 0.939, and 0.772.

Legume Residue Nutrient Concentration

There was no interaction between legume and defoliation effects on legume residue N concentration, except for the root fraction (Table 5-3). During the 1999/2000 season the leaf + stem fraction of mucuna contained higher ($P < 0.001$) N concentration than lablab, and defoliation reduced ($P = 0.001$) the N concentration of both legumes. Treatment effects were not significant for litter N concentration. Mucuna roots contained higher ($P < 0.001$) N concentration than lablab. In the same season, mucuna total residue contained higher ($P < 0.001$) N concentration than lablab, and defoliation reduced ($P < 0.001$) the N concentration.

During the 2000/2001 season, mucuna leaf and stem fraction contained higher ($P = 0.067$) N concentration than lablab. As in the first year, there were no treatment effects for litter N concentration during the 2000/2001 season. There was a significant ($P = 0.018$) legume by defoliation effect for root N concentration.

The legume by defoliation interaction for P and K concentration of all residue fractions was not significant (Table 5-4). The leaf + stem and root fractions of mucuna contained higher ($P < 0.001$, and $P = 0.022$, respectively) P concentration than lablab, but lablab litter was higher ($P = 0.044$) than mucuna in P concentration. Defoliation resulted in a reduction in P concentration in both the leaf + stem ($P = 0.012$), and litter ($P = 0.091$) fractions. Mucuna roots contained higher ($P = 0.022$) P concentration than lablab. The P concentration in the total residue was higher ($P < 0.001$) in mucuna than lablab and defoliation reduced ($P < 0.001$) P concentration in both legumes.

Table 5-3. Nitrogen concentration of various mucuna and lablab residue fractions at time of soil incorporation in 2 yr.

	Treatments†					Effects		
Fraction	UD-M	D-M	UD-L	D-L	SE	Legume (L)	Defoliation (D)	L X D
1999/2000	---------- g kg^{-1} ----------					---------- P values ----------		
Leaf + stem	27.1	18.1	17.4	9.50	1.57	< 0.001	< 0.001	0.756
Litter	13.9	14.9	14.2	13.5	0.29	0.423	0.824	0.212
Roots	16.1	16.1	11.8	10.6	0.62	< 0.001	0.481	0.462
Total residue	25.0	18.1	16.5	10.7	1.20	< 0.001	< 0.001	0.647
2000/2001								
Leaf + stem	24.5	20.9	19.2	18.0	1.24	0.067	0.244	0.578
Litter	10.9	10.8	13.5	12.2	1.20	0.322	0.713	0.732
Roots	15.1	12.9	11.5	18.5	1.10	0.583	0.192	0.018
Total residue	16.5	13.7	15.9	18.2	0.98	0.262	0.895	0.122

† UD-M = Undefoliated mucuna, D-M = Defoliated mucuna, UD-L = Undefoliated lablab, D-L = Defoliated lablab

Legume, defoliation, and their interaction effects were not significant for K concentration of all the fractions, except in the total residue where defoliation reduced ($P = 0.047$) K concentration (Table 5-4).

The leaf + stem fraction and roots fraction of mucuna contained higher ($P < 0.001$) Ca concentration than lablab, and defoliation reduced ($P = 0.043$) the Ca concentration in the leaf + stem fraction (Table 5-5). The interaction of legume by defoliation was significant ($P = 0.033$) for Ca concentration in the total residue. The total residue of UD-M contained higher ($P = 0.041$) Ca concentration than UD-L, but there was no difference ($P = 0.878$) between D-M and D-L. Defoliation did not affect ($P > 0.249$) the Ca concentration in the total residue. Magnesium concentration was higher in the leaf + stem ($P = 0.052$), litter ($P = 0.083$), roots ($P < 0.001$), and total residue ($P = 0.095$) fractions of mucuna than lablab, but defoliation had no effect ($P > 0.181$) (Table 5-5).

The higher quality of mucuna residue could be attributed to the slower maturation of mucuna under the northwestern Kenya conditions. At the time of residue sampling/incorporation (30 WAP), lablab had set seed while mucuna had not flowered. The N concentration in mucuna was higher than the critical level of 20 g kg^{-1} above which net mineralization of N would be expected (Palm et al., 1997) and the P concentration was within the critical range of between 2 and 3 g kg^{-1} for net P mineralization (Singh et al., 1992; Palm et al., 1997; Mafongoya et al., 2000), suggesting a net N and P mineralization due to the application of mucuna green manure residue. The P concentration of mucuna and lablab residue used in this study was similar to that reported from the sub-humid highlands of eastern Africa (Wortmann et al., 2000).

Table 5-4. Phosphorus and K concentrations of various mucuna and lablab residue fractions at time of soil incorporation during the 1999/2000 season.

	Treatments†					Effects		
Fraction	UD-M	D-M	UD-L	D-L	SE	Legume (L)	Defoliation (D)	L x D
	---------- g kg^{-1} ----------					---------- P values ----------		
Phosphorus								
Leaf + stem	2.50	2.10	1.80	1.30	0.11	< 0.001	0.012	0.919
Litter	0.89	0.81	1.30	0.93	0.06	0.044	0.091	0.263
Roots	1.40	1.30	1.10	1.10	0.06	0.022	0.394	0.826
Total residue	2.28	1.72	1.65	1.12	0.10	< 0.001	< 0.001	0.915
Potassium								
Leaf + stem	11.5	10.6	10.4	11.0	0.87	0.709	0.874	0.426
Litter	5.0	4.2	5.5	5.6	0.57	0.248	0.713	0.534
Roots	5.80	5.20	5.60	5.90	0.46	0.596	0.722	0.350
Total residue	10.4	8.14	9.50	8.31	0.80	0.662	0.047	0.518

† UD-M = Undefoliated mucuna, D-M = Defoliated mucuna, UD-L = Undefoliated lablab, D-L = Defoliated lablab

Table 5-5. Calcium and Mg concentration of various mucuna and lablab residue fractions at time of soil incorporation during the 1999/2000 season.

	Treatments†					Effects		
Fraction	UD-M	D-M	UD-L	D-L	SE	Legume (L)	Defoliation (D)	L x D
Calcium	---------- g kg^{-1} ----------					---------- P values ----------		
Leaf + stem	19.5	15.6	12.2	10.3	1.13	< 0.001	0.043	0.449
Litter	26.2	25.0	21.2	28.9	1.77	0.808	0.236	0.096
Roots	5.90	5.10	11.2	12.8	0.78	< 0.001	0.572	0.133
Total legume	18.3	14.6	13.2	14.1	0.96	0.013	0.191	0.033
Magnesium								
Leaf + stem	5.70	5.30	4.80	4.10	0.35	0.052	0.261	0.727
Litter	5.84	6.09	7.21	8.02	0.71	0.083	0.570	0.749
Roots	5.80	4.80	2.60	2.40	0.37	< 0.001	0.181	0.310
Total legume	5.71	5.36	4.92	4.59	0.34	0.095	0.453	0.990

† UD-M = Undefoliated Mucuna, D-M = Defoliated Mucuna, UD-L = Undefoliated Lablab, D-L = Defoliated Lablab

Defoliation resulted in a reduction of N, P, and Ca concentration of the above-ground residue. This reduction of N results in a wider lignin:N ratio, which lowered the residue quality of the remaining stubble (Nyambati et al., 2001).

Legume Residue Nutrient Content

During the 1999/2000 season, there was legume by defoliation interaction for N content in the leaf + stem fraction ($P < 0.001$) (Table 5-6). The N content in mucuna leaf + stem fractions was greater ($P < 0.01$) than lablab, but much more so for undefoliated than defoliated plants, and defoliation reduced ($P < 0.001$) the N content of both legumes. Neither legume or defoliation affected ($P > 0.684$) N content of the litter. The N content of mucuna roots was greater ($P < 0.001$) than lablab. There was legume and defoliation interaction ($P < 0.001$) for total residue N content. The N in mucuna total residue was greater ($P < 0.01$) than in lablab regardless of defoliation treatment, and defoliation reduced the N content in total residue of both mucuna ($P < 0.001$) and lablab ($P = 0.013$), but to a much greater degree for mucuna.

The interaction of legume by defoliation for N content of leaf + stem fraction was significant ($P = 0.038$) during the 2000/2001 season (Table 5-6). Undefoliated mucuna had greater ($P = 0.007$) N content than UD-L, but there was only a trend ($P = 0.120$) toward a difference between defoliated treatments. Defoliation of mucuna reduced ($P = 0.006$) N content of mucuna leaf + stem fraction, but it did not affect ($P = 0.308$) lablab, probably because of low yields obtained from lablab treatments. Mucuna litter and roots had greater ($P = 0.043$, $P = 0.001$, respectively) N content than lablab. Legume by defoliation interaction for N content of total residue was significant ($P = 0.044$).

Table 5-6. Nitrogen content of mucuna and lablab residue fractions at time of soil incorporation in 2 yr.

Fraction	Treatments†					Effect		
	UD-M	D-M	UD-L	D-L	SE	Legume (L)	Defoliation (D)	L x D
	---------- kg ha^{-1} ----------					---------- P Values ----------		
1999/2000								
Leaf and stem	57.1	12.7	13.5	2.3	4.60	< 0.001	< 0.001	< 0.001
Litter	2.7	1.7	1.9	2.2	0.37	0.783	0.684	0.403
Roots	5.0	4.4	1.4	1.8	0.43	< 0.001	0.799	0.345
Total residue	64.8	18.8	16.8	6.3	4.90	< 0.001	< 0.001	< 0.001
2000/2001								
Leaf and stem	20.1	7.0	5.2	3.4	1.74	0.002	0.007	0.038
Litter	10.0	9.9	2.3	5.3	1.30	0.043	0.457	0.150
Roots	2.6	2.1	0.6	1.3	0.22	0.001	0.848	0.104
Total residue	32.7	19.1	8.1	9.9	2.75	0.001	0.093	0.044

† UD-M = Undefolated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab

The N content in UD-M residue was greater (0.002) than UD-L, but there was only a trend (P = 0.201) towards a difference between defoliated treatments. Defoliation of mucuna reduced (P = 0.044) N content of total residue, but it did not affect (P = 0.771) lablab.

The interaction of legume by defoliation was significant (P < 0.001) for P content of leaf + stem fraction (Table 5-7). The leaf + stem fraction of mucuna had greater (P < 0.01) P content than lablab, and defoliation reduced (P = 0.001) the P content of both legumes but more so for mucuna. Neither legume or defoliation effects were significant for litter P content. The P content in mucuna roots was greater (P < 0.001) than lablab. The P content in the total residue followed similar trends as in the leaf + stem fraction (Table 5-7).

The interaction of legume by defoliation for K content in the leaf + stem fraction was significant (P = 0.018) (Table 5-7). Both UD-M and D-M had greater (P = 0.009, and P = 0.069, respectively) K content than UD-L and D-L. Defoliation reduced the K content of both mucuna (P = 0.008) and lablab (P = 0.035) leaf + stem. The K content in the litter fraction was not affected by treatment. Mucuna roots had greater (P < 0.001) K content than lablab. The interaction of legume by defoliation was also significant (P = 0.019) for the total residue K content. The K content in total residue of UD-M was greater (P = 0.019) than UD-L, but there was only a trend toward a difference (P = 0.123) between defoliated treatments. Defoliation decreased (P = 0.024) the K content of mucuna total residue, but it only tended (P = 0.120) to affect lablab residue.

Table 5-7. Phosphorus and K content of various fractions of mucuna and lablab relay cropped in maize on farmers' fields in 1999/2000.

Fraction	Treatments†					Effects		
	UD-M	D-M	UD-L	D-L	SE	Legume (L)	Defoliation (D)	L x D
	---------- kg ha^{-1} ----------					---------- P values ----------		
Phosphorus								
Leaf + stem	5.2	1.3	1.4	0.3	0.40	< 0.001	< 0.001	< 0.001
Litter	0.2	0.1	0.2	0.1	0.03	0.494	0.385	0.817
Roots	0.4	0.4	0.1	0.2	0.04	< 0.001	0.888	0.434
Total residue	5.7	1.8	1.7	0.6	0.42	< 0.001	< 0.001	< 0.001
Potassium								
Leaf + stem	25.2	7.0	7.6	3.0	2.24	0.001	0.001	0.018
Litter	1.0	0.5	0.5	0.8	0.16	0.767	0.747	0.270
Roots	1.8	1.6	0.6	1.0	0.19	< 0.001	0.858	0.135
Total residue	28.1	9.0	8.8	4.8	2.35	0.001	0.001	0.019

† UD-M = Undefoliated mucuna, D-M = Defoliated mucuna, UD-L = Undefoliated lablab, D-L = Defoliated lablab

The interaction of legume by defoliation effects for Ca content in the leaf + stem fraction was significant ($P < 0.001$) (Table 5-8), however, mucuna had greater ($P < 0.030$) Ca content than lablab, and defoliation decreased ($P < 0.009$) Ca content in the leaf and stem fraction of both legumes. There was an interaction between legume and defoliation for Ca content of the roots ($P = 0.028$). There was no difference ($P = 0.181$) between undefoliated treatments in Ca content, but D-L tended to have greater ($P = 0.092$) Ca content in the root than D-M. Defoliation had no effect ($P = 0.174$) on Ca content of mucuna, but increased ($P = 0.092$) content in lablab. The interaction of legume by defoliation for Ca content in the total residue was significant ($P < 0.001$). Calcium content in the total residue was greater ($P < 0.001$) in UD-M than UD-L, but there was no difference ($P = 0.242$) between the defoliated treatments. Defoliation decreased Ca content in mucuna residue ($P < 0.001$), but had no effect ($P = 0.347$) on lablab residue.

The treatment effects on Mg content followed the same trends as for Ca, except that Mg content in mucuna roots was greater ($P < 0.01$) than lablab. The leaf and stem fraction contributed the highest proportion of the total N, P, K, Ca and Mg supplied by the residues. During the 1999/2000 season, defoliated treatments of mucuna and lablab contributed 29 and 36% the amount of N supplied by the undefoliated treatments, respectively. Under the UD-M and UD-L treatments, the above-ground fraction contributed the highest amount of N (88% and 80%, respectively) and root contributed 7.8 and 8.4%, respectively. During the 2000/2001 growing season D-M contributed 58%

Table 5-8. Calcium and Mg content of various fractions of mucuna and lablab relay cropped in maize on farmers' fields in 1999/2000.

Fraction	Treatments†					Effects		
	UD-M	D-M	UD-L	D-L	SE	Legume (L)	Defoliation (D)	L x D
	---------- kg ha^{-1} ----------					---------- P values ----------		
Calcium								
Leaf + stem	41.1	10.3	9.9	2.6	3.43	< 0.001	< 0.001	< 0.001
Litter	4.6	2.9	2.4	5.3	0.92	0.948	0.731	0.201
Roots	1.8	1.3	1.3	2.2	0.16	0.560	0.504	0.028
Total residue	47.5	14.5	13.6	10.1	3.87	< 0.001	<0.001	< 0.001
Magnesium								
Leaf + stem	11.8	3.3	3.8	1.1	0.92	< 0.001	< 0.001	0.002
Litter	1.0	0.6	0.9	1.3	0.21	0.453	0.888	0.328
Roots	1.6	1.3	0.3	0.4	0.12	< 0.001	0.289	0.049
Total residue	14.3	5.2	5.0	2.8	1.07	< 0.001	< 0.001	<0.001

† UD-M = Undefoliated mucuna, D-M = Defoliated mucuna, UD-L = Undefoliated lablab, D-L = Defoliated lablab

of N supplied by UD-M, whereas D-L supplied about the same amounts of N as UD-L due to the higher proportion of litter fraction which constituted 65% under D-L vs 35% in UD-L. Generally the results show that mucuna residue supplied greater amounts of nutrients than lablab, and that defoliation resulted in a decrease of nutrient content in the residues, especially for mucuna.

Yield Responses

Bean Grain and Straw Yield

There were no year by treatment interactions ($P > 0.10$) for bean grain and straw yields, therefore the data are presented averaged across the 2 yr (Table 5-9). The interaction of legume by defoliation for bean yield was not significant. Mucuna plots resulted in higher ($P = 0.002$) subsequent bean grain yield than lablab, and defoliation did not affect ($P = 0.485$) bean grain yield. The low bean yield under lablab treatment could be due to the low nutrient contribution from lablab and the damage by aphids (*Aphis craccivora*) and leaf rust disease (Anthracnose, caused by *Colletotrichum spp*.) that affected both lablab and common bean. Single degree of freedom comparisons showed that cattle manure yielded higher ($P = 0.076$) bean grain than the natural fallow control, however, UD-M tended ($P = 0.119$) to yield higher bean grain than the natural fallow control. The bean grain yields in this study were at the lower end of the range (0.5 to 1.4 t ha^{-1}) reported previously from the highlands of eastern Africa under maize intercrops (Giller et al., 1998; Wortmann et al., 2000). These low yields could in part be due to the bean rot disease (caused by a complex of fungal pathogens) and low soil fertility, which has been shown to cause low yields in the sub-humid highlands of western Kenya (Otsyula et al., 1999). There was a trend toward greater bean straw DM yield on mucuna

Table 5-9. Mean grain and straw yield of common bean relay cropped in maize after mucuna and lablab residue incorporation on farmers' fields for 2 yr.

Treatments[†]	Grain	Straw
	kg ha^{-1}	
UD-M	147	132
D-M	138	105
UD-L	95	107
D-L	80	81
Effects	P values	
Legume (L)	0.002	0.111
Defoliation regime (D)	0.485	0.067
L x D	0.843	0.959
Year (Y)[±]	0.038	0.241
SE	10.5	8.16
Controls		
Inorganic N	102	96
Natural fallow	110	94
Cattle manure	156	132

[†] UD-M = Undefoliated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab

[±] No treatment by year interactions were significant (P > 0.10).

plots (P = 0.111), and defoliation resulted in a decrease in straw yields. Undefoliated legume treatments tended (P = 0.135) to yield higher straw DM than the natural fallow control.

Maize Grain and Stover

Maize grain yield during 1999 (data not shown), when legumes were first relay cropped in maize, was not different among treatments, suggesting that under this type of relay cropping competition from the legumes was not severe. Because the interaction of year by treatment was not significant (P > 0.10), mean maize grain and stover yields are presented across years (Table 5-10). The interaction of legume by defoliation for maize grain and stover yields was not significant ($P \geq 0.194$). Maize grain yield after mucuna residue was higher (P = 0.003) than after lablab. Defoliation of the legumes reduced (P = 0.028) maize grain yield. Stover yield was not affected by either legume or defoliation regime (Table 10).

Relative to the controls, maize grain yields were higher under cattle manure (P = 0.005), inorganic N (P = 0.016), and UD-M (P = 0.023) than the natural fallow control. Defoliated mucuna tended (P = 0.155) to yield higher maize grain than the natural fallow. The maize grain yields under UD-M and D-M were not different (P = 0.793, and P = 0.169, respectively) from the inorganic N control. The higher maize grain yields under cattle manure treatment is in agreement with previous reports (Bationo and Mokwunye, 1991; Probert et al., 1995; Murwira and Kirchmann, 1993). Undefoliated legume treatments yielded higher (P = 0.082) maize grain than the natural fallow control. Only cattle manure and UD-M yielded higher stover DM than the natural fallow control. The UD-M, D-M, and UD-L residue treatments resulted in 97, 54, and 41% maize grain yield

Table 5-10. Mean grain and stover yield of subsequent maize after relay cropped mucuna and lablab residue incorporation on farmers' fields for 2 yr.

Treatments[†]	Grain	Stover
	---------- t ha^{-1} ----------	
UD-M	3.19	3.93
D-M	2.49	3.25
UD-L	2.28	3.30
D-L	1.92	3.38
Effects	---------- P values ----------	
Legume (L)	0.003	0.334
Defoliation regime (D)	0.028	0.272
L x D	0.449	0.194
Year (Y) [±]	< 0.001	< 0.001
SE	0.21	0.24
Controls	---------- t ha^{-1} ----------	
Inorganic N	3.32	3.71
Natural fallow	1.62	2.91
Cattle manure	3.62	4.14

[†] UD-M = Undefoliated mucuna; D-M = Defoliated mucuna; UD-L = Undefoliated lablab; D-L = Defoliated lablab

[±] No treatment by year interactions were significant (P > 0.10).

increases, respectively, compared to the natural fallow control in agreement with previous reports (Versteeg et al., 1998a; Akobundu et al., 2000; Tian et al., 2000), which have shown positive fertilization effects of green manures.

The lower on-farm performance of maize after lablab is attributed to the low lablab biomass and N concentration. Lablab reached maturity and set seed earlier than mucuna which continued to grow during the dry season. Mucuna residue contained N and P concentration above the levels at which net mineralization is expected (Singh et al., 1992; Palm et al., 1997; Mafongoya et al., 2000) and accumulated greater amounts of nutrients (Tables 5-6, 5-7, and 5-8). The high maize yield response from 2 t ha^{-1} of green manure residue is not unexpected, given that this was combined with 13 kg P ha^{-1}. This maize response to a combination of organic residue and P application was consistent with the results of previous studies in western Kenya (Jama et al., 1997) which showed that a combination of *Calliandra calothyrsus* biomass and inorganic P was more economical than when organic residue alone was used to supply P. Other studies in sub-Saharan Africa have indicated a substantial residual effect of P fertilization at moderate application rates of 20 kg ha^{-1} (Warren, 1992).

These results show that mucuna was adapted to the on-farm relay-intercrop conditions more than lablab. Maize yields after mucuna were not affected by defoliation despite the reduction in nutrient contents, suggesting that the nutrient recovery and residual effects under D-M were higher compared to UD-M. This is in agreement with previous reports (Ibewiro et al., 1998; Oikeh et al., 1998), which have showed that even legume roots alone had positive effect on subsequent maize grain yield. The defoliated treatments yielded proportionally higher yields than the estimated nutrient contribution, possibly

because of underestimation of the below-ground contribution (Peoples et al., 1995), which can constitute as much as 39 to 49% of the total N accumulated by the legume (Ramos et al., 2001).

Stability Analysis

The stability analysis (Figure 5-3) showed that the magnitude of the difference between the undefoliated mucuna residue treatment, which achieved the highest maize grain yield of all the residue treatments, and the natural fallow control treatment was greater under poor farm environments (i.e., farms with low soil fertility) than under good farm environments. The analysis also showed that the defoliation of mucuna in poor environments (i.e., farms with very low soil fertility), where the biomass yield was very low, resulted in very low response of maize grain yield, whereas on farms with better soils, D-M resulted in yield approaching that of UD-M. This suggests that use of mucuna topgrowth for livestock feed and soil incorporation of the stubble is more likely to be a viable option on higher fertility soils. In an on-station experiment where the fertility was higher (Chapters 3 and 4), defoliation of mucuna resulted in higher efficiency of N uptake and recovery and subsequent maize grain yields were at least as great as those following UD-M.

Farmer Evaluation

Mucuna was preferred over lablab in overall ranking based on the five farmers' criteria (Table 5-11), however, the opinions differed between gender. In the context of improving food security, the men preferred D-M because it provided feed for the animals, whereas women preferred lablab because it provided edible grain for the family. The

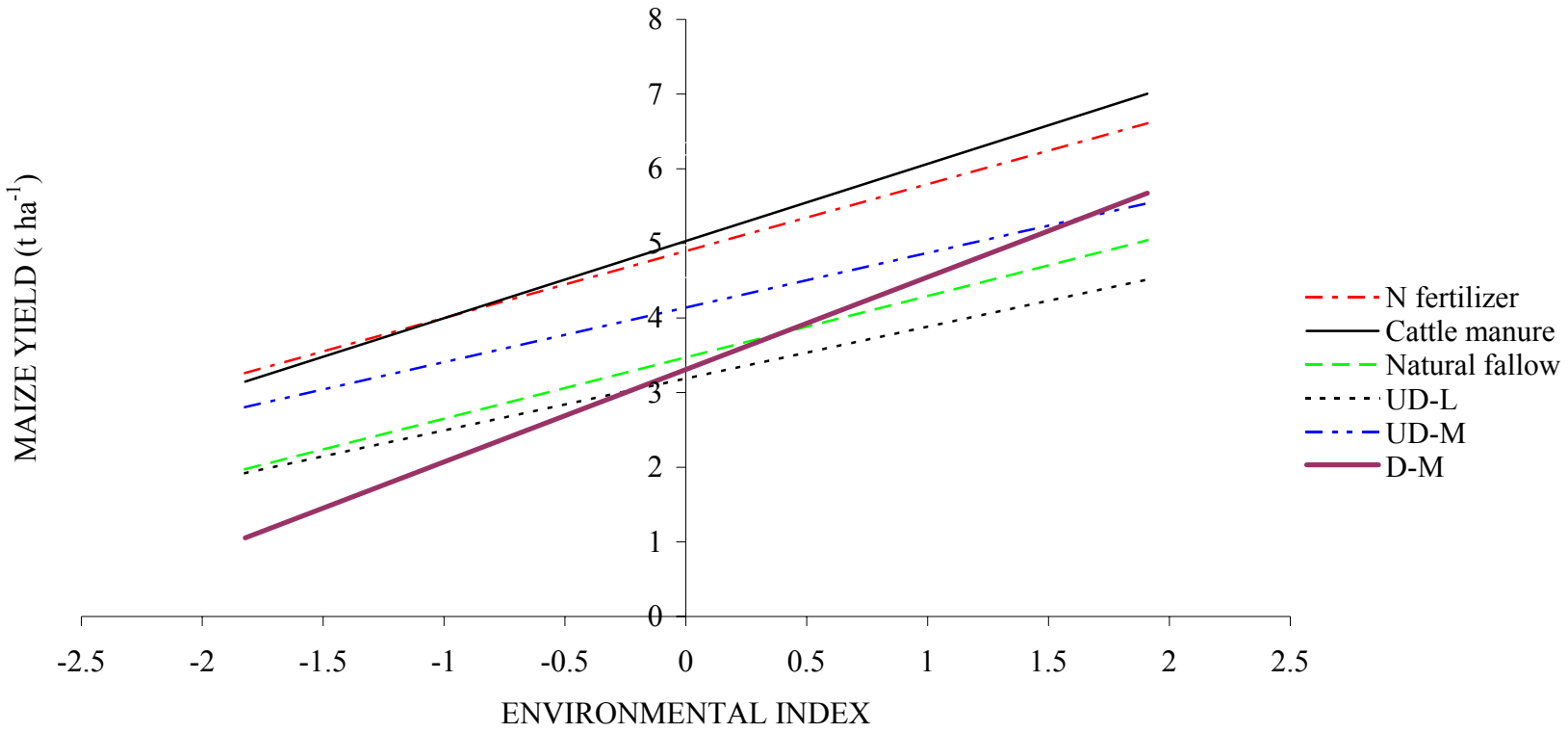


Figure 5-3. Stability analysis of maize grain yield (t ha^{-1}) after incorporating undefoliated or defoliated relay cropped mucuna and lablab on farmers' fields at Kitale, Kenya. A low environmental index is associated with low soil fertility. Treatments are undefoliated mucuna (UD-M), defoliated mucuna (D-M), undefoliated lablab (UD-L), and defoliated lablab (D-L).

Table 5-11. Farmer ranking (1 = highest) of the green manures for suitability in improving soil fertility and providing fodder.

Criteria	Farmer ranking		
	Mucuna	Lablab	Observations
Human food	2	1	Lablab provides food for the family
Soil fertility improvement	1	2	Plot of mucuna had higher maize grain yield, and soil texture of soil was like forest soil, and easy to plow
Fodder supply	1	2	Mucuna produces more biomass
Weed suppression	1	2	Mucuna spreads to suppress weeds
Suitability as intercrop	1	2	Lablab is susceptible to leaf rust due to much rain at establishment in August
Mean rank	1.2	1.8	
Overall rank	1	2	

Table 5-12. Ranking by farmers of the performance of maize in various treatment plots.

Treatment[†]	Farmer						Mean	Overall Rank
	1	2	3	4	5	6		
UD-M	4[±]	2	4	6	3	2	3.50	3
D-M	3	3	5	5	7	3	4.33	4
UD-L	5	6	2	7	4	6	5.00	5
D-L	7	5	7	3	5	4	5.17	6
N fertilizer	2	1	3	2	2	1	1.83	1
Weed fallow	6	7	6	4	6	7	6.00	7
Cattle manure	1	4	1	1	1	5	2.17	2

[†] UD-M = Undefoliated mucuna, D-M = Defoliated mucuna, UD-L = Undefoliated lablab, D-L = Defoliated lablab
[±] 1 = highest and 7 = least.

performance of the various treatments based on the farmers' evaluation was in the order of: N fertilizer > cattle manure > UD-M > D-M > UD-L > D-L > natural fallow (Table 5-12).

Conclusions

Undefoliated mucuna was the most effective in improving soil fertility on farm as indicated by the performance of succeeding maize and bean crops. In both seasons, mucuna produced more biomass of higher quality than lablab, indicating that mucuna was better adapted to low soil fertility on farm, the shaded conditions under maize, particularly in August during seedling establishment, and to drought conditions when it continued to grow. In both 1999/2000 and 2000/2001 growing seasons, the low maize grain yield response to the lablab treatment could be attributed to the low biomass yield

and nutrient content of lablab. Defoliation of relay-cropped green legume manure yielded on average 0.9 t ha^{-1} of top canopy herbage from either mucuna or lablab. Chemical analysis of this herbage showed that it was of high nutritive value and could form a protein supplement during the dry season when high quality feeds are unavailable. Our results show that even after removing mucuna upper canopy biomass as feed, the incorporation to the soil of the remaining stubble and root residues resulted in grain yields higher than those from the natural fallow, with the exception of sites where soil fertility was extremely poor.

CHAPTER 6
NUTRITIVE VALUE OF TOP-CANOPY HERBAGE OF MUCUNA AND LABLAB RELAY CROPPED IN MAIZE IN THE SUB-HUMID HIGHLANDS OF NORTHWESTERN KENYA

Introduction

Declining soil fertility and inadequacy of livestock feeds, particularly the lack of protein during the dry season, are major production constraints in many smallholder, mixed crop-livestock farming systems in the tropics. These constraints arise due to land limitations, which cause farmers to practice continuous cropping and grazing, and to use little or no fertilizer.

Although cycling of biomass through livestock and use of manure and urine to fertilize soil have been an important link between livestock and soil fertility (Powell and Valentine, 1998), the quantities of manure available on farm may not be enough to replenish nutrients removed in grain and crop residues (Williams et al., 1995). Intercropping of grain legumes such as the common bean (*Phaseolus vulgaris* L.) with cereals, provides little or no N to the concurrent or subsequent crop as the majority of fixed N is harvested in the grain (Giller et al., 1991; Giller et al., 1994; Amijee and Giller, 1998).

In recent years, there has been a resurgence of interest from the scientific community in leguminous green manure/cover crops in many parts of the tropics where the use of commercial inorganic N fertilizers is not economically feasible. Although green manures give greater yields of subsequent crops than intercropping with grain legumes, their use is sometimes limited because they occupy the land without providing human food or

livestock feed. Thus benefits in addition to improving soil fertility are necessary in order for farmers to adopt them.

Few studies have reported the testing of legumes for the combined purposes of enhanced soil fertility and feed supply for livestock (Tarawali and Mohamed-Saleem, 1995; Tarawali and Peters, 1996; Muhr et al., 1999c). In a derived savanna of sub-humid west Africa, Muhr et al. (1999c), tested a range of forage legumes in rotation with maize (*Zea mays* L.) in short-term improved fallow systems. Studying the rotational effects of forage legumes, Muhr et al. (1999c) found that even though large amounts of N, P, and K (up to 120, 10, and 135 kg ha^{-1}, respectively) were removed in dry-season herbage, subsequent growth followed by soil incorporation of the green manure biomass increased grain yields of maize grown on the legume plots.

Ibewiro et al. (1998) studying the N contribution of mucuna (*Mucuna pruriens* (L.) DC. var. *Utilis* (Wright) Bruck), lablab (*Lablab purpureus* (L.) Sweet), cogongrass (*Imperata cylindrica*) and maize roots, shoots, and whole-plant biomass to succeeding maize, showed that, although N in mucuna and lablab roots constituted only 3 and 4% of total legume N, their incorporation increased maize grain yield 38 and 89%, respectively, as much as when whole legume residue was incorporated. These results suggest that incorporation of root and stem stubble after removing topgrowth for livestock feed may enhance N contribution to succeeding maize in low-external input, continuous cropping systems as well as provide quality fodder.

Weber (1996) concluded that mucuna and lablab are among the species adapted to cropping systems in sub-Saharan Africa that could be relay-cropped into maize-based cropping systems and provide additional benefits to the cropping system. This study is

part of a research program evaluating use of mucuna and lablab for both soil fertility improvement and as livestock feed. The specific objective of this experiment was to assess the nutritive value of the harvested top-canopy biomass of mucuna and lablab when relay cropped in maize in the sub-humid highlands of northwestern Kenya.

Materials and Methods

Study Site and Treatments

The study was conducted at the National Agricultural Research Center (NARC), Kitale in the sub-humid highlands of northwestern Kenya. The altitude was 1860 m and the soil a humic ferralsol (oxisol) (pH =5.5). In the years of this trial, 1999/2000 and 2000/2001 growing seasons, the total annual rainfall received was 1115 and 1050 mm, respectively, falling between April and November. Other characteristics of the site were described in Chapter 3.

This study was part of the experiment reported in Chapters 3 and 4. The treatments were two legume species arranged in three replications of a randomized block design. The legumes were relay cropped in maize in August after harvesting a first crop of common bean intercropped with maize in April. Maize was planted at an inter- and intra-row spacing of 75 cm by 30 cm (target population of 44,444 plants/ha), respectively, using two seeds per hill of hybrid 614D maize seed in April. The legumes were planted between the maize rows at an intra-row spacing of 30 cm using two plants per hill (target population of 88,888 plants/ha). At planting the maize received a basal application of 13 kg P ha^{-1}.

Top-Canopy Biomass Sampling

After harvesting maize in November, the legumes were hand weeded and continued growing into the dry season. The legumes were cut to stubble of 10 cm before land

preparation in mid-March, 210 days after planting (DAP). Prior to clipping the entire plot, two representative 0.5-m^2 quadrats were sampled. Herbage above 10 cm (top canopy) was composited across the two sites per plot and part of the sample was separated into leaf and stem fractions. Fractions were dried, weighed, and ground for laboratory analysis. In these same quadrats, all material below 10 cm was removed at soil level (lower canopy), composited across the two sites per plot, and separated into the same fractions described above. Fresh weights of each fraction were taken, fractions were sub-sampled, and the remainder of the herbage was returned to the two sampling sites. The sub-sample was weighed fresh, dried at 60^0C for 48 h, weighed again and then ground for analysis.

Chemical and Statistical Analysis

First-year samples of live leaf, stem, and leaf plus stem top-canopy fractions from defoliated plots were analyzed for crude protein (CP), ash, neutral detergent fiber (NDF), and in vitro dry matter (DM) digestibility (IVDMD). Second-year samples were analyzed for CP only. Total plant N was analyzed by Kjeldahl digestion with concentrated sulfuric acid, followed by colorimetric determination (Anderson and Ingram, 1993; AOAC, 1990). The NDF was determined by the method of Goering and Van Soest (1970) as modified by Van Soest et al. (1991). In vitro DM digestibility was determined using the procedure of Tilley and Terry (1963).

The general linear models procedure of SAS was used to test legume species effects on DM yield and nutritive value. The model for DM mass and plant-part proportions included the legume and year effects and their interaction, but only the legume effect was tested for chemical composition data because these data were collected only in the first year. Treatment effects were considered significant at $P \leq 0.10$.

Results and Discussion

Mass and Plant-part Proportions

The interactions of the effects of legume by year were not significant ($P > 0.10$) for DM mass and plant-part proportions, except for lower canopy leaf and leaf + stem fractions ($P = 0.002$). Because the primary focus of this work was top-canopy herbage and to simplify presentation of the data, the means across the 2 yr are reported in Table 6-1. There was no difference ($P = 0.461$) between mucuna and lablab in the top-canopy leaf mass, however lablab yielded a greater mass both in the stem ($P = 0.023$) and leaf + stem fractions ($P = 0.096$). The top-canopy herbage of mucuna had a higher ($P = 0.001$) leaf:stem ratio.

Mucuna yielded greater ($P = 0.020$) leaf mass in the lower-canopy herbage than lablab, but there was no difference ($P = 0.389$) in lower-canopy stem mass. Also mucuna yielded greater ($P = 0.064$) mass for leaf + stem in the lower canopy. The greater mass in the top canopy for lablab than mucuna can be explained by growth morphology of the two legumes. Lablab has an upright growth habit, and defoliation to a 10 cm-stubble resulted in a greater ($P = 0.011$) proportion (0.76) of total DM removed than for mucuna (0.52) (Table 6-1). Defoliation of mucuna removed about the same quantity in the top canopy as that left on site in the lower canopy. The results show that relay cropping mucuna or lablab into maize in August after harvesting a first crop of common bean, and defoliating them to a 10 cm-stubble at 210 DAP could on average yield from 1 t ha^{-1} yr^{-1} (average of two seasons) of mucuna herbage to 1.8 t ha^{-1} yr^{-1} of lablab herbage, at least in soils like those on the research station.

Chemical Composition

There were no differences in CP (P = 0.461) or NDF (P = 0.582) in the leaf fraction of top-canopy herbage of mucuna and lablab, but lablab leaf contained (P = 0.003) higher IVDMD (Table 6-2). The CP concentration of mucuna stem was greater (P = 0.022) than that of lablab, but lablab stem fraction contained higher (P =0.006) NDF concentration than mucuna. There was no difference (P = 0.681) in stem IVDMD between the legumes. The CP and IVDMD of total (leaf + stem) herbage were also not different between the two legumes (Table 6-2), although IVDMD tended to be greater for lablab. Lablab contained greater (P = 0.003) NDF concentration than mucuna. Top-canopy herbage harvested during the 2000/2001 growing season was analyzed only for CP, and there was no difference (P = 0.174) in leaf CP concentration, but the stem fraction of mucuna contained higher (P = 0.064) CP concentration than lablab (Table 6-3).

The CP of top canopy herbage of lablab harvested after 210 DAP in this study was comparable to the above-ground herbage harvested at 140 DAP reported by Agyemang et al. (2000). The NDF concentrations of top canopy herbage were lower than those reported for above-ground, whole-plant herbage (Mupangwa et al., 2000; Agyemang et al., 2000; Adjorlolo et al., 2001). The higher NDF concentration in lablab was expected because lablab had lower leaf:stem ratio than mucuna (Table 6-1).

Table 6-1. Herbage dry matter mass and plant-part proportions of various fractions of defoliated mucuna and lablab relay cropped in maize for 2 yr.

Fraction	Treatment		SE	Legume effect
	Mucuna	Lablab		
Top canopy (TC)	----------t ha^{-1} ----------			--- P value ---
TC-Leaf	0.72	0.87	0.08	0.461
TC-Stem	0.29	0.94	0.13	0.023
TC-Leaf + stem	1.01	1.81	0.20	0.096
TC-Leaf:stem	2.94	1.01	0.34	0.001
Lower Canopy (LC)				
LC-Leaf	0.48	0.08	0.09	0.021
LC-Stem	0.58	0.50	0.08	0.389
LC-Leaf + stem	1.05	0.58	0.16	0.064
LC-Leaf:stem	0.84	0.17	0.11	0.024
Total	2.06	2.39	0.27	0.485
TC:Total	0.52	0.76	0.04	0.011

Table 6-2. Nutritive value of top-canopy biomass of mucuna and lablab relay cropped in maize during the 1999/2000 growing season at NARC-Kitale.

Fraction†	Treatment		SE	Legume effect
	Mucuna	Lablab		
	----------g kg^{-1} ----------			-- P value --
Leaf				
CP	145	152	4.4	0.461
Ash	65	90	5.7	< 0.001
NDF	337	365	15.3	0.582
IVDMD	613	764	34.3	0.003
Stem				
CP	115	86	6.7	0.022
Ash	49	88	8.8	0.001
NDF	419	517	24.4	0.006
IVDMD	601	649	46.1	0.681
Leaf + stem				
CP	130	111	9.4	0.281
Ash	68	86.3	4.3	0.002
NDF	325	446	29.3	0.003
IVDMD	617	693	20.1	0.110

† CP = Crude protein; NDF = Neutral detergent fiber; IVDMD = In vitro dry matter digestibility.

Table 6-3. Crude protein concentration of top-canopy biomass leaf and stem fractions of mucuna and lablab relay cropped in maize during the 2000/2001 growing season at NARC, Kitale.

Fraction	Treatment		SE	Legume effect
	Mucuna	Lablab		
	----------g kg^{-1} ----------			-- P values --
Leaf	246	281	10.6	0.174
Stem	135	111	8.61	0.064

The IVDMD of top canopy biomass of mucuna and lablab in this study was higher compared to mucuna and lablab forage harvested at maximum biomass yield (16 and 18 WAP, respectively) reported by Maasdorp and Titterton (1997). This could partly be attributed to the higher proportion of leaves in the top-canopy biomass compared to total above-ground biomass (Chapter 4). Although lablab contained greater NDF concentration than mucuna, it tended to have greater IVDMD than mucuna, concurring with the results of Maasdorp and Titterton (1997) and Chapter 7. This could be attributed in part to the higher lignin concentration in mucuna biomass compared to lablab (Chapter 7).

Previous studies have shown that mucuna has an aggressive twining and trailing habit (Singh and Relwani, 1978) that could reduce the yield of maize when the legume is planted together with maize earlier than 5 wk after planting (Maasdorp and Titterton, 1997; Versteeg et al., 1998a). Our results show that upper canopy herbage obtained after defoliating mucuna and lablab at 10 cm above the ground is of higher nutritive value than

that of whole biomass hay. Thus defoliation provides a management option that could provide high quality of fodder for livestock while reducing the competitive ability of the legumes. Moreover, the adoption of green manure has been shown to be higher when these legumes provide other uses (Becker et al., 1995; Versteeg et al., 1998a). A complementary study (Chapter 3), found that the reduction of quality of the mucuna stubble residue may enhance the efficiency of N uptake by succeeding maize. Also at the time of residue defoliation and incorporation, relay-cropped lablab produced seed yield higher than the second crop of beans.

Results from this study show that mucuna and lablab have potential to provide 1 to 1.8 t ha^{-1} yr^{-1} of livestock fodder respectively, when relay cropped in maize and defoliated to 10 cm at 210 DAP. A smallholder farmer keeping one dairy cow would need 0.225 or 0.125 ha yr^{-1} of relay-cropped mucuna or lablab, respectively, to produce sufficient herbage for supplementation (2.5 kg cow^{-1} d^{-1}) for at least the 3-mo dry season when feed scarcity is most severe. These acreages are feasible given that the same piece of land on which the legumes grow is used for maize and common bean production. In a feeding experiment to evaluate the potential of mucuna or lablab hay as protein supplements for dairy cows (Chapter 7), supplementation resulted in an extra 0.41 kg milk cow^{-1} d^{-1} and an additional 208 kg cattle manure DM yr^{-1}. The manure could supply 5 kg N, 0.6 kg P, 0.53 kg K, 1.4 kg Mg, and 5.5 kg Ca yr^{-1} (13 kg of nutrients yr^{-1}).

Conclusion

The use of forage legumes in smallholder farms in the tropics has been generally low (Thomas and Sumberg, 1995). For increased adoption of legume-based forage technologies in smallholder farms, these legumes must fit into the overall farming strategy based on food production for the family household. This study has shown that

mucuna or lablab relay cropped into maize after harvesting a first crop of common beans, and defoliated to a 10-cm-stubble, provide fodder that could be a valuable protein supplement during the dry season, which is a major constraint to livestock production. This could reduce the trade-off associated with the introduction of green manure legumes for soil fertility improvement alone and increase their adoption.

CHAPTER 7
FEED INTAKE AND LACTATION PERFORMANCE OF DAIRY COWS OFFERED NAPIERGRASS SUPPLEMENTED WITH LEGUME HAY

Introduction

A major constraint to smallholder dairy cattle production in the tropics is the scarcity and poor quality of on-farm feed resources and the high cost and uncertain supply of purchased concentrates. In the highlands of northwestern Kenya, mixed farming based on high yielding fodder grasses has potential for improving both the quantity and quality of feed available throughout the year. Within these systems, the main feed constraint to dairy cattle production occurs during the dry season when the quality of available feed is low. Napiergrass [*Pennisetum purpureum* (Schum) cv. Bana] is the most important fodder grown on smallholder farms practicing intensive mixed crop-livestock production in northwestern Kenya (Nyambati, 1997). Napiergrass, which can tolerate mild drought (Skerman and Riveros, 1990), is low in N and digestible nutrients when mature, reducing the efficiency with which it is utilized for milk production (Muia et al., 2000b).

Previous research has shown that diet crude protein (CP) concentration of 60 to 80 g kg^{-1} dry matter (DM) is the minimum range for optimum rumen microbial activity (Minson and Milford, 1967). Working on smallholder farms in Kenya, Wouters (1987) indicated that napiergrass had a mean CP concentration of 76 g kg^{-1} DM. Later reviews (Shreuder et al., 1993; Muia et al., 2000b) reported a mean CP concentration ranging between 50 and 90 g kg^{-1} DM confirming that CP in napiergrass may limit milk production.

Protein supplementation (concentrates, byproducts, and *Leucaena leucocephala* as sources) to napiergrass-based diets has been shown to increase feed dry DM intake (DMI) and milk production (Muinga et al., 1992; 1993; 1995; Muia et al., 2000a). The benefits of using protein-rich forages as supplements include improved energy and protein intake, improved feed efficiency, increased availability of minerals and vitamins, improved rumen function, and generally, enhanced animal performance (Norton and Poppi, 1995).

In addition to improving the nutritive value of livestock feeds, legumes have the potential to improve soil fertility through their ability to fix N (Sanginga et al., 1996a) or when incorporated into the soil as green manures (Tian et al., 2000). Thus the integration of legume-based technologies into intensified farming systems has the potential to increase both crop and livestock productivity (Weber, 1996).

Although napiergrass provides fodder throughout much of the year, its CP may be inadequate for production needs of lactating cows (Anindo and Potter, 1986). Mucuna [*Mucuna pruriens* var. *utilis* (L.) DC (Wright) Burck] and lablab [*Lablab purpureus* L. (Sweet) cv. Rongai] are legumes that can serve as both green manures and livestock feeds, but data are limited which assess their value as supplements to cattle diets. The objective of this study was to evaluate the effects of feeding mucuna and lablab hay as supplements to lactating dairy cows fed a basal diet of napiergrass on DMI, diet digestibility, cow body condition, body weight gain, and on the quantity and quality of milk produced.

Materials and Methods

Production Environment

The experiment was conducted at the Kenya Agricultural Research Institute's National Agricultural Research Center, Kitale (1^0 01" N, 35^0 00'' E) in agroecological zone upper midlands 4 as described by Jaetzold and Schmidt (1983). The center receives an average annual rainfall of 1100 mm and is on a clay loam soil with a pH (2.5:1 water soil ratio) of 5.5. During the period of the feeding experiment from June to August mean monthly minimum and maximum temperatures were 12 and 24.4^0C, respectively. The study was started at the beginning of June 2000 and lasted 12 wk.

Experimental Diets

The tall type of napiergrass was planted at NARC, Kitale in 1999 for the production of fodder. At planting, 10 kg ha^{-1} of P was applied as triple-super phosphate. The napiergrass was weeded twice and top-dressed with calcium ammonium nitrate fertilizer at the rate of 60 kg N ha^{-1} after cutting it back to a 5-cm stubble. The napiergrass was cut back in sequential blocks, to ensure uniformity of maturity during the feeding period. The napiergrass was harvested at a height of approximately 1 to 1.5 m using a machete, leaving a stubble of approximately 5 cm. The harvested material was chopped manually into 2- to 4-cm pieces using a forage chopper and was fed fresh.

Mucuna and lablab were grown in 1999 at NARC, Kitale prior to the start of the feeding experiment. One hectare each of mucuna and lablab were established at an inter-row spacing of 50 cm and within row spacing of 25 cm. They were weeded three times before flowering, and spot hand weeding was done just before harvesting. The legumes were harvested manually at the 50% flowering stage to a stubble height of 5 to 10 cm using hand shears. Lablab was harvested 16 wk after germination while mucuna was

harvested 20 wk after germination because of delayed flowering. The harvested herbage was sun dried for 24 to 48 h before transferring it to a drying shade. The material was then spread in raised-wire stands inside a barn and turned several times until it was completely air dry. The material was chopped into 2- to 4-cm pieces using a manually operated forage chopper and stored in a well-ventilated room ready for feeding. Dairy meal was purchased in bulk from a local feed miller.

Experimental Animals

Eight multiparous (with two to five previous lactations) lactating Holstein-Friesian cows (377 $\pm$ 43 kg) were selected from the dairy herd at NARC, Kitale, based on days in milk, lactation number, milk yield, and body weight to minimize any carry over effects. The cows (261 $\pm$ 23 days in milk) were grazing on low quality pastures prior to the start of the experiment and their average milk yield was 3.7 kg d^{-1}. The cows were treated with 10 mL of 34% nitroxynil (Trodax)[1] and drenched with 100 mL of 3% Oxyclozanide/1.5% Levamisole hydrochloride/0.385% Cobalt sulphate (Nilsan)[2] 3 wk prior to the start of the experiment against endoparasites and sprayed weekly with a diamidide acaricide (Triatix)[3] against ectoparasites. The cows were also injected with 10 mL of a multivitamin[4] supplement at the beginning of the experiment, composition of which is given in Appendix B. The cows were housed in an open-draft, free-stall barn, partitioned to facilitate individual feeding. Each stall was equipped with two feed

[1] Rhone Merieux, Lyon-France

[2] Cooper Kenya Ltd

[3] Welcome Ltd, Nairobi Kenya

[4] Alfasan, Woerden-Holland

troughs and a water trough, and cows were able to comfortably move around. The stalls had concrete floors, and no bedding was provided; they were cleaned every morning.

Experimental Design

The eight cows were divided into two groups each having similar milk yield based on milk production observed prior to commencement of the experiment. The two groups were used in a 4 x 4 cross-over design (Cochran and Cox, 1957). The change-over design was chosen to measure the direct effects of cows at post-peak lactation and to reduce variation among cows (Strickland, 1975). The four periods were 21 d each (14-d adjustment period and 7-d collection period). The treatments comprised a basal diet of fresh-cut napiergrass either fed alone or supplemented with legume hay or a commercial dairy meal. The treatments were 1) napiergrass basal diet fed alone (NG), 2) napiergrass supplemented with mucuna hay (MH), 3) napiergrass supplemented with lablab hay (LH), and 4) napiergrass supplemented with commercial dairy meal (CDM). Each of the four diets was allotted at random to one cow within a group.

Diets and Feeding Management

Napiergrass was used as basal diet because it is the major high yielding fodder available on smallholder crop-livestock production farms in western Kenya (Nyambati, 1997). The supplements were offered at iso-nitrogenous levels calculated to meet the requirement of a 350-kg cow producing 8 to 10 kg d^{-1} of 4% fat corrected milk (FCM) and with DMI of 2.7% of live weight (9.45 kg d^{-1}, necessary to fulfill nutrient requirement for maintenance, milk production, and normal live weight gain) (NRC, 1989). The digestible energy requirement will be met (calculation not shown) from the diets based on the estimation of DE (Mcal kg^{-1} DM) from NRC (1989) for napiergrass, and from the equation of Heaney and Pigden (1963) for mucuna and lablab. The basal

diet was fed ad libitum in two equal batches at 0800 h and 1600 h to ensure 10% refusal. The supplement portion was fed in a separate trough once at 0800 h every morning. Before morning feeding, refusals from each treatment were removed and weighed. A complete mineral mixture,[5] at a level of 170 g $head^{-1}$ d^{-1} was provided to ensure an adequate supply of all minerals. The animals had ad libitum access to clean drinking water.

Measurements

Feed intake, body weight changes, milk yield and composition, and total fecal output were measured. Orts were weighed every morning and feed intake recorded. Samples of feeds offered and refused were taken every morning in the last 7 d of every period. Body weight (BW) change of cows during each experimental period was determined using an Avery (Birmingham, England) weighing scale of 1000 x 1 kg precision attached to a weighing crate. Each estimate of BW was the mean of two weight records taken on two consecutive days. The animals were weighed prior to the morning feeding. The cows were milked twice daily at 0630 and 1430 h and individual cow milk yield was determined using a Waymaster (Precision Weighers, Reading, England) milk scale of 25 x 0.05 kg precision. Milk production is expressed as 4% FCM yield. Body condition changes were measured using a body condition score ranging from 1 to 9 (Kunkle et al., 1994). The scoring was done by three evaluators in the morning before feeding at the beginning and end of every collection period. Scores were used from the two evaluators that were closest to each other. During the last 5 d of the collection period the total daily

[5]Approximate elemental composition (% of DM): Ca = 15.2, P = 6.5, Na = 11.0, Chlorine = 17.0, Mg = 1.5, Fe = 0.4, Cu = 0.14, Mn = 0.2, Zn = 0.30, S = 0.2, Co = 0.016, I = 0.01, K = 0.003

fecal output of the cows was collected by stationing an attendant with buckets by each animal (Abdulrazak et al., 1997). Feces from every animal were weighed in the morning before feeding. In vivo apparent dry matter digestibility of diets was computed using feed intake and total feces (Osuji et al., 1993).

Sample Preparation and Chemical Analysis

Milk samples were taken on Tuesday and Thursday morning and afternoon during the collection period. Morning and afternoon milk samples were composited by cow for each day of sampling. Two subsamples were derived from the composite sample for each day. One subsample was analyzed for butterfat, density, solids-not-fat, and total solids. The other subsample was kept under refrigeration and later analyzed for CP. The Gerber method (Appendix C; Pearson, 1976) was used to determine milk butter fat on the same day the milk samples were taken. To determine total solids, the density of milk was measured by a lactometer calibrated at 20^0C. A correction for density of 0.24 for every 1^0C above 20^0C was made. The total solids were calculated using Fleischmann's formula, total solids = 1.2F + 2.665 (100D –100)/D, where F = % butter fat, and D = density (Pearson, 1976). The solids-not-fat was derived by difference (total solids-butter fat). Samples of feeds offered and refused were weighed and dried in an oven at 60^0C to constant weight for about 48 h and weighed again. Dry samples were bulked per cow and per treatment in each period before being subsampled for grinding. The samples were ground in a Christy Norris hammer mill to pass 1-mm screen and stored in airtight plastic bags. Feed samples were analyzed for CP, neutral detergent fiber (NDF), in vitro dry matter digestibility (IVDMD), Ca, P, lignin, and total soluble polyphenol. Each morning a sample of feces (approximately 300 g) from each cow was taken after mixing.

The sample was weighed and dried at 65^0C to constant weight in forced air oven. After drying, it was weighed again to determine the DM.

Total N, P, and Ca of feed and milk samples were determined following the procedures outlined by the Association of Official Analytical Chemists (AOAC, 1990). The NDF and lignin were determined by the method of Goering and Van Soest (1970) modified by Van Soest et al. (1991). In vitro dry matter digestibility was determined using the procedure of Tilley and Terry (1963). Total extractable polyphenols were determined using the Folin-Denis method as outlined by Anderson and Ingram (1993). The DE concentration was estimated from the regression equation, DE concentration = – 0.559 + 0.056X; R^2 =0 97 and SE = 0.083 (Heaney and Pigden, 1963) where X = digestible DM in g 100 g^{-1} DM.

Statistical Analysis

Analysis of variance using the general linear model procedure of SAS (SAS, 2001) was used to determine the effects of treatment diets on intake, apparent digestibility, milk yield and composition, body condition score, and BW changes. The analysis was done by the combined analysis of two Latin squares according to Cochran and Cox (1957). The statistical model was $\gamma_{ijkn} = \mu + \eta_i + \alpha_j + \beta_k + T_n + \varepsilon_{ijkn,}$, where γ_{ijkn} = observed value; μ = overall mean; η_i = effect of ith group (i = 1, 2); α_j = effect of jth period (j = 1, 2, 3, 4); β_k = effect of kth cow (k = 1, 2, 3, 4); T_n = effect of nth treatment (n = 1, 2, 3, 4); and ε_{ijkn} = experimental error.

Preplanned treatment comparisons were made using single degree of freedom contrasts (Montgomery, 1997). The comparisons were NG vs. MH + LH, MH vs. LH,

and MH + LH vs. CDM. The separation of means and pre-planned contrasts were done using the general linear model procedure in SAS (2001).

Results

Chemical Composition of Feeds

The chemical composition of the feeds is shown in Table 7-1. Napiergrass CP concentration was 68 g kg^{-1} compared to over 160 g kg^{-1} for the supplements. Lignin and polyphenol concentrations were 114 and 23.7 g kg^{-1} for mucuna and 86 and 18.8 g kg^{-1} for lablab. The DE concentration ranged from 2.68 Kcal kg^{-1} DM for mucuna to 2.81 and 2.95 Kcal kg^{-1} DM for napiergrass and lablab, respectively, to 3.76 Kcal kg^{-1} DM for dairy meal.

Intake, Fecal Output, and Apparent Digestibility

There was no difference in legume hay DMI between MH and LH treatments (Table 7-2). The cows provided CDM ate all daily supplement offered while those provided legume hay did not (68 and 78% of hay offered was consumed for MH and LH, respectively). Supplementation did not affect ($P>0.568$) DMI of napiergrass (Table 7-2), however, feeding MH, LH, and CDM increased ($P<0.001$) total dry matter intake (TDMI) by 21, 26, and 37% over the control, respectively, and TDMI expressed per unit of metabolic body weight (TDMI g kg^{-1} $BW^{0.75}$) by 20, 25, and 31%, respectively. Dairy meal supplementation had a greater positive effect on TDMI ($P = 0.003$) and TDMI expressed as g kg^{-1} $BW^{0.75}$ ($P = 0.005$) than did legume hay supplementation, but there was no difference ($P = 0.173$) between MH and LH.

Table 7-1. Chemical composition of feeds fed to experimental cows.

Constituents[†]	Feeds			
	Napiergrass	Mucuna Hay	Lablab Hay	Dairy Meal
DM (g kg $^{-1}$)	176	883	884	914
CP (g kg $^{-1}$ DM)	68.4	170	163	179
NDF (g kg $^{-1}$ DM)	712	564	565	485
Lignin (g kg $^{-1}$ DM)	44.2	114	85.8	38.3
Total polyphenol (g kg^{-1} DM) [‡]	Nd	23.7	18.8	13.2
P (g kg $^{-1}$ DM)	1.5	2.4	2.8	7.5
Ca (g kg $^{-1}$ DM)	3.2	14.7	14.7	10.5
IVDMD (g kg $^{-1}$ DM)	602	578	626	772
IVOMD (g kg $^{-1}$ OM)	579	529	591	756
DE (Kcal kg^{-1} DM)	2.81	2.68	2.95	3.76

[†] DM = dry matter; CP = crude protein; NDF = neutral detergent fiber; IVDMD = in vitro dry matter digestibility; IVOMD = in vitro organic matter digestibility; DE = Digestible energy estimated from the equation, DE = –0.559 + 0.056X; R^2 = 0.97 and SE = 0.083 (Heaney and Pigden, 1963) where X = digestible DM in g 100 g^{-1} DM.
Nd = not determined
[‡] Tannic acid equivalent

Table 7-2. Intake, fecal output, and apparent digestibility when Friesian cows were fed napiergrass alone or supplemented with legume hay or dairy meal.

Constituents[†]	Treatments					Contrasts		
	Napiergrass alone (NG)	Napier + mucuna (MH)	Napier + lablab (LH)	Napier + dairy meal (CDM)	SE	MH + LH vs NG	MH vs LH	MH + LH vs CDM
						----------P value----------		
NDMI (kg)	9.80	9.72	10.1	10.5	0.30	0.807	0.296	0.377
SDMI (kg)	-	2.06	2.20	2.90	0.07	nd	0.891	0.011
TDMI (kg)	9.80	11.8	12.3	13.4	0.31	< 0.001	0.173	0.003
NDMI (g kg^{-1} $BW^{0.75}$)	108	107	111	110	3.26	0.823	0.334	0.790
TDMI (g kg^{-1} $BW^{0.75}$)	108	130	136	142	3.27	< 0.001	0.065	0.005
DMFO (kg)	3.96	4.60	4.46	4.87	0.08	< 0.001	0.246	0.001
Fecal N (g kg^{-1} DM)	17.8	17.6	18.8	20.2	0.59	0.798	0.882	0.116
ADMD (g kg^{-1})	558	587	625	615	13.2	0.004	0.049	0.589

[†] NDMI = napiergrass dry matter intake; SDMI = supplement dry matter intake; TDMI = total dry matter intake; BW = body weight; DMFO = dry matter fecal output; ADMD = apparent dry matter digestibility; nd = not determined

Effect of supplementation on fecal output followed a similar trend to that for TDMI. Mucuna hay, LH, and CDM supplementation increased fecal output by 16, 13, and 23%, respectively, compared to napiergrass alone. However, supplementation had no effect (P = 0.384) on fecal N concentration. Compared to the control, supplementation increased apparent digestibility by 29, 67, and 57 g kg^{-1} for MH, LH, and CDM treatments, respectively. There was no difference (P=0.589) in in vivo digestibility of the DM between the average of the legume hay treatments and CDM (Table 7-2), however cows fed LH had a greater apparent DM digestibility than cows fed MH (P=0.049). Effect of supplementation on DE intake followed a similar trend to that of in vivo digestibility (Table 7-3).

Legume hay supplementation did not affect napiergrass CP intake (P=0.759), but it increased (P=0.001) total CP intake (Table 7-3) over the control. There was no difference (P=0.680) in total CP intake between mucuna- and lablab-supplemented cows, but the total CP intake of CDM-supplemented cows was higher than those of the legume hay-supplemented cows. Intake of DE followed trends similar to those for total CP intake except that cows fed LH diets had greater DE intake than cows fed MH diets.

Milk Yield

Cows supplemented with MH, LH, or CDM produced more raw milk and 4% FCM ($P \leq 0.004$) than those fed only napiergrass (Table 7-4). There was no difference ($P > 0.05$) in milk yield between MH and LH treatments. Cows supplemented with dairy meal produced more ($P < 0.001$) raw milk and FCM (25%) than those supplemented with legume hay.

Table 7-3. Crude protein intake (CPI) and digestible energy intake (DEI) of Friesian cows fed a basal diet of napiergrass alone or supplemented with legume hay or dairy meal.

Constituents[†]	Treatments					Contrasts		
	Napiergrass alone (NG)	Napier + mucuna (MH)	Napier + lablab (LH)	Napier + dairy meal (CDM)	SE	MH + LH vs NG	MH vs LH	MH + LH vs CDM
						----------P value----------		
NCPI (g d^{-1})	695	680	757	791	58.0	0.759	0.770	0.418
SCPI (g d^{-1})	-	343	367	522	37.2	nd	0.943	0.003
TCPI (g d^{-1})	695	1060	1090	1310	57.9	0.001	0.680	0.02
TCPI (g $kg^{-1}BW^{0.75}$ d^{-1})	7.7	11.7 [b]	12.0	13.8	0.63	0.001	0.759	0.055
DEI (Kcal d^{-1})	25.2	32.1	37.4	39.0	1.76	< 0.001	0.033	0.053

[†] NCPI = Napiergrass crude protein intake, SCPI = Supplement crude protein intake, TCPI = Total crude protein intake, DE = Digestible energy estimated from the equation DE = –0.559 + 0.056X; R^2 = 0.97 and SE = 0.083 (Heaney and Pigden, 1963) where X = digestible DM in g 100 g^{-1} DM, nd = not determined

Table 7-4. Milk production, body condition score (BCS), and body weight gain (BW Gain) of Friesian cows fed napiergrass alone or supplemented with legume hay or dairy meal.

Constituents†	Treatments					Contrasts		
	Napiergrass alone (NG)	Napier + mucuna (MH)	Napier + lablab (LH)	Napier + dairy meal (CDM)	SE	MH + LH VS NG	MH vs LH	MH + LH vs CDM
						----------P value----------		
Milk (kg cow^{-1})	3.32	3.75	3.80	4.72	0.05	0.004	0.868	< 0.001
FCM (kg cow^{-1})	3.62	4.22	4.18	5.27	0.06	< 0.001	0.778	< 0.001
Mean BCS	4.6	5.2	5.0	4.9	0.13	0.013	0.254	0.299
BW Gain (kg/7 d)	5	10	12	17	4.89	0.304	0.804	0.347

† FCM = 4% Fat corrected milk [FCM = (Milk yield x 0.4) + (Milk fat yield x 15)].

Milk Composition

Legume hay supplementation had no effect ($P<0.05$) on milk composition (Table 7-5). Yield of milk fat and CP per cow were greater for legume hay-supplemented than control animals (Table 7-5) because of higher milk production of supplemented cows. Milk from cows supplemented with LH had greater ($P<0.002$) P concentration than those supplemented with MH. Dairy meal supplementation produced milk that was greater in solids-not-fat ($P<0.001$), Ca ($P=0.046$), and P ($P=0.008$) concentration than that of cows supplemented with the legume hays.

Live-weight Changes and Body Condition Score

Supplemented animals tended to gain more weight (5, 7, and 12 kg for MH, LH, and CDM, respectively) than those fed napiergrass alone, but these differences were not significant (Table 7-4). The mean body condition score of legume hay-supplemented animals was greater than that of cows fed napiergrass alone.

Discussion

Chemical Composition of Feeds

The nutritive value of napiergrass was relatively low (Table 7-1) but it was within the ranges reported by Muinga et al. (1995), Kariuki et al. (1999), and Muia et al. (1999). In this study, the growth period for napiergrass was longer than originally anticipated due to fewer showers than normal during the dry season and the later than usual onset of the rainy season. The longer growth period likely resulted in lower napiergrass nutritive value. This is a relatively typical occurrence on farms, so the napiergrass used in the trial is considered representative of that fed in the region during the dry season.

Table 7-5. Milk composition of Friesian cows fed napiergrass alone or supplemented with legume hay or dairy meal.

Constituents†	Treatments					Contrasts		
	Napiergrass alone (NG)	Napier + mucuna (MH)	Napier + lablab (LH)	Napier + dairy meal (CDM)	SE	MH + LH vs NG	MH vs LH	MH + LH vs CDM
						----------P value----------		
MF (g kg^{-1})	46.0	48.4	46.7	47.8	0.37	0.328	0.350	0.888
MF (kg cow^{-1})	0.15	0.18	0.18	0.22	0.01	< 0.001	0.565	< 0.001
TS (g kg^{-1})	132	134	132	136	1.53	0.589	0.274	0.169
SNF (g kg^{-1})	86.0	85.9	85.1	87.9	0.51	0.414	0.330	< 0.001
MCP (g kg^{-1})	34.8	33.8	34.8	33.7	0.58	0.508	0.224	0.418
MCP (kg cow^{-1})	0.13	0.14	0.14	0.17	0.01	0.008	0.853	< 0.001
Ca (g kg^{-1})	11.1	11.1	10.8	11.3	0.13	0.431	0.078	0.046
P (g kg^{-1})	7.7	7.6	7.9	7.9	0.06	0.739	0.002	0.008

† MF = Milk fat, TS = Total solids, SNF = Solids not fat, MCP = Milk crude protein

Chemical composition of the legume hays was similar except for lignin concentration which was greater for mucuna. This may partially explain the greater IVDMD for lablab. In addition these responses are likely due to the 4-wk longer regrowth period for mucuna, associated with its delayed flowering. Lablab CP was similar to that reported in Nigeria when hay was harvested at a similar number of days after planting (Agyemang et al., 2000). Mucuna, harvested at the same flowering stage in Sri Lanka (Ravindran, 1988), had higher CP (206 g kg^{-1}) than in the current study (170 g kg^{-1}), likely due to the 50-d longer growth period required to reach 50% flowering in northwestern Kenya.

Apparent Digestibility and Intake

Apparent DMD was greater for the cows fed the supplement treatments than those fed the napiergrass control diet and was greater for cows fed LH than for those fed MH. Apparent DMD of napiergrass was 44 g kg^{-1} less than IVDMD, perhaps indicative of a CP deficiency of cattle fed the control diet, whereas apparent DMD of MH and LH diets were similar to IVDMD of mucuna and lablab hays. An increase in apparent DMD can be caused by longer retention times in the rumen associated with a decrease in intake. In this case, feeding legume hays increased apparent DMD while also increasing intake, supporting the argument that apparent DMD of the napiergrass control diet was limited by availability of CP to rumen microbes. It seems likely that the additional N from the legumes increased activity of the microbial population and increased the rate of digesta breakdown (Abule et al., 1995) to such an extent that even shorter retention time did not result in lower apparent DMD.

The feeding value of forage depends not only on the digestibility and chemical composition of the feed but also on the quantity voluntarily eaten. Of the variation in digestible DMI or DEI, 60 to 90% is thought to be due to differences in intake while 10

to 40% is due to differences in digestibility (Mertens, 1994). Intake can be expressed simply as the quantity of DM or digestible nutrients consumed, or to minimize the effects of body weight differences, intake can be expressed per unit of metabolic body weight.

Napiergrass DMI was lower than previously reported (Muinga et al., 1995; and Muia et al., 2000a), likely due to its maturity (Table 7-2). There was no observed substitution (i.e., negative associative effects on intake) of supplement for napiergrass in the diet, therefore feeding 2 to 3 kg DM d^{-1} of the three supplements served to increase total DMI. Similar increases in total DMI resulting from legume fodder supplementation to roughage diets have been reported by other workers (Muinga et al., 1992; 1995; and Muia et al., 2000b). Increased total DMI due to hay and dairy meal supplementation in the current study seems to be linked at least in part to N nutrition. Napiergrass CP concentration (68 g kg^{-1}) was lower than the requirement for maintenance of many classes of animals and was very likely deficient for lactating cows in this study (NRC, 1989). The occurance of CP deficiency was supported by the non-significant supplemental effect on fecal N. Assuming rumen degradability of CP in napiergrass of about 0.8, the rumen degradable protein concentration in the napiergrass control would be approximately 55 g kg^{-1} and the ratio of digestible energy (2.61 Kcal kg^{-1} DM) to rumen degradable protein of 1:21 would be well below 1:28 that is recommended by NRC (1989). The supplements provided additional CP, minimizing a deficiency which likely was limiting growth and cellulose digestion by rumen microbes (Poppi and Norton, 1995). The supplemental CP likely increased the rate of digesta breakdown, passage rate, and intake (Poppi and Norton, 1995; Nsahlai et al., 1998). These data support the hypothesis that rumen degradable

protein concentration was limiting in the control diet and provide evidence that protein supplementation of cattle fed napiergrass may often be needed in this production system.

Cattle ate all of the dairy meal offered resulting in higher intake of the CDM treatment than of MH and LH. Consumption of mucuna and lablab hays was 68 and 78% of that offered, respectively, and this resulted in lower intake of legume hay supplement and total CPI compared to the CDM treatment (Table 7-3). Greater CPI may have increased DMI of cattle on the CDM treatment, but it is not possible to separate the effects of additional CP and DE intake from the supplement. Refusal of legume hays likely was due in part to loss of leaf during hay harvest and leaf shattering during processing. Orts had a relatively high proportion of legume stem (not quantified) compared to the hay offered. Low palatability of the stem fraction or perhaps some other plant factor affecting palatability may have limited intake of legume hays. Mucuna hay had greater concentrations of lignin and lower concentrations of IVDMD than lablab hay and these factors contributed to lower apparent DMD of the MH diet. There also was a trend (P=0.173) toward lower DMI of the MH vs. LH diet, and DEI was lower for MH than for LH.

Milk Yield and Composition

Supplementation increased yield of raw and 4% FCM. The increase in 4% FCM relative to the control was 17, 15, and 46% for cows fed the MH, LH, and CDM diets, respectively. Milk production trends generally followed those of DMI and CPI, being greatest for the CDM treatment, intermediate and similar for the legume hay treatments, and least for the control. Digestible energy intake was greater for cows fed LH than MH, but this did not result in greater milk production for cows fed the LH treatment. The CP and DE intakes of supplemented cows met the requirements of a 350-kg Friesian cow

producing 10 kg of milk (NRC, 1989). All cows gained weight during the experiment, thus the increase in milk yield of cattle fed supplements can be attributed to greater DE intake and CPI rather than mobilization of body tissues. Supplemented cows also had higher body condition scores than control cows. Increases in milk yield due to supplementation were similar to those reported by Muinga et al. (1992; 1993; 1995) and Muia et al. (2000a). The cows produced on average 0.23 and 0.52 kg of additional milk (above the control) per kg of legume hay and dairy meal fed, respectively, and these data are comparable to the mean value of 0.34 reported by Combellas et al. (1979) across several experiments.

Milk fat, solids-not-fat, and protein concentrations of milk are at a maximum at the start of lactation, fall to a minimum for solids-not-fat and protein after 6 wk and for milk fat about 10 wk after parturition, and finally increase until the end of lactation (Pearson, 1976). Cows used in this experiment were in the latter part of lactation, and concentrations of these components were greater than those reported by Muia et al. (2000a) who used cows in early lactation. Although yield of fat and protein was increased by supplementation, their concentrations in milk were not affected by treatment. These results are consistent with those of Muinga et al. (1992) who reported that when dairy cows were fed a basal diet of napiergrass supplemented with leucaena forage there was no effect of supplement on milk composition. In the current study, solids-not-fat, Ca, and P concentrations were greater for cows fed the CDM than for those fed MH and LH, but these differences were small.

Conclusions

Mucuna and lablab hay supplementation did not affect napiergrass intake of lactating cows fed a napiergrass basal diet but did increase total diet DMI, apparent DMD, DE

intake, and milk production. Concentration of ruminally degradable CP in napiergrass was likely limiting microbial growth and forage digestion, and these data support the hypothesis that greater intake of CP from feeding the legume hays was important in increasing digestibility, intake, and animal performance.

Both mucuna and lablab are being tested for use as soil improving, green manures in smallholder, mixed-farming systems in western Kenya. These farmers also need feed for their livestock, and our results show that these legumes can provide good quality hay that can be used as a supplement to relatively low quality basal diets such as mature napiergrass. Despite widespread speculation that L-DOPA [3 - (3, 4-dihydroxyphenyl) alanine] in mucuna may be detrimental to livestock, results from this study do not support that conclusion, at least in diets where mucuna constitutes only about 20% or less of the dietary DM. Incorporation of these legumes into farming systems could improve milk yield and also result in increased maize yield following the relay cropping of legume green manures with previous maize (Chapters 4 and 5).

CHAPTER 8
CONCLUSIONS, SYNTHESIS, AND RECOMMENDATIONS

The overall objectives of this study were 1) to assess the productivity of relay-cropped legume green manures and their effect on maize (*Zea may* L.)-bean (*Phaseolus vulgaris* L.) intercrop performance, 2) to gain greater understanding of the N-release from soil-incorporated legume residue and its uptake by succeeding maize, 3) and to determine the effect of harvesting top canopy biomass of legumes as fodder for livestock on their contributions to soil enhancement and livestock nutrition. The overall study is presented in five parts as found in Chapters 3 through 7 of the dissertation.

Chapter 3 reports on the N contribution of relay-cropped mucuna [*Mucuna pruriens* var. Utilis (L) DC (Wright) Burck] and lablab [*Lablab purpureus* L. (Sweet) cv. Rongai] to the succeeding maize-bean intercrop when part of the legume biomass was harvested for fodder. Mucuna had a higher leaf-to-stem ratio (1.43) than lablab (0.82). Defoliation to a 10-cm stubble reduced the high N-containing leaf fraction in mucuna to a lesser extent (40%) than lablab (80%). The effect of legume residue incorporation on maize growth was greatest between 8 and 21 wk after planting (WAP) when maize biomass yield was higher in legume treatments than the natural fallow. The greater maize biomass under legume treatment was a result of N uptake by maize, which was greater between 8 and 10 WAP in the legume residue plots than the natural fallow control. Maize growth and N uptake was highest under undefoliated lablab (UD-L), and defoliation of lablab resulted in reduced performance while for mucuna it had no effect. At 8 WAP, when the demand for N by maize was high, the N recovery was greatest

under UD-L (27%). The mean recovery across all time periods was in the range of 21% for cattle manure to 52% for UD-L. The N recovery for defoliated mucuna (D-M) plots averaged 45% compared to 35% for undefoliated mucuna (UD-M). Maize grain yield followed similar trends as N uptake, and was in the order of inorganic N = UD-L > cattle manure = D-M > UD-M = defoliated lablab (D-L) > natural fallow.

In Chapter 4 the effect of legume cropping system, defoliation regime, and cropping sequence (number of years of residue application) on subsequent maize and beans were evaluated on the research station. Relay-cropped mucuna and lablab survived the dry season producing a total biomass yield of 4 and 2.7 t ha^{-1}, respectively, and contributing 78 and 57 kg N ha^{-1}. After 1 yr of residue application, UD-L yielded more (6.5 t ha^{-1}) maize grain than UD-M (5.2 t ha^{-1}), and defoliation reduced grain yield following lablab, but not following mucuna. Legume residue treatments yielded more (5.6 t ha^{-1}) than the natural fallow control (4.4 t ha^{-1}). Both after one and two consecutive years of residue application, mucuna plots yielded higher (510 kg ha^{-1}) bean grain than lablab (372 kg ha^{-1}), and mean bean grain yield on plots after 1 yr of residue application (437 kg ha^{-1}) were not different from those where residue had been applied for two consecutive years (446). Maize grain yield after 2 yr of residue application showed that D-M outyielded D-L, whereas UD-L outyielded UD-M, suggesting that the residual effects were higher under UD-L and D-M treatments. Defoliation of mucuna resulted in grain yield increase after 2 yr of residue application, but defoliation of lablab reduced grain yield. Generally, there was no apparent advantage of applying residue for two consecutive years (5.3 t ha^{-1}) compared to 1 yr (5.1 t ha^{-1}), but UD-L after 2 yr (6.7 t ha^{-1}) yielded higher maize grain than after 1 yr (5.6 t ha^{-1}). Across the 2 yr, legume residue treatments resulted in higher

yields (5.2 t ha^{-1}) than the natural fallow control (4.1). Maize grain yields from plots where the residue was applied the previous year but not in the current year, showed that the treatments with lower quality residue (D-M, UD-L, and D-L) resulted in the highest residual effects, and the yields under these treatments were higher than the natural fallow that had not received any N the previous year.

The results from Chapter 4 and those reported in Chapter 3 showed that mucuna residue had a greater proportion of leaf fraction in total residue biomass, whereas lablab had a greater proportion of low quality stem, suggesting that lablab residue was likely of lower quality than mucuna. Defoliation of mucuna resulted in residue of intermediate quality due to the reduced proportion of high quality leaves. Defoliation of lablab, which has an upright growth morphology, removed a greater proportion of the above-ground biomass (0.76) than for mucuna (0.52). After two years of consecutive residue application, D-M and UD-L treatments resulted in subsequent maize grain yield increases, suggesting that the efficiency of N uptake by subsequent maize and residual effects were higher under residues of intermediate than high quality. Our hypothesis was that the incorporation of intermediate quality (low N and P, high lignin) residue at the onset of rain extends the time period of nutrient availability to succeeding maize, resulting in increased efficiency of N recovery due to reduced losses. The results show that in the sub-humid highlands of northwestern Kenya, the use of green manure technology could be enhanced by relay cropping the legumes in maize and removing part of the biomass for livestock feed before incorporating the remaining intermediate quality stubble and roots to succeeding maize-bean intercrop.

Chapter 5 describes the evaluation of relay-cropped mucuna and lablab on low soil fertility, smallholder farms in the sub-humid highlands of northwestern Kenya. On farmers' fields where nutrient depletion is more severe than on the experiment station, mucuna yielded more biomass (2.3 t ha^{-1}) than lablab (0.75) and contributed more nutrients. This resulted in greater maize growth and grain yield after mucuna residue application than after lablab. Green manure treatments (UD-M, D-M, and UD-L) resulted in 97, 54, and 41%, respectively, greater grain yields than the natural fallow control where no N was applied. This study revealed that when biomass yield of green manures are very low the positive effects of defoliation on residue quality did not result in better maize performance. Stability analysis of maize grain yield showed that on farms where the legume herbage yields were higher, the defoliation of mucuna did not reduce the grain yield achieved by the undefoliated mucuna, suggesting that farmers could utilize the top-canopy biomass for fodder when the legume biomass yields are higher.

The plant-part proportions and nutritive value of top canopy herbage of mucuna and lablab defoliated to 10-cm stubble are reported in Chapter 6. The results show that defoliation at 10 cm above ground provides an average of 1 to and 1.8 t ha^{-1} of mucuna and lablab fodder, respectively, that is of high CP (130 and 111 g kg^{-1}, respectively) and digestibility (617 and 693 g kg^{-1}, respectively). These yields were 52 and 76% of the above-ground leaf + stem herbage from mucuna and lablab, respectively, suggesting that the upper canopy herbage has potential as dry-season protein supplement, but this practice significantly reduces the quantity of nutrients that are soil incorporated.

The objective of the feeding experiment reported in Chapter 7 was to evaluate the effects of feeding mucuna and lablab hay as supplements to lactating dairy cows fed a

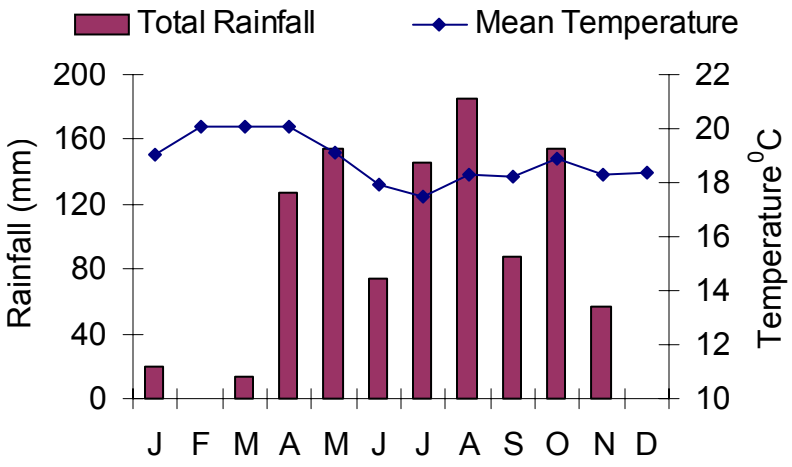
basal diet of napiergrass on dry matter intake and digestibility, body condition and body weight gain, and on the quantity and quality of milk and manure produced. The CP of mucuna and lablab hay (170 and 163 g kg^{-1}, respectively) was comparable to that of commercial dairy meal (179 g kg^{-1}), and their feeding as supplements to low quality napiergrass increased total dry matter intake (130 and 136 g kg^{-1} $BW^{0.75}$, respectively) compared to napiergrass alone (108 g kg^{-1} $BW^{0.75}$). Legume hay supplementation also increased apparent digestibility (587 and 625 g kg^{-1}, respectively) compared to napiergrass (558 g kg^{-1}), and daily yield of 4% fat corrected milk (4.20 and 4.12 kg) compared to napiergrass (3.69 kg). The results show that milk production can be increased in smallholder mixed farming systems by supplementing a napiergrass-based diet with mucuna or lablab hay, highlighting the importance of integrating legumes into the low-input, mixed cropping systems.

Based on the studies presented here, the following recommendations can be drawn:

1. Relay cropping mucuna or lablab in the current maize-common bean intercrop has potential to increase grain yields of subsequent maize and beans when P is not limiting.
2. The impact of defoliating upper canopy herbage of legumes as fodder on yields of subsequent maize and beans depends on the legume growth morphology. Defoliation of lablab, which has upright growth habit, decreases grain yields of subsequent maize, but it does not eliminate its longer term residual effects on soil fertility. Defoliation of mucuna enhances the synchrony of N release with maize demand for the current crop, and appears to increase the longer term residual effects on soil fertility.

3. There is no apparent advantage of incorporating undefoliated mucuna residue for two consecutive years compared to one year, but application of lablab residue for two consecutive years has cumulative residual effects.
4. Farmers can skip one year of residue application and still realize some residual benefit of residue applied the previous year.
5. Feeding part of mucuna or lablab herbage as dry season protein supplement to lactating cows has potential to increase milk yield and cattle manure output. The fodder quality of mucuna is comparable to that of lablab, therefore harvesting the top-canopy biomass of either mucuna or lablab as fodder can improve the productivity of smallholder low-external input mixed crop-livestock systems by providing benefits in addition to soil fertility improvement, such as increased milk and manure yields. This could increase the adoption of the green manure technology.
6. Future research should focus on the efficiency of N uptake and recovery in relation to different times of residue application in relation to onset of rains and planting of maize. Also on-farm evaluation of mucuna and lablab as supplements for dairy cows feeding on low quality feeds such as maize stover and napiergrass should be undertaken to elucidate the potential of these legumes in providing additional benefits to the smallholder farmers.

APPENDIX A
TOTAL MONTHLY RAINFALL AND MEAN MONTHLY TEMPERATURES
RECORDED AT NARC–KITALE, KENYA, IN 2000



APPENDIX B
COMPOSITION OF MULTIVITAMINS FED TO EXPERIMENTAL COW

INGREDIENT	COMPOSITION
Vitamin A	15,000 I.U
Vitamin D3	1,000 I.U
Vitamin E	20 ug
Vitamin B1	10 mg
Vitamin B2	6.85 mg
Vitamin B6	3 mg
Nicotinamide	35 mg
Vitamin B12	50 mg
Dexpanthenol	25 mg

APPENDIX C
GERBER METHOD FOR BUTTER-FAT DETERMINATION IN FRESH MILK

1. Put 10 ml sulphuric acid in the butyrometer.
2. Mix the milk and add 11 ml into the butyrometer. Avoid mixing with the acid.
3. Add 1 ml amyl-alcohol (density 0.815).
4. Fix the stopper, wrap in a cloth and shake while holding the stopper.
5. Turn the butyrometer upside down a few times.
6. Place it in a water bath at $60^0 – 70^0$C for 10 min.
7. Centrifuge at 1100 rpm for 5 min.
8. Put it back to the water bath for 5 min before reading.
9. Results are expressed as percentage or g butter fat per 100 ml of milk.

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BIOGRAPHICAL SKETCH

Elkana Momanyi Nyambati was born on 20 Dec. 1961, in Kisii District in Kenya. Nyambati attended Ngenyi Primary School between 1968 and 1974. His seccondary and high school education were obtained between 1975 and 1980 at Nyansabakwa in Kisii and Strathmore School in Nairobi, respectively. Nyambati attended Egerton University in 1981and graduated with a Distinction Diploma in Range Management in 1984 and was immediately employed by Kenya's Ministry of Agriculture and Livestock Development as a Technical Officer. He was posted to Kajiado District where he worked as an Agricultural Extension Officer. In 1985, he was transferred to the Scientific Research Division of the same ministry (later the Kenya Agricultural Research Institute, KARI) and posted to the National Agricultural Research Centre (NARC) at Kitale. In 1986 Nyambati joined the University of Nairobi on a study leave where he graduated with a BSc degree (honors) in 1989. He was immediately awarded a University of Nairobi scholarship to pursue an MSc degree which he obtained in 1993. Between 1994 and 1997, Nyambati worked as a Research Scientist in KARI at NARC-Kitale. Nyambati is currently on a study leave at the University of Florida where he is pursuing a doctoral degree in agronomy on a Rockefeller Foundation Scholarship. Nyambati is married to Florence and they have three children, Kelvin, Newton, and Nancy.