ABSTRACT

NJUNIE, MICHAEL NGUNJIRI. Evaluation of forage legumes for soil fertility improvement in maize/cassava production systems. (Under the direction of Michael Gary Wagger.)

Soil fertility decline is a major factor limiting crop production in smallholder farms in sub-Saharan Africa. Coastal Kenya farmers are aware of the problem of declining soil fertility caused by continuous cropping without returning nutrients, soil erosion, burning of plant residues, and short fallow intervals in food crops production. This research examined intercropping of forage legumes as potential nutrient sources in maize and cassava production systems. The overall objective was to study the effects of harvest frequency and developmental stage at harvest of an annual (dolichos) and perennial (clitoria) forage legume on: i) biomass and nutrient accumulation ii) rate of nutrient release from the respective legume residues, and iii) availability of residue derived nutrients to maize and/ or cassava. The design for the experiments was a split-plot with five replications, consisting of cropping system (main plot) and harvest management (subplot) factors. Main plot treatments were clitoria or dolichos grown as monocultures or as an intercrops with two tropical food crops (cassava and maize). Clitoria was first cut at 2 mo after planting, and subsequently every 6 or 10 wk after the first cut, while dolichos was cut at 2 and 4 mo after planting the legume. The harvested foliage was applied as surface mulch. A third experiment monitored the decomposition and nutrient release from clitoria and dolichos residues. Following each legume harvest, three replicates of nylon mesh bags containing legume residue as intact plants were placed on the ground surface within their respective cropping system and legume management plots, and then retrieved at 0, 1, 2, 4, 8 and 16 wk in the field. Nonlinear regression equations for percentage of original dry weight, N, P, K, Ca, and Mg

remaining at each retrieval date were determined by cropping system and legume cutting strategy and data was fit to single, double, and asymptotic models of NLIN procedure.

Results from the maize/cassava production experiments revealed that the legumes accumulated nutrients (2-yr avg.) ranging from 50 to 101kg N ha^{-1}, 4 to 8kg P ha^{-1}, 33 to 83 kg K ha^{-1}, 7 to 32 kg Ca ha^{-1}, and 5 to 7 kg Mg ha^{-1} during the long rain season, with dolichos producing the greater values. Unlike the long rain season, nutrient contents of clitoria were greater than dolichos during the short rain season, with values ranging from 36 to 54 kg N ha^{-1}, 3 to 5 kg P ha^{-1}, 26 to 40 kg K ha^{-1}, 5 to 8 kg Ca ha^{-1}, and 5 to 7 kg Mg ha^{-1}. Intercropping reduced nutrient contents of the legumes to < 80% of the monoculture, and was most pronounced for clitoria intercropped with cassava. Delayed harvest of dolichos from two to four mo after planting increased dolichos nutrient accumulation between two and fourfold, but harvest management was not significant for clitoria nutrient accumulation.

As expected, fertilizer inputs increased maize and stover yields by 70% over maize grown without fertilizer inputs. Intercropping maize with clitoria increased grain and stover nutrient accumulation by values ranging from 50 to 80%, compared to maize monoculture without fertilizer inputs, while intercropping maize with dolichos yielded less grain and stover. Cassava monoculture resulted in the greatest tuber yields (9 Mg ha^{-1}), while intercropping of cassava with a legume reduced tuber yield by an average of 21%. Overall, positive nutrient balance results occurred for maize monoculture systems supplied with fertilizer, and maize/legume intercropping systems with maize stover returned to the system and P supplied to the legume as inorganic fertilizer. Generally, the presence of cassava in a cropping system resulted in negative N and K balances, supporting the need to review N and K replenishment recommendations for maize and/or cassava cropping systems in the region.

Results of the decomposition and nutrient release study revealed that an asymptotic model best described clitoria and dolichos dry matter disappearance across different harvest management strategies, while legume residue decomposition rates were unaffected by cropping system. The rate coefficients for dry matter disappearance of clitoria and dolichos residues were 0.2 and 0.5 wk^{-1}, respectively. Similarly, nutrient release from clitoria and dolichos residues best fit an asymptotic model. The *k*-values obtained for dolichos showed the greatest variation (0.2 to 2.5 wk^{-1}) compared to those obtained for clitoria (0.3 to1.0 wk^{-1}). Nitrogen release was generally slowest in clitoria and in dolichos 4 mo cut foliage. Across harvest management strategies, the general order of nutrient release was K > P > Mg > N, while that of dolichos cut at 2 mo was K>Mg> N>P and K>N>P>Mg for dolichos cut at 4 mo.

Calculations of the area by time equivalent ratios (ATER) based on totals of long and short rain seasons' yields of maize, legume, and cassava revealed that intercropping of clitoria or dolichos with maize or cassava resulted in the most efficient way of utilizing land area and time, with the longer cutting intervals of legume indicating a more efficient use of space and time. The ATER for clitoria intercropping with maize and/and or cassava ranged from 1.2 to 1.6, while that of dolichos ranged from 1.1 to 2.0. Generally, greater values of ATER were observed where the basis for the comparisons was the no fertilizer input control, implying that advantages of intercropping would be noticeable in situations where fertilizer inputs are a constraint, as is the case in coastal Kenya.

These results demonstrated the legumes potential to supply nutrients for maize grain and cassava tuber production, and indicated that biological efficiency may be improved by intercropping maize with legumes. The need to develop N and K replenishment recommendations for cropping systems with cassava is suggested. Further research aimed at reducing nutrient losses by synchronizing nutrient release with principal crop demand is recommended.

Evaluation of forage legumes for soil fertility improvement in maize/cassava production systems

by

Michael Ngunjiri Njunie

A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

SOIL SCIENCE

Raleigh

2002

APPROVED BY:

Robert L. Mikkelsen, Ph.D	**James Paul Mueller, Ph.D**
Thomas Jot Smyth, Ph.D	**Michael Gary Wagger, Ph.D** **Chair of Advisory Committee**

Biography

Michael Njunie was born and raised at Othaya, Nyeri, Kenya. His Parents, Mariamu Wambui and Zacharia Njunie, brought him up with his three brothers. He obtained a Certificate of Primary level Education (C.P.E.) from Birithia Primary School, 1971, an East African Certificate of Education (E.A.C.E.) in 1975, and East African Advanced Certificate of Education (E.A.A.CE.) from Nyeri High School 1977. Michael graduated with a BSc. degree (Agriculture) from Nairobi University, Kenya, in 1981. He obtained a Masters of Science degree (Grassland Science) from Reading University, UK, in 1985. He is currently an employee of Kenya Agricultural Research Institute (KARI), as research scientist focusing mainly on forage agronomy. Michael was awarded a grant by The Rockefeller Foundation to pursue his Ph.D. in Soil Science at North Carolina State University (NCSU), Raleigh, North Carolina, U.S.A. Michael has made numerous presentations on forage research at national, regional, and international workshops and conferences, and has co-authored a journal paper. Michael is happily married and has three lovely children.

Acknowledgements

There are several people I would like to acknowledge. I thank Dr. Michael Wagger, chair of my graduate committee, for his advice and guidance throughout my study. It has been a greatly rewarding experience for me while working with him. I thank the other members of my graduate committee, Dr. Robert Mikkelsen, Dr. Paul Mueller and Dr. Jot Smyth, for providing valuable comments towards my research and the dissertation. I also thank Dr. Marcia Gumpertz for her guidance in statistical analysis. I also thank Dr. Pedro Luna-Orea for sharing his experiences on data analysis. I thank the Rockefeller Foundation for offering me a full fellowship to complete my Ph.D program. The kind support by the Foundation's staff in Nairobi and New York Fellowship Offices is highly appreciated. I cannot forget to thank Dr. Elizabeth Dyck and Dr. Joseph Mureithi for their useful ideas when developing the original proposal, and encouraging me to start my Ph.D. I also thank Dr. Cheryl Palm, our link to TSBF/ICRAF, Nairobi, where part of the soil and plant analyses occurred. I would like to thank several field and laboratory technicians for their contributions towards successful implementation of the field study and laboratory analyses. In TSBF/ICRAF, I thank Mr. Wilson Ngului and Benson Musau for their commitment to analyzing soil and plant samples. In Mtwapa, I thank Samuel Bimbuzi, Gibson Furaha and William Muriithi for laboratory sample preparations and field data collection. In NCSU, I thank Mr. Robert Walters for freely sharing of his field and laboratory experiences with me, Peggy Longmire for helping me in preparation and analyzing soil samples, Beverly Taylor and Lisa Lentz for analyzing most of the plant samples. Also, I thank Bertha Monar, for making all necessary arrangements for shipping of the plant samples from Kenya to North Carolina. To the

Director of KARI and Center Director Mtwapa, I say thank you for providing a site for field study, and logistical support while carrying out the study. Finally, I thank my wife Susan, and my children, Scola, Zachary and Minnie, for standing with me during the whole process, and consistently reminding me that I should spend more time with them. To all mentioned above and many who worked with me sometimes under the intense temperatures in Kenya, I sincerely thank you all, and pray for God’s blessings upon your lives.

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CHAPTER 1

Introduction

The Kenyan coast is part of a lowland strip bordering the Indian Ocean and characterized by higher temperatures compared with the highlands of the interior. It stretches from Somalia in the north to the tip of South Africa in the south. The coastal region of Kenya has good potential for farming because it receives relatively higher rainfall compared to the immediate semi-arid hinterland. It also has large urban centers like Mombasa that serves as main port for goods destined for the interior. These large urban centers and a flourishing tourism industry create high demand for crop and livestock products.

One way to satisfy the demand for food is through improvement of land productivity of both crops and livestock. To improve agricultural productivity of the coastal lowlands, the Kenya Agricultural Research Institute (KARI) has one of its Research Centers located within the coastal region. The Regional Research Center, Mtwapa (RRC-Mtwapa), is situated 20 km north of Mombasa. The RRC-Mtwapa is mandated to carry out adaptive research relevant to the coastal region's crop and livestock production systems (RRC Mtwapa report number 2, 1995). On-going research programs broadly cover the development of suitable crop varieties, improvement of crop and livestock management practices, and the use of sustainable resource management for smallholder farming. The Research center is located in a transitional area between the coconut-cassava (CL3) and cashewnut-cassava (CL4) zones, the main agroecological zones (AEZ) in the coastal region. The CL3 zone has a medium to long cropping season (155 to 175 d) start with a 60% reliability in mid-Mar, and decrease gradually until Oct. The short rain season (75 to 105 days) start towards the end of Oct, lasting until Dec or Jan but with no pronounced end, and variability is high. The CL4 zone has a medium first cropping season (115 to 155 days) and a short second cropping season (40 to 75 days). In CL3, the average annual rainfall ranges from 1000 to 1230 mm, while that of CL4 ranges from 800 to 1100 mm. The dominant soils have a sandy surface and are low in fertility. The soils have low levels of N, P, and organic matter, along with low cation exchange and water holding capacities (Boxem et al., 1987). The regions major constraints to farming include poor soils and erratic rainfall distribution (Jaetzold and Schimdt, 1983).

Cropping systems

Tree crops, mainly coconut (*Cocos nucifera*) and cashewnut (*Anarcadium occidentale*), are the dominant cash crops. Fruit trees [citrus species, mangoes (*Mangifera indica*)] and oil crops are also grown. Maize (*Zea mays*) is the main staple food crop and cowpea (*Vigna unguiculata*) is the main pulse crop grown in the region. Cassava (*Manihot esculenta*) is the second important staple crop and is widely grown because of its low input requirements. It is also adaptable to the poor soils and erratic rainfall in the region. Intercropping of maize, cassava, and cowpea is a common practice. Maize is planted first at the onset of rains, while cassava and cowpea are often planted together three to four wk later after, the first weeding of maize. Maize yields from farmers' fields when planted at the onset of the main rainy season ranges from 1 to 2 tons ha^{-1}, while the short rains crop is about half of that obtained during the long rains (Waaijenbeg, 1994). Cassava yields range from 5 to 15 tons ha^{-1} for sole crops, but considerably less when planted as a relay crop at low densities. Yields of cassava are more reliable than those of maize (Waaijenbeg, 1994). However, yields of both crops are too low to satisfy food requirements in most households. In a farming systems survey in a representative area (Thorpe et al., 1992b), household plots were small, with over 75% between two to six ha. The farming systems are based on labor intensive, low input, risk averse practices. Fertilizers, whether inorganic or organic, are rarely used.

Objectives

The overall objective was to study the effects of harvest frequency and developmental stage at harvest of annual and perennial forage legumes on: i) biomass and nutrient accumulation by clitoria (*Clitoria ternatea*) and dolichos (*Lablab purpureus*), ii) rate of nutrient release from the respective legume residues, and iii) availability of residue derived nutrients to maize and/ or cassava.

Research Approach

Two experiments were carried out concurrently. In the first experiment, the perennial legume clitoria was evaluated primarily for biomass and quality of foliage produced, and soil fertility improvement. By harvesting the legume every six or ten wk, it was thought that competition (especially for light) with the maize and /or cassava crop would reduced In addition, the legume foliage would likely differ in terms of biomass produced and nutrient concentration due to the harvest frequency. The quantities and quality of the foliage produced may also be influenced by the presence or absence of the maize and/or cassava in the cropping system. The harvested foliage was used as mulch and to supply plant nutrients to the accompanying maize or cassava crop. Considering that more than 40% of the original dry weight of legume foliage may be lost within two wk after slashing a legume cover crop, application of the mulch to an already established maize or cassava crop may ensure a more efficient use of the plant nutrients released from the residues because of more immediate uptake by the accompanying crops. Also, nutrients may be available to the maize and/or cassava crops through root exudes and/or decaying roots and nodules. Perennial legumes are slow in initial growth, but once established, they accumulate dry matter quickly and withstand frequent cutting. Successful establishment of perennial legume in the interrow spacing of the maize/cassava is expected to restrict weed growth, control leaching of nutrients and soil erosion on steep terrain, and contribute to the recycling of plant nutrients.

A second experiment evaluated an annual legume dolichos for soil fertility improvement. Dolichos has a larger seed and the rate of establishment is faster compared to perennial legumes. However, annual legumes lack re-growth ability after cutting. To ensure availability of legume forage during the two possible cropping seasons, two planting dates (long rain and short rain seasons) were utilized. In order to produce adequate legume mulch without an adverse effect on maize production, two stages of harvesting (two and four mo after planting) were compared. During the first year of production, cassava in the latter half of the long rain season, and short rain season of maize, were expected to benefit from nutrients supplied by the legume mulch.

Results obtained would be useful in estimating nutrient budgets of the different cropping systems, evaluating the biological efficiency of intercropping forage legumes in maize and/or cassava cropping systems, and may be a step towards integrating crops and livestock farming.

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CHAPTER 2

Intercropping and Harvest Management of Two Tropical Legumes in Maize and Cassava Production Systems

ABSTRACT

Crop yields in coastal Kenya are limited by poor soils and erratic rainfall. Legumes as cover crops and intercrops have potential to improve land productivity by increasing soil fertility through N fixation and decomposition of foliage green manure. A two-year field study was conducted in fine-loamy, kaolinitic, isohyperthermic, arenic Paleustalfs to evaluate the effects of an annual legume (*Lablab purpureus*) cut at 2 or 4 mo after planting and a perennial legume (*Clitoria ternatea*) cut every 6 or 10 wk for biomass and nutrient accumulation, availability of residue derived nutrients to maize (*Zea mays*) and /or cassava (*Manihot esculenta*), and changes in soil chemical characteristics. In addition, the effects of commercial fertilizer on crop yields and nutrient accumulation were evaluated. Two crops of maize and dolichos were grown per year, utilizing long and short season precipitation.

Results from the maize/cassava production experiments revealed that the legumes accumulated nutrients (2-yr avg.) ranging from 50 to 101kg N ha^{-1}, 4 to 8kg P ha^{-1}, 33 to 83 kg K ha^{-1}, 7 to 32 kg Ca ha^{-1}, and 5 to 7 kg Mg ha^{-1} during the long rain season, with dolichos producing the greater values. Unlike the long rain season, nutrient contents of clitoria were greater than dolichos during the short rain season, with values ranging from 36 to 54 kg N ha^{-1}, 3 to 5 kg P ha^{-1}, 26 to 40 kg K ha^{-1}, 5 to 8 kg Ca ha^{-1}, and 5 to 7 kg Mg ha^{-1}. Intercropping reduced nutrient contents of the legumes to < 80% of the respective monocultures, and was most pronounced for clitoria intercropped with cassava. Delayed harvest of dolichos from two to four mo after planting increased dolichos nutrient

accumulation between two and fourfold, but harvest management did not influence nutrient accumulation by clitoria. Fertilizer inputs increased maize and stover yields by 70% over maize grown without fertilizer inputs. Intercropping maize with clitoria increased grain and stover nutrient accumulation by values ranging from 50 to 80%, compared to maize monoculture without fertilizer inputs, while intercropping maize with dolichos yielded less grain and stover. Cassava monoculture resulted in the greatest tuber yields (9 Mg ha^{-1}), while intercropping of cassava with legume reduced tuber yield by 21%. Soil chemical characteristics were only modestly affected by treatment variables. Positive nutrient balances occurred for maize monoculture systems supplied with fertilizer, and for maize/legume intercropping systems with maize stover returned to the system and P supplied to the legume as inorganic fertilizer. Generally, the presence of cassava in a cropping system resulted in negative N and K balances, supporting the need to review N and K replenishment recommendations for maize and/or cassava cropping systems in the region.

Calculations of the area by time equivalent ratios (ATER) based on totals of long and short rain seasons' yields of maize, legume, and cassava revealed that intercropping of clitoria or dolichos with maize or cassava resulted in the most efficient way of utilizing land area and time, more so with the longer cutting interval. The ATER for clitoria intercropping with maize and/and or cassava ranged from 1.2 to 1.6, while that of dolichos ranged from 1.1 to 2.0. Generally, greater values of ATER were observed where the basis for the comparisons was the no fertilizer input control, implying that advantages of intercropping would be noticeable in situations where fertilizer inputs are a constraint, as is the case in coastal Kenya. These results demonstrated the legumes potential to supply nutrients for maize grain and cassava tuber production. Further research aimed at reducing nutrient losses by synchronizing nutrient release with principal crop demand is recommended.

INTRODUCTION

Soil fertility decline is a major factor limiting crop production in smallholder farms in sub-Saharan Africa (Sanchez et al., 1997; Nandwa and Bekunda, 1998). In coastal Kenya, the main constraints to farming include low soil N and P contents, organic matter, CEC, and water holding capacity (FURP, 1994). Exacerbating these constraints are soils susceptible to nutrient leaching during the rain season. The loss of nutrients can lead to land degradation and environmental pollution. Food production, particularly maize, is not adequate to sustain farm families from one harvest season to the next. The loss in yield potential has been attributed to unreliable rainfall (Jaetzold and Schmidt, 1983), low inherent soil fertility (FURP, 1994), limited use of inputs (Mose, 1998) and weed infestation (Gacheru et al., 1993). Coastal Kenya farmers are aware of the problem of declining soil fertility caused by continuous cropping without returning nutrients, soil erosion, burning of plant residues, short fallow intervals in food crops production, overgrazing and shallow cultivation (Mureithi et al., *19*96). The common methods used by farmers for managing soil fertility include the use of farm yard manure, plant residues, and intercropping with grain legumes. The use of farmyard manure is limited by its availability, while few farmers use inorganic fertilizer because of its unavailability and high cost. Also, the grain legumes commonly used as intercrops with maize are efficient in translocation of N to the grain and may result in net N removal from the field through harvested grain (Karlen et al., 1994; Peoples et al., 1995). In such situations, the potential contribution of improved management of crop residues and legume green manure to improve soil fertility assumes great importance. Among the solutions advocated to reverse declining crop and soil productivity are the introduction of cropping systems that conserve moisture and soil fertility (Lal, 1986). It has been suggested that increased agricultural output in sub Saharan-Africa requires improved farming systems, integrating traditional and modern technologies, as farmers are more likely to adopt modifications to existing farming systems than completely new enterprises (Nnadi and Haque, 1986).

There is considerable literature relating to the use of forage legumes in sub-Saharan Africa, especially as components of grass/legume mixtures, fodder banks, intercrops, and relay cropping systems (Nnadi and Haque, 1986; Thomas and Sumberg, 1994). Despite the wide scope of research conducted, the practice of growing legumes specifically for forage is limited. Principal crop-based systems present an opportunity for legume introductions, if the benefits can be quantified. The potential of legumes to improve soil fertility through biological N fixation, either as green manures (Wade and Sanchez, 1983; Buresh et al., 1996; Rochester et al. 2001) or cover crops (Luna-Orea and Wagger, 1996; Wortmann et al. 2000) is well documented in the tropics. In addition, the maintenance of plant residues on the soil surface improves soil productivity by increasing soil organic matter, fertility, tilth, water storage capacity, and microbial activity (Lal, 1986; Keisling *et al.,* 1994; Rochester et al., 2001).

Intercropping of food crops is a common practice in Africa (Okigbo, 1976,1978; Norman et al., 1995). The farmers' reasons for intercropping in Africa is often due to a desire for yield stability, ensuring food security for the family. Intercropping legumes in cassava and maize provided a continuous ground cover which reduced runoff, soil loss, and also contributed to yield gains in succeeding crops (El-Swaify et al., 1988). The yield advantage from component crops is derived from the more efficient use of plant growth resources such as light, soil moisture, and nutrients (Willey, 1979). Temporal and spatial complementarities of component crops can also result in increased yields. Intercropping of cassava with legumes led to similar yields in monoculture and mixed culture, while reducing the cost of weeding and rate of organic matter decline (Ashokan, et al., 1985). In a three-yr field experiment in India, cassava was intercropped with different legumes, including cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogea*) and soybean (*Glycine max*). Averaged over three yr, tuber yield in cassava monoculture was 14 Mg ha^{-1}, similar to yields in cassava/cowpea (14.2 Mg ha^{-1}) and cassava/groundnut (14.2 Mg ha^{-1}) intercrops, and not significantly different from 12.6 Mg ha^{-1} obtained from a cassava/soybean intercrop. However, the legumes used were short period crops, and fertilizer was supplied to meet requirements of cassava and the intercrops. The cost of weeding was reduced by 50% in the cassava/cowpea cropping system, compared to monoculture systems. In addition, the harvested products from intercrop contributed to the overall profitability the cropping systems.

Intercropping systems are widespread in tropical latitudes, and therefore generated interest in quantifying their productive potential. The land equivalency ratio (LER) is the conventional concept for intercrop vs. monoculture comparisons (Willey, 1979; Baguma and Osiro, 1994). However, after a detailed review of various methods for estimating intercrop productivity, Hiebsch and McCollum (1987) concluded that an area by time equivalency ratio (ATER) would be a more appropriate concept, particularly where one or more of the intercropped species have different production cycle durations. The ATER concept would be appropriate when comparing maize-cassava intercropping systems, since it is possible to grow two crops of maize within the cropping duration of one cassava crop. Under similar management levels of the monoculture and intercropped treatments, the ATER compares the relative productive capacities of the crop in the two systems, indicating which system is more efficient in the use of area and time to produce a given quantity of yield. Other workers, for example, used the concept in a cassava/beans (*Phaseolus vulgalis*) intercropping study at Cali, Columbia (Leihner, 1983). In that study, the ATER concept was found to be a much stricter criterion, compared to LER, for including area and time as determinants of system productivity.

Herbaceous legume cover crops and green manures play a major role in N capture and internal N cycling (Wagger, 1989; Peoples et al., 1995). The use of organic inputs as nutrient sources has been advocated as an alternative to expensive fertilizers. Though response of crops to applied mineral fertilizers are positive, their adoption in coastal Lowland Kenya is less than 4%, applying an average of less than 3 kg ha^{-1} (Mose, 1998). Legumes have the potential to improve soil fertility through biological N fixation and the recycling of nutrients via legume foliage used as green manure and/or ground surface mulch (Agboola and Fayemi, 1972; Peoples et al., 1995). However, the biomass production by promising green manure legumes does not necessarily insure that all nutrients will be available to an accompanying crop or subsequent crops (Myers et al., 1994). Decomposition and nutrient release from crop residues are influenced by moisture conditions and resource quality (polyphenolics, C:N ratio, and lignin/polyphenol:N ratios (Palm and Sanchez, 1990; Tian et al., 1992; Vanlauwe et al., 1997). Harvesting the foliage at a short growth interval rather than a long interval is likely to influence the residue quality (Mafongoya et al., 1997), and in turn, the rate of decomposition and release of nutrients (Tian et al., 1992; Schroth, et al., 1992). Quantities and quality of the foliage produced may also be influenced by the cropping system. Considering that more than 40% of the original dry weight of legume foliage may be lost within two weeks after slashing a legume cover crop (Luna-Orea et al., 1996), application of the mulch to an already established crop may ensure a more efficient use of the plant nutrients released from the residues because of more immediate uptake by the accompanying crops.

Clitoria is the recommended herbaceous forage legume species for introduction into the farming systems in coastal Kenya (Mureithi et al., 1995; Thomas and Sumberg), with potential use as an intercrop in food production systems for soil fertility improvement (Saha et al., 1997). Clitoria's foliage N concentration is often greater than other herbaceous legumes species. In a study that measured leaf and stem quality of several legumes in multi-site experiments (Jones et al. 2000), clitoria N concentration in the terminal 15 cm of shoots averaged 40 g kg^{-1}, compared to 30 g kg^{-1} measured in *Stylosanthes scabra.* Food production and N uptake has increased when clitoria was used as a green manure (Ladha, et al., 1996). Dolichos is another herbaceous legume that demonstrated potential as a green manure crop in coastal Kenya (Njunie et al., 1996). The large seeds make it easy to establish, and an erect growth habit facilitates intercropping with food crops while still providing some weed control. Dolichos produces abundant foliage biomass yields, due in part to a greater water-use efficiency compared to other legumes (Cameron, 1988; Mcdonald *et al*. 2001). Unfortunately, information on the biological compatibility of these legumes with the main staple food crops (maize and cassava) in coastal Kenya is not available. A study was therefore designed to evaluate the two legumes as mulch and for soil fertility improvement in maize and cassava production systems. The overall objective was to study the effects of harvest frequency and developmental stage at harvest of annual and perennial forage legumes on: i) biomass and nutrient accumulation by clitoria and dolichos, ii) rate of nutrient release from the respective legume residues, and iii) availability of residue derived nutrients to maize and/ or cassava and soil water availability during the principal cropping season.

MATERIALS AND METHODS

The experiment was conducted over a two-yr period from 1999 to 2001 at the Regional Research Center in Mtwapa, Kenya ($3^{o}36'S$, $39^{o}44'E$). The soils at the experimental site were fine-loamy, kaolinitic, isohyperthermic, arenic Paleustalfs. The soils are well drained, deep, low in available nutrients, and have low to moderate moisture storage capacity. The topsoil texture is sandy loam to sandy clay loam with low organic matter content. Soil chemical and physical characteristics at the start of the experiment are shown in Table 2.1. The site is in the coconut/cassava agro-ecological zone with a semi-humid, bimodal rainfall regime (Jaetzold and Schmidt, 1983). There are two distinct rainfall patterns in the area, a long rain season from Apr to Jun (avg. 430 to 750 mm) and a short rain season from October to Dec (avg. 220 to 260 mm). Rainfall obtained during the experimental period is presented in Fig 2.1. The mean monthly temperature is $28^{o}C$ from Dec to Mar and 24 to $26^{o}C$ from Jun to mid September. The site was previously planted with cassava and had been under natural fallow for approximately three yr.

Two experiments were conducted concurrently. The design for experiment 1 (Exp1) was a split-plot with five replications consisting of cropping system (main plot) and harvest management (subplot) factors. Main plot treatments were the perennial legume clitoria grown as a monoculture or as an intercrop with two tropical food crops (cassava and maize). The main plot size was 5.4 x 8.1 m with 2-m spacing between main plots. The subplot treatments were two cutting management strategies for clitoria. The subplots dimensions were 5.4 x 4 m. Clitoria was first cut at 2 mo after planting, and subsequently every 6 or 10 wk after the first cut. The design of the second experiment (Exp2) was similar to the first one, but evaluated the annual legume dolichos and the legume cutting management strategy was at 2 and 4 mo after planting the legume. In both experiments, control plots were monoculture of maize or cassava, and their combinations, with or without inorganic fertilizer inputs. Treatment combinations for both experiments are shown in Table 2.2.

Cultural activities and data collected for both experiments during 1999 and 2000 were similar (Fig. 2.2 and 2.3). Before planting, 20 kg P ha^{-1} was applied as triple super phosphate in bands0.3 m apart and 2 to 3 cm deep to all legume plots and selected maize and cassava sub-plot treatments. The fertilizer P applications occurred on 16 Apr and 21 Oct during 1999, and 5 Apr and 10 Oct during 2000. Maize (Pwani Hybrid 4) was planted on 17 both years, after the onset of the long rain season. The maize monoculture plots were planted in rows oriented along an east to west direction, at an intra-row spacing of 0.9 m and inter-row spacing of 0.6 m (three seeds per hill). The three seeds per hill were later thinned two seeds per hill, resulting in a final plant density of 37,000 plants ha^{-1}. Cassava in maize/cassava plots replaced 33% of the maize rows, resulting in a lower maize plant density of 24,800 maize plants ha^{-1}. This spatial arrangement would allow planting two rows of legume, 0.3 m apart at the middle of the 0.9-m spacing. After maize germination, clitoria in Exp1 and dolichos in Exp2 were planted without any inoculation on 23 Apr, 1999. Clitoria planted in monoculture was drilled along rows, spaced 0.1 m apart, at a rate of 10 kg ha^{-1}. Clitoria in maize and cassava intercropping systems was seeded at 5.5 and 8 kg ha^{-1}, respectively. Dolichos in Exp2 was planted in rows 0.6m apart and intra-row spacing of 0.2 m, three seeds per hole, and was later thinned to two seeds per hole. This resulted in a final plant density of 166,600 plants ha^{-1}. Dolichos in maize and cassava intercropping systems was planted at densities of 83,300 and 133,300 dolichos plants ha^{-1}, respectively. With the exception of cassava/maize, clitoria/cassava/maize and dolichos/cassava/maize cropping systems, second crops of maize and dolichos were planted during the short rain season. Maize was planted on 12 Oct, 1999 and 11 Oct, 2000; while dolichos was planted on 22 Oct, 1999 and 21 Oct, 2000. All experimental plots were maintained free of weeds using hand tools. In both 1999 and 2000, the first weeding was conducted 2 to 3 wk after planting maize.

Cassava (cv 'Guzo') stem cuttings (three nodes) were placed into the soil at a 45^o angle relative to the ground surface. The cassava was planted on 12 May,1999 and 10 May, 2000, one month after planting maize, at a spacing of 1.8 m interrow by 0.5 m intra-row (11,100 plants per ha^{-1}). In the maize/cassava/legume intercropping system, two rows of maize spaced 0.6 m apart were grown between two rows of cassava (Fig. 2.3). This spatial arrangement would allow planting two rows of legume, 0.3m apart at the middle of the 0.9 m spacing.

Fertilizer N was applied at 60 kg N ha^{-1} as calcium ammonium nitrate (26%N) to the maize-fertilizer control treatments in both experiments. Fertilizer N application was accomplished in two splits each season. Long rain season fertilizer N application occurred on 21 and 31 May in 1999, and 12 and 24 May in 2000. During the short rain season, fertilizer N was applied on 16 and 26 Nov in 1999, and 23 Nov and 5 Dec in 2000. Maize stalk borer control in both yr was achieved using beta-cyfluthrin [cyano(4-fluoro-3-phenoxy-phenyl)methyl 3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate], at 0.01 to 0.05 kg a.i ha^{-1}. An armyworm outbreak in May 1999 was successfully controlled by

spraying with chlorpyrifos ULV [phosphorodithioic acid, O, O-diethyl O-(3,5,6-trichloro-2-

pyridyl) ester]. No major disease outbreaks occurred since the cassava and maize varieties used in the experiments were resistant to common diseases such as cassava mosaic and maize streak viruses.

In both experiments, legume foliage cuts were conducted from center rows to avoid edge effects. Clitoria and dolichos biomass were determined by cutting the foliage 10-cm above the soil surface from an area 3 m long and 1.8 m wide. The first cut of clitoria was conducted in late Jun both yr, on both the 6 and 10-wk subplot treatments, and was described as the uniformity cut. Consequently the time elapsed before the 6 and 10-wk cuts began on the date of two-mo cut. The second cut in each subplot was conducted in Aug and Sep for 6 and 10-wk treatments, followed by another uniformity cut in Oct, at the beginning of the short rain season. Subsequent 6 and 10-wk cuts were conducted in Nov and Dec and coincided with the short rain season. At the end of the short rain season, each clitoria subplot had received four cuts (Fig. 2.2). The harvested foliage was applied as surface mulch. The regrowth of clitoria occurring after the last cut in Dec and coinciding with the long dry season (mid Dec to Mar), was incorporated during land preparation for the second yr long rain cropping season. Similar to Exp1, dolichos planted during the long rain season received the first cuts in late Jun and Aug both yr for the 2 and 4-mo cuts, respectively. The second cuts from dolichos two- and four-mo treatments were conducted from the dolichos planted during the short rain season. The cuts occurred in late Dec and Feb in 1999, and in Jan and Mar of 2000, for the two- and four-mo dolichos cutting management, respectively (Fig. 2.3).

All the foliage cut from the harvested area was weighed immediately to obtain the fresh weight. To determine the foliage dry matter, a sample (ca. 100 g) was taken and oven dried at 105^{o}C for at least 48 hr, or to constant weight. The foliage fresh weight and foliage dry weight were later used to calculate the biomass yield in Mg ha^{-1}. Another sample (ca. 200 g) was dried at 60 ^{o} C to constant weight and was later used for nutrient concentration determinations.

The long rain season maize was harvested at maturity in late Aug both yr, using the center rows for yield determination. The ears were hand shelled and grain yield was adjusted to a 155 g kg $^{-1}$ moisture basis. Maize stover from the same harvest area was cut at ground level, weighed, and samples taken for biomass and nutrient determinations. Cassava was harvested in Feb of 2000 and 2001, about ten mo after planting, by identifying plants within a 3 by 1.8 m area covering the two inner rows of each subplot. Tuber harvesting required digging around the base of individual plants using hand tools and then uprooting the whole plant. All the tubers from the net plot area were weighed and counted. Cassava tops were separated into leaves and stem components, weighed, stems chopped into smaller pieces, and samples taken for biomass and nutrient determinations.

Nutrient concentrations in plant samples were determined by wet oxidation procedure (Parkinson and Allen, 1975) based on a Kjeldahl digestion using H_2SO_4 and H_2O_2. The N and P were determined colorimetrically, while K, Ca, and Mg were measured by atomic absorption spectrometry. To obtain complete information from the study while minimizing the cost of laboratory analyses, a linear regression analysis was performed of measured nutrient contents versus dry matter yields of legume foliage and maize grain and stover (Appendix Table A2.1). Annual N, P and K budgets were prepared, where the nutrients inputs were added through inorganic fertilizers (N and P applications) and/or returned in plant residues (legume foliage, cassava leaves, and maize stover). Nutrient removals comprised mainly of crop harvests (maize grain, cassava tubers, and cassava stems) (Tables 2.3 and 2.4). Though cassava stems are not harvested for food, they are usually removed from the field at tuber harvest and preserved under shade as propagation material in the next planting system.

Initial soil characteristics of the experimental site were determined on 24 Mar, 1999, before land preparation (Table 2.1). Soil samples were taken to 20-cm depth from nine locations within the entire experimental area, and also from a soil profile pit at 40- and 70-cm depths. Subsequent soil sampling was conducted after experiments were established, at the beginning of each long rain season using a 25-mm dia soil probe. Three cores (20-cm deep) were taken per plot, composited, air-dried, and ground to pass a 2-mm sieve. Soil particle analysis was conducted using the hydrometer method, relying on the sedimentation rate of silt and clay through a water column. Soil samples were also analyzed for: 1) pH (1:2.5 soil: water), 2) organic C [wet oxidation by acidified dichromate and heat the reaction at 150^{o}C for 30 min, organic C measured colorimetrically] 3) available P, K, Fe, Mn and Zn [1:10 soil:extracting solution (0.5 M $NaHCO_3$, 0.01M EDTA, pH 8.5); Olsen P, K extracting solution modified by Hunter, 1989; P measured colorimetrically, K by atomic emission]; Fe, Mn and Zn read on atomic absorption 4) Ca and Mg [1:10 soil: extracting solution (1M KCl),diluted with 1% lanthanum solution), by atomic absorption]. To determine cropping system and legume management effects on soil inorganic N, composited samples from three cores per subplot were collected from 0 to 20 and 20 to 40-cm depths at the beginning of each long rain season. Subsequent soil sampling for inorganic N occurred at the beginning of each maize crop and about one wk before and after each legume harvest (Table 2.5). Fresh soil samples were kept in a cooler while in the field and later stored frozen until analyzed for NO_3 and NH_4. The NO_3 and NH_4 were measured colorimetrically after extracting with a 1:5 soil: solution (2M KCl).

Gravimetric soil moisture determinations were conducted for each cropping system and harvest management strategy. During the first yr of cropping (1999), samples for soil moisture determination were collected to a 20-cm depth on 3 May during the long rain season. Maize and legumes were in their early growth stages at this sampling date, but cassava had not been planted and moisture was not expected to be limiting. Subsequent moisture determinations for 1999 were taken during the short rain season on 28 Oct and Dec 24, when the perennial legume and cassava were well established and plant stress due to lack of moisture was expected. During 2000, samples for soil moisture determinations were collected to two depths (0 to 20 cm and 20 to 40 cm). These samples were collected in conjunction with the sampling dates for inorganic N determination.

Soil bulk density at the 2 to 7-cm depth was measured on 30 Mar, 1999 and 24 Mar, 2000, corresponding to the beginning of the long rain season for each yr. Cylindrical cores (5-cm dia and 5-cm tall) were carefully forced into the soil using a flat piece of timber. The soil within the cylinder was removed, dried at 105^{o}C to a constant weight, weighed, and bulk density calculated.

A split-plot analysis of variance was conducted by season (long or short rain) to test the effects of cropping system and management strategy on clitoria or dolichos (dry matter yield), maize (grain and stover yields), cassava (tuber, stem, and leaf yields), plant nutrient status, and soil chemical characteristics. Data was analyzed using the mixed model of

Statistical Analysis Systems (SAS, 1998). The models used to generate the variances for comparing cropping systems and management strategies means were as follows:

[1] $y_{ijklm} = \mu + B_i + Y_j + C_k + (CY)_{jk} + \delta_{ijk} + M_{l(m)} + MY_{jl(m)} + E_{ijklm}$

[2] $y_{ijkl} = \mu + B_i + Y_j + C_k + (CY)_{jk} + \delta_{ijk} + H_l + HY_{jl} + E_{ijkl}$

where μ= overall mean; B_i=block, i=1 to 5; Y_j=yr, j=1,2; C_k=cropping system, k=1 to 7; $M_{l(m=1)}$ =harvest interval, m=legume (1) or no legume (0); and $M_{l(m=0)}$=fertilizer, H=legume harvest management, l=1,2. The block, block by yr, whole plot by yr, and δ_{ijk} effects were treated as random effects, while E_{ijklm} and E_{ijkl} are random subplot errors.

Model [1] was used for maize/cassava yield and soil data. The model tested the effects of yr (1999 and 2000), cropping system (clitoria or dolichos planted in monoculture or intercropped with maize, cassava or maize/cassava), and management strategies within cropping systems (harvesting clitoria at 6 or 10-wk intervals; or dolichos at 2 or 4 mo after planting and/or maize, cassava or maize/cassava with or without fertilizer input. Model [2] was similar to [1], except that maize, cassava and cassava/maize cropping systems, and their respective management strategies (with or without fertilizer input), were not included. Model [2] was a combined analysis of two-yr forage legume yield of clitoria or dolichos and their respective nutrient contents, and comprised a maximum of four cropping systems and two harvest management strategies. Orthogonal contrasts were used to compare treatments means.

The productivity of the intercrops was evaluated using the land equivalent ratio (LER) and area by time equivalent ratio (ATER) concepts (Tables 2.6 and 2.7). Efficiency of intercropping vs monoculture is measured using relative yield (RY), which is the ratio of yield of intercropped species per unit area to yield per unit area of the same species under monoculture. The summation of relative yields over the number of intercropped species gives the LER. The ATER for each species was calculated by multiplying the RY by the ratio of the time (days) taken by a crop when grown in monoculture to the total time taken by all components under intercropping. The final ATER value is the summation of ATER values of the different species. Value of ATER >1 indicate greater efficiency of land area and time when the different plant species were planted as intercrops, compared to monoculture. The relative productive capacity of the maize and cassava monoculture vs. intercrops was compared for different management strategies, indicating which cropping systems was more effective in the use of land area and time.

RESULTS AND DISCUSSION

Legume Establishment and Biomass Accumulation

Experiment 1

As expected, clitoria's initial establishment was slow and hand pulling of weeds along the rows of clitoria was carefully done to avoid smothering clitoria by the aggressive weeds. Three weedings were necessary before clitoria was well established, approximately two mo after planting. The 6 and 10-wk harvest strategy for clitoria allowed two harvests in each long and short rain season, respectively. Year of establishment influenced aboveground biomass accumulation in both the long and short rain-growing season, while cropping system and cutting management influenced aboveground biomass during the short rain season only (Table 2.8).

Establishment of clitoria in 1999 was more uniform than in 2000, a growing season characterized by rainstorms during the early establishment stage for clitoria. Overall, aboveground biomass accumulation for clitoria was greatest during the short rain season compared to the long rain season, reflecting the pattern of its growth. Clitoria developed a deep root system during the short rain season, and was therefore more effective in extracting nutrients and water from the soil. Averaged over 2 yr, clitoria monoculture produced the greatest foliage biomass (1.9 Mg ha^{-1}) during the short rain season, compared to 1.0 Mg ha^{-1} during the long rain season (Table 2.9). Generally, intercropping of clitoria with cassava, maize, and cassava/maize reduced clitoria yield to 74, 89, and 63 %, respectively, of clitoria monoculture forage biomass accumulation.

The greater reduction in clitoria's cumulative biomass accumulation with cassava intercropping may be related to cassava's growth pattern. The slow initial growth of cassava allowed for adequate early growth of the short stature clitoria, but cassava canopy cover by five mo after planting shaded clitoria from direct sunlight. Clitoria monoculture plants benefited from direct sunlight during most of the growing season, while plants in the clitoria/maize intercrop system received more sunlight after harvesting the long rain season maize crop. During the short rain season, cumulative yield of clitoria foliage in the 6-wk cutting strategy was 46% greater (1.9 vs. 1.3 mg ha^{-1}) than the 10-wk cutting strategy. The greater cumulative yield in clitoria 6-wk cut could be attributed to a longer between-season period of growth in the 6-wk cutting strategy compared to the 10-wk strategy. This occurred because the 6-wk cutting strategy resulted in a longer interval between cuts during the long and short rain seasons (nine wk from Aug to Oct), compared to five wk resulting in the 10-wk cutting strategy (Sep to 8 Oct). The greater biomass accumulated in the 6-wk cutting strategies at the beginning of the short rain season suggests that a greater proportion of plant nutrients were available at this time that, in turn, could influence crop yields during the short rain season. In situations where mixed farming is practiced, more forage would be available for livestock feeding, and nutrients recycled back through animal manure. Nutrient flows in crop livestock/ mixed farming systems to determine the biological efficiency of such a system merits further study.

Experiment 2

Dolichos biomass yield was influenced by yr effects during the long rain season only. Cropping system and management effects were significant in both long rain and short rain seasons (Table 2.8). Monoculture dolichos accumulated the greatest above ground biomass (3.8 Mg ha^{-1}) compared to dolichos grown in intercropping systems (Table 2.10). Intercropping dolichos with cassava, maize, or cassava/maize led to dolichos biomass values of 3.4, 2.7, and 2.7 Mg ha^{-1}, respectively. This reduction in biomass accumulation ranged from 70 to 90% of monoculture dolichos. The reduction in dolichos biomass in dolichos/cassava was less drastic because dolichos is a shorter cycle crop and therefore accumulated most of its biomass before cassava developed a full canopy. Leihner (1983) observed that cassava's slow initial growth allows for intercropping with a rapidly growing short stature and short-cycle crops.

During the long rain cropping season, dolichos cut four mo after planting produced about 300% (5.1 vs. 1.3 Mg ha^{-1}) more biomass than dolichos cut 2 mo after planting. During the short rain season, harvest management influenced dolichos biomass accumulation in dolichos monoculture and dolichos maize cropping systems (Table 2.10). Dolichos biomass accumulation was 1.1 Mg ha^{-1} in the monoculture system and 0.5 Mg ha^{-1} in the dolichos/maize systems. Dolichos cut four mo after planting produced about 60% (1.0 vs. 0.6 Mg ha^{-1}) more foliage biomass than dolichos cut two mo after planting. The low dolichos foliage biomass accumulation observed during the short rain season can be attributed to reduced rainfall amounts from Jul to Dec during 1999 (Fig. 2.1), and the long dry season that followed.

Legume Nutrient Accumulation

Experiment 1

During the long rain season, cropping systems influenced P and K accumulation in clitoria, while legume management strategy influenced Ca and Mg contents (Table 2.8). Averaged across cropping systems and cutting management, clitoria monoculture accumulated 50 kg N ha^{-1}, 4 kg P ha^{-1}, 33 kg K ha^{-1} and 7 kg Ca ha^{-1} and 5 kg Mg ha^{-1} (Table 2.9). Under intercropping conditions, clitoria nutrient accumulation averaged 40 to 60% of clitoria monoculture. Intercropping with maize led to the least nutrient accumulation in clitoria. Legume management strategy during the long rain season had an impact on clitoria nutrient accumulation, with a delay in the cut to 10 rather than 6-wk increasing Ca and Mg contents in clitoria foliage.

The influences of clitoria intercropping with cassava and maize during the short rain season were similar to those observed in the long rain season. With the exception of the clitoria/cassava cropping system, nutrient contents of clitoria foliage were generally greater during the short rain season compared to the long rain season. Clitoria monoculture during the short rain season accumulated 67 kg N ha^{-1}, 5 kg P ha^{-1}, 49 kg K ha^{-1}, 9 kg Ca ha^{-1} and 10 kg Mg ha^{-1}. Under intercropping conditions, clitoria nutrient accumulation ranged from 6 to 40 kg N ha^{-1}, 1 to 3 kg P ha^{-1}, 5 to 33 kg K ha^{-1}, 1 to 6 kg Ca ha^{-1}, and 1 to 6 kg Mg ha^{-1}. The lower limit mainly reflected nutrient accumulation by clitoria in the clitoria/cassava system, while the upper limit was from clitoria/maize. Unlike the long rain season, the 6-wk cutting strategy generally increased nutrient contents in clitoria foliage. This result could be associated with greater biomass yields obtained for the 6-wk cut strategy in the uniformity cut for the short rain season, which produced three-fold greater clitoria foliage biomass than the 10-wk cutting strategy. A greater proportion (60%) of clitoria's foliage biomass accumulated during the short rain season came from the uniformity cut for the season, compared to 16% obtained with the 10-wk cut.

Experiment 2

Year effects were significant for N, K, and Ca contents during long rain season, and Ca only during the short rain season (Table 2.8). During the long rain season, monoculture dolichos accumulated 101 kg N ha^{-1}, 8 kg P ha^{-1}, 83 kg K ha^{-1}, 32 kg Ca ha^{-1}, and 7 kg Mg ha^{-1} (Table 2.10). These values were higher than nutrients accumulated with the intercropped treatments, as nutrient accumulation in these systems ranged from 66 to 90 kg N ha^{-1}, 5 to 6 kg P ha^{-1}, 55 to 82 kg K ha^{-1}, 20 to 27 kg Ca ha^{-1}, and 4 to 6 kg Mg ha^{-1}. Compared to dolichos monoculture, nutrient contents of dolichos foliage were influenced by intercropping of dolichos with maize during the long rain season, but not cassava (Table 2.10). Nutrient contents in the dolichos/maize system averaged 65%, and 85% in the dolichos/cassava system, of the monoculture system. Delaying harvest of dolichos by 2 mo (2 vs. 4 mo) increased total nutrient accumulation between two and fourfold. Averaged across cropping systems, dolichos cut at 2 mo accumulated 41 kg N ha^{-1}, 3 kg P ha^{-1}, 33 kg K ha^{-1}, 11 kg Ca ha^{-1}, and 2 kg Mg ha^{-1}; compared to 123 kg N ha^{-1}, 9 kg P ha^{-1}, 104 kg K ha^{-1}, 40 kg Ca ha^{-1}, and 9 kg Mg ha^{-1} for dolichos cut at 4 mo.

Legume Residue Decomposition and Nutrient Release

The nutrients accumulated in the foliage of the legumes are an indication of the potentially available nutrient pools applied as surface mulch. A decomposition and nutrient release study (Chapter 3) was conducted concurrently with the study reported herein to assess nutrient availability to the cropping systems in the region. Legume residue decomposition and nutrient release patterns were affected more by harvest management strategy than the cropping systems in which the residue material was produced. Across all cropping systems, cutting dates, and legume cutting strategy, the asymptotic model provided the best fit for clitoria and dolichos residue decomposition. Clitoria harvested at 6 or 10-wk, or dolichos harvested at 2 or 4 mo after planting, did not differ in rate of dry matter disappearance. Consequently, reduced models were used to represent clitoria and dolichos decomposition. The use of reduced models suggests that clitoria or dolichos may be harvested at various growth stages without compromising the decomposition rate. Generally, dolichos residue disappeared faster than clitoria. The rate coefficient (k wk^{-1}) for clitoria and dolichos dry matter disappearance were 0.2 and 0.5 wk^{-1}, respectively. Estimated values for dry matter remaining from clitoria surface residue placement, averaged across 6 and 10-wk cutting intervals, were 67% at 2 wk, 45% at 4 wk, and 30% at 8 wk. The percentage of initial dolichos dry weight remaining during the same periods averaged 54, 35, and 25%.

Nutrient release from both clitoria and dolichos foliages best fit an asymptotic model. Across all cropping systems in Exp1, N, P and K release from the 6 and 10-wk cutting strategies best fit reduced models, such that single curves represented the amounts of each nutrient remaining at different times after litterbag placement in the field. The only exception was noted for Mg release, where Mg in the 10-wk cutting strategy was released much slower compared to the 6-wk cutting strategy. Across harvest management strategies, the general order of nutrient release was K > P > Mg > N.

Similar to clitoria residue, dolichos foliage residue in Exp2 fit the asymptotic model. Unlike clitoria, a shorter harvesting strategy resulted in faster nutrient release rates from dolichos foliage. The order of nutrient release from dolichos cut at 2 mo was K>Mg> N>P, and K>N>P>Mg for dolichos cut at 4 mo. The *k*-values obtained for dolichos showed the greatest variation (0.2 to 2.5 wk^{-1}) compared to those obtained for clitoria (0.3 to 1.0 wk^{-1}). Nitrogen release was generally slowest in clitoria, and in the dolichos 4-mo foliage cut. Though the dolichos two-mo cut released N rapidly (k=2.50 wk^{-1}), almost all the N release occurred during the first wk after litterbag placement, before forming a plateau with over 40% N still remaining in the residue.

Principal Crop Yields and Nutrient Uptake

Maize

Maize was the first crop planted after land preparation. Two crops of maize were planted within the first year of cropping, utilizing the long and short rain season precipitation. The long rain season received adequate precipitation to support maize production, while the short rain season received below average precipitation (Fig.1).

Experiment 1

Year effects influenced maize grain production during the long rain season, but not in the short rain season (Table 2.11). In contrast, yr effects had no influence on maize stover in both seasons. With a few exceptions, cropping system and harvest management influenced maize and stover production in both seasons. During the long rain season, application of fertilizer N and P increased overall grain production by 80% (5.4 vs. 3.0 Mg ha^{-1}), compared to monoculture maize with no fertilizer inputs (Table 2.12). Stover yield obtained from the same treatments increased by 62% (3.4 vs. 2.1 Mg ha^{-1})(Table 2.13). During the short rain season, the response to fertilizer application was less pronounced, as fertilizer increased grain and stover yield by 30%.

Across management strategies, orthogonal comparisons indicated significant intercropping influences on grain yield. Intercropping of maize with clitoria increased grain and stover yield during the long rain season, but decreased the yields during short rain season, compared to a maize monoculture system without fertilizer inputs (Table 2.12). This yield depression during the short rain season was likely due to competitive effects for moisture by clitoria, which were noticeable during the short rain season. The short rain season maize crop was 4-leaf stage, compared to the already well-established clitoria, with approximately six-mo growth, such that competition for moisture likely masked any beneficial effect of nutrients supplied by the clitoria foliage mulch. Intercropping maize and cassava during the long rain season did not influence maize grain and stover yield. Among the intercropping systems, the lowest maize production was obtained from clitoria/cassava/maize, with grain yield of 3.2 Mg ha^{-1} and a stover yield of 1.8 Mg ha^{-1}.

Year effects influenced N, P, and Ca content in grain or stover during the long rain season, but not during the short rain season (Table 2.7). Also, cropping system and harvest management significantly influenced most nutrient contents of maize grain and stover in both long and short rain seasons. Averaged over two yr, maize monoculture grown without fertilizer inputs accumulated 41 kg N ha^{-1}, 7 kg P ha^{-1}, 9 kg K ha^{-1}, 0.6 kg Ca ha^{-1}, and 3 kg Mg ha^{-1} in the grain during the long rain season (Table 2.11). Similar amounts were accumulated during the short rain season. Application of fertilizer to maize resulted in a two-fold grain yield increase, resulting in comparable nutrient content increases. Orthogonal contrasts revealed that intercropping maize with clitoria increased N, P, K, and Mg content in grain, accumulating 55 to 81% more nutrients than maize monoculture without fertilizer. With the exception of N and K accumulation, grain nutrient accumulation in the clitoria/maize intercrop was not significantly different to that in maize monoculture with fertilizer. A different pattern was evident for maize stover nutrient contents, as less N (10 v*s*. 41 Mg ha^{-1}) and P (1 vs. 7 Mg ha^{-1}), greater Ca (5 vs. 0.6 Mg ha^{-1}) and K (21 vs. 9), and equal amounts of Mg (3 Mg ha^{-1}) were accumulated in the maize monoculture without fertilizer input system (Table 2.13). Similar to maize grain, fertilizer input increased nutrients in stover by values ranging from 50 to 100% over those obtained with maize monoculture and no fertilizer inputs.

During the short rain season, grain nutrient contents in the clitoria/maize system were only 30% of nutrient values in maize monoculture cropping system (Table 2.12). Differences between seasons may be due to competition for light and moisture between clitoria and maize, since the perennial clitoria was fully established by then. Though clitoria was cut to allow for maize planting (Oct cut), the regrowth rate was rapid, enough to smother the newly planted maize. Fertilizer inputs increased grain nutrient accumulation in the clitoria/maize intercropping system by 27 to 100% compared to maize monoculture and no fertilizer inputs. Overall, the impact of cropping system and legume management on maize stover nutrient accumulation differed from results for grain. Nitrogen accumulated in maize stover contributed 20% of the total amount accumulated in both grain and stover, while the amounts of K and Ca were higher in stover than in grain, contributing about 64 and 90% of the total K and Ca of maize grain and stover combined, respectively.

Experiment 2

During the long rain season, cropping system and management strategy influenced maize grain and stover production, but yr effects were not significant (Table 2.11). The application of fertilizer increased mean grain production by 77% (5.5 Mg ha^{-1} vs. 3.1 Mg ha^{-1}) compared to monoculture maize with no fertilizer inputs (Table 2.14). Likewise, maize stover yield increased by 61% (3.7 Mg ha^{-1} vs. 2.3 Mg ha^{-1}) due to fertilizer inputs (Table 2.15). Orthogonal comparisons revealed that intercropping of dolichos with maize or cassava/maize did not significantly influence grain yield during the long rain season compared to maize monoculture with no fertilizer inputs. Averaged over two yr, grain yields obtained from dolichos/maize and dolichos/cassava/maize cropping systems averaged 2.8 Mg kg $^{-1}$, a decrease of 13 % compared to maize monoculture without fertilizer inputs (Table 2.14). The effect of cropping system on stover yield was even significant for dolichos/maize, resulting in a yield decline of 30 %, compared to monoculture maize without fertilizer inputs. Maize grain yield in the cassava/maize system did not significantly differ from the maize monoculture system with no fertilizer input, showing an insignificant decline of 17%. It would be expected that the 33 % lower plant density in the maize/cassava system would result in lower grain and stover yields compared to maize monoculture. The improved yield in cassava/maize cropping system was partly due to nutrients returned in cassava leaves and maize stover, and also compensatory growth of maize as cassava was establishing. The lower grain and stover yields in dolichos intercropping systems during the long rain seasons can be attributed to vigorous growth of dolichos from above average rainfall during the period, leading to shading of maize plants. Delayed harvesting of dolichos during the long rain season within the intercropping systems had no effect on maize grain yield.

During the short rain season, cropping system and management strategy influenced maize grain and stover yields (Table 2.11). Precipitation was lower compared to the long rain season (Fig. 2.1), reducing dolichos growth and potential nutrient contributions (Table 2.10). Looking at the orthogonal comparisons, maize grain production in the dolichos/maize cropping system was greater than maize monoculture with no fertilizer inputs, and equivalent to yields obtained in the maize monoculture with commercial fertilizer (Table 2.14). Grain and stover production in the dolichos/maize cropping system was 79% greater than in maize monoculture with no fertilizer inputs. The competitive effect of dolichos for moisture was reduced during the short rain season, favoring maize growth and performance. Also, residue effects of the foliage applied during the long rain season may have contributed to the relatively improved performance of the short rain season maize crop.

Considering nutrient content in grain and stover, yr effects were significant for Ca during the long rain season; and N, P, K, and Ca during the short rain season (Table 2.11). Cropping systems effects were significant during long rain season only, while harvesting management effects were significant in both seasons. Generally, grain nutrient accumulation was greatest in maize grown as monoculture compared to maize in intercropping systems; (Table 2.14). Nutrient content values during the long rain season ranged from 38 to 55 kg N ha^{-1}, 6 to 8 kg P ha^{-1}, 8 to 11 kg K ha^{-1}, 0.5 to 0.7 kg Ca ha^{-1}, and 3 to 4 kg Mg ha^{-1} for the intercropping systems compared to 54 kg N ha^{-1}, 7 kg P ha^{-1}, 9 kg K ha^{-1}, 1 kg Ca ha^{-1}, and 3 kg Mg ha^{-1} for maize monoculture without fertilizer input. Fertilizer increased grain nutrient contents from 80 to 100% compared to maize monoculture grown without fertilizer inputs. Harvest management strategy within cropping systems showed a greater influence on the dolichos/cassava/maize system, in which delayed harvest of dolichos to 4 mo led to a reduction in grain nutrient contents of 33% for N, 21% for P, 19% for K, 34% for Ca, and 23 % for Mg.

Similar to the grain results, nutrient accumulation in stover during the long rain season was greatest in the maize monoculture cropping system, averaging 14 kg N ha^{-1}, 1 kg P ha^{-1}, 35 kg K ha^{-1}, 8 kg Ca ha^{-1}, and 5 kg Mg ha^{-1} (Table 2.15). Nutrients accumulated in maize stover under intercropping systems ranged from 8 to 10 kg N ha^{-1}, 0.7 kg P ha^{-1}, 15 to 20 kg K ha^{-1}, 4 to 5 kg Ca ha^{-1}, 3 kg Mg ha^{-1}. Fertilizer increased stover nutrient contents by 38 to

69% compared to maize monoculture and no fertilizer inputs. Unlike the grain results, maize stover contained low amounts of N and P, but greater amounts of K, Ca, and Mg.

As with the long rain season, the harvesting management of dolichos influenced nutrient accumulation in grain and stover during the short rain season (Table 2.11). Application of fertilizer doubled the nutrients accumulated in grain monoculture maize without fertilizer inputs, while delayed harvest of dolichos to 4 mo marginally increased nutrient contents by 12% (Table 2.14). Averaged over two yr, stover nutrient contents during the short rain season for maize monoculture without fertilizer inputs were11 kg N ha^{-1}, 1 kg P ha^{-1}, 25 kg K ha^{-1} and 4 kg ha^{-1} for both Ca and Mg. Averaged over harvesting management, maize stover nutrient content in dolichos/maize system were 18 kg N ha^{-1}, 1 kg P ha^{-1}, 51 kg K ha^{-1}, 6 kg Ca ha^{-1}, and 5 kg Mg ha^{-1}.

Cassava

Cassava cuttings were planted during the long rain season, one month after planting maize (Fig. 2.3). Adequate precipitation at planting enabled cassava cuttings to sprout. The crop was harvested during the long dry season, approximately nine mo after planting.

Experiment 1

Only cropping system influenced cassava tuber yield (Table 2.16). Generally, tuber dry matter yields in the cassava monoculture system exceeded those of the intercropping systems (Table 2.17). Intercropping of cassava and clitoria reduced tuber yield by 21% (9 vs. 7 Mg ha^{-1}) compared to the cassava monoculture system. Cassava yields in cassava/maize, clitoria/cassava, and clitoria/cassava/maize systems averaged 6, 7, and 6 Mg ha^{-1}, respectively. Application of P fertilizer in cassava monoculture and cassava/maize systems improved cassava tuber yield by an average of 15%, compared to cassava without any fertilizer inputs.

Cassava stem dry matter yields reflected a pattern similar to that of tuber yield (Table 2.17). Stem yield in the monoculture system averaged 6.7 Mg ha^{-1}, while the intercropping systems averaged 4.7 Mg ha^{-1}. Cassava leaf dry matter yield contribution to the overall cassava plant dry matter was relatively small, averaging 0.8 Mg ha^{-1} (Table 2.18). Intercropping of clitoria with cassava /maize depressed leaf yield by 35%. In the same treatments, nutrient contents of cassava leaf were also significantly depressed, especially in the clitoria 10-wk cutting strategy, reflecting evidence of competition for moisture and nutrients between cassava and clitoria.

Nutrient accumulation in cassava tuber, stem, and leaf varied in response to cropping system (Table 2.16). Cassava removed relatively large amounts of nutrients from the soil in tubers and stems, while leaf nutrient contents were considerably less. Averaged across yr, cropping system influenced K content in cassava leaf, and all nutrients in cassava stem and root tuber. Cutting management influenced P, K, and Ca contents in cassava tuber. Generally, application of P fertilizer to cassava monoculture, and N and P fertilizers to cassava/maize systems, led to greater values of accumulated nutrients in cassava tuber (49 vs. 60 kg N ha^{-1}, 8 vs. 11 P ha^{-1}, 96 vs. 127 K kg ha^{-1} ,21 vs. 27 kg Ca $ha^{-1,}$ and 8 vs. 10 kg Mg^{-1} (Table 2.17). Cassava intercropping with clitoria or maize decreased nutrient content in cassava stem. Accumulated nutrient contents ranged from 32 to 43 kg N ha^{-1}, 4 to 7 kg P ha^{-1}, 52 to 78 kg K ha^{-1}, 25 to 37 kg Ca ha^{-1}, and 9 to 11 kg Mg ha^{-1}.

Experiment 2

Cropping system influenced cassava tuber yield, as the monoculture system led to greater yields compared to intercropping systems (Table 2.16). Mean tuber dry matter production in the monoculture systems was 9 Mg ha^{-1}, compared to 7, 7, and 5 Mg ha^{-1} in cassava/maize, dolichos/cassava, and dolichos/cassava/maize cropping systems, respectively (Table 2.19). Intercropping of cassava and dolichos reduced cassava tuber yield by 23% compared to cassava monoculture. The application of fertilizer P in cassava monoculture and cassava/maize systems improved tuber yield by 22% (7.9 to 9.6 Mg ha^{-1}) and 25% (5.8 to 7.7 Mg ha^{-1}) compared to the same systems without fertilizer. Also, delayed harvesting of dolichos to 4 mo rather than 2 mo reduced cassava tuber yield in dolichos/cassava and dolichos /cassava/maize cropping systems by 39 % (8.3 to 5.1 Mg ha^{-1}) and 20% (5.5 to 4.4 Mg ha^{-1}), respectively (Table 2.19).

Cassava stems are important in cassava production systems as planting material, and thus represent a source of nutrient export from the farming systems. Larger stem cuttings are often transported to a selected site within the farm and preserved as planting materials for subsequent cropping seasons. Eventually only a small proportion of the stems may be returned to the system as planting material, while some may be exported to neighboring farms. In this study, stem yield patterns were similar to those for tuber yield. The cassava monoculture system had greater stem yields than intercropped cassava. Mean cassava stem yield (2-yr. avg.) in the cassava monoculture system was 7Mg ha^{-1}, while intercropping systems averaged 5.5 Mg ha^{-1} (Table 2.19). Application of fertilizer P to cassava monoculture and cassava/maize systems had no significant effect on stem yield, nor did dolichos harvest management.

Nutrient accumulation by cassava tubers was modestly affected by cropping system and management strategy, primarily for P, Ca, and Mg contents (Table 2.16). The orthogonal comparisons indicated that application of fertilizer to cassava monoculture or cassava/maize systems led to greater accumulations of the above nutrients compared to cassava or cassava/maize/dolichos intercropping systems. Nutrients accumulated in cassava tubers harvested from the cassava monoculture system with fertilizer input were 54 kg N ha^{-1}, 10 kg P ha^{-1}, 89 kg K ha^{-1}, 20 kg Ca ha^{-1}, and 12 kg Mg ha^{-1}; while the average nutrient content in cassava stems in the dolichos/cassava system was 41 kg N ha^{-1}, 6 kg P ha^{-1}, 75 kg K ha^{-1}, 13 kg Ca ha^{-1}, and 6 kg Mg ha^{-1}. Between the two systems, P, K, and Mg accumulation in the stems of cassava harvested from the fertilized treatment were significantly greater than removal from the dolichos/cassava system. This indicates that P supplied from the dolichos foliage residues from dolichos/cassava system had limited influence on P accumulated in the cassava stems. Cassava leaf nutrient content was generally not a reliable indicator of nutrient input differences. Averaged over cropping systems and harvest management, mean nutrients accumulated in cassava leaves were 17 kg N ha^{-1}, 1 kg P ha^{-1}, 5 kg K ha^{-1}, 11 kg Ca ha^{-1}, and 5 kg Mg ha^{-1} (Table 2.20). These values represent cassava's contribution to potential soil nutrient pools. Cassava stems in the monoculture system accumulated 58 kg N ha^{-1}, 6 kg P ha^{-1}, 73 kg K ha^{-1}, 33 kg Ca ha^{-1}, and 16 kg Mg ha^{-1} (Table 2.19). This compares to a range in the intercropping systems of 41 to 56 kg N ha^{-1}, 4 to 6 kg P ha^{-1}, 62 to 89 kg K ha^{-1}, 22 to 33 kg Ca ha^{-1}, and 10 to 13 kg Mg ha^{-1}.

It is clear from the above results that cassava removed relatively large amounts of nutrients from the soil in the form of cassava tubers and stems. Though cassava leaf also accumulated nutrients, the amounts involved were much less than that contained in stems and tubers. The nutrients in dolichos residues were readily released, as observed in the biomass decomposition and nutrient release study conducted concurrently with this study

(Chapter 3). Measures that minimize nutrient removal from the systems, primarily in cassava stems and leaves need to be emphasized. Knowledge of nutrient release rates from the plant parts would be useful for nutrient management decisions.

Soil Chemical Properties

Experiments 1 and 2

Soil chemical properties were only modestly affected by treatment variables (Table A2.2). Cropping systems influenced soil K and P, while management strategy within cropping systems influenced soil pH and K. There were no yr effects or significant interactions for any of the measured soil chemical properties. Due to the relatively short duration of the experiment, the observed changes in soil chemical properties were unlikely to have lasting agronomic influences. The soil pH at the start of the experiments averaged 6.3 (Table 2.1). In Exp1 the soil pH did not deviate from this initial value two yr later (Table A2.3). Orthogonal comparisons indicated that soil K in the clitoria monoculture systems was lower than in cassava monoculture systems (0.3 vs. 0.2 $cmol_c kg^{-1}$). Unlike Exp1, soil pH in Exp2 decreased from the initial 6.3 to an average of 6.1 two yr later (range pH 5.9 to 6.3)(Table A2.4). The lower limit was measured in dolichos monoculture while the upper value occurred with maize monoculture and fertilizer inputs. Greater soil P and K concentrations were also measured in dolichos monoculture systems compared to maize and dolichos/cassava systems. Phosphorus levels in maize monoculture systems with fertilizer input showed significantly greater soil P levels compared to clitoria monoculture or clitoria/maize systems. Soil K showed the least variation, despite large amounts of K recorded in plant biomass. Extractable soil P values varied widest, with greater amounts in treatments that received basal amounts of P fertilizer. The values of extractable P were very low, however, far below the 15 mg kg^{-1} required for optimal maize production in the region (Nandwa and Bekunda, 1998). Considering critical minimum requirements for adequate plant growth of 0.2 $cmol_c kg^{-1}$ for Ca and Mg (FURP, 1994), Ca and Mg were adequate in all cropping systems and management strategy combinations. Potassium was also above the critical range of 0.13-0.20 $cmol_c kg^{-1}$ (Norman et al., 1995) for maize.

Soil Inorganic N

<u>Experiment 1</u>

Initial mean soil inorganic N concentrations in the 0 to 20 and 20 to 40 cm depths were 7 and 2 mg kg^{-1}, respectively (data not presented). By the end of the first cropping yr, soil inorganic N in the surface 20 cm increased 41% (6.6 to 9.3 mg kg^{-1}) and 171% (2.0 to 5.3 mg kg^{-1}) in the 20 to 40-cm depth from initial levels (Fig. 2.5). The increase in subsoil inorganic N is likely the result of leaching during the rain season. Table 2.21 shows the sampling dates when significant differences in soil inorganic N concentrations occurred among Exp1 treatments. The influence of cropping system and management strategy on inorganic N were marginal, being evident in five out of seventeen sampling dates. Soil inorganic N is an indication of the N remaining after plant residue and soil organic matter N mineralization, plant uptake, and losses from through leaching, denitrification, or volatilization processes. These processes are likely to be influenced by the cropping systems and management strategies used in this study. As expected in a hot tropical environment, temperatures were favorable throughout the experimental period for N mineralization to occur. Soil moisture and presence of a suitable substrate were likely to be the main modifying factors to the N mineralization and immobilization process.

After the initial sampling on 18 May, 1999, the next sampling occurred on 3 Jul, 1999 (Fig. 2.5). Clitoria, cassava, and maize were well established by then. Clitoria mulch from the initial cut at 2 mo after planting and fertilizer had been applied to the respective treatments. Generally low levels of soil inorganic N were measured from 18 May to 2 Sep,

1999. The significant influence of cropping systems and management strategy from 3 Jul to 3 Aug can be attributed to greater N uptake by maize during this period. Generally, cropping systems with maize as main crop had lower soil inorganic N concentrations, about 25% less than clitoria/cassava intercrop. On 3 Jul the greatest soil inorganic N concentrations occurred in cassava cropping systems (9.7 mg kg^{-1}), while the least soil N was in maize monoculture system (5.2 mg kg^{-1}). Similarly, low soil N concentrations were evident on 3 Aug in clitoria and maize monoculture treatments. The results suggest that most of the inorganic N was immobilized by the microbial biomass, and/or maize crops. Although the cut legume foliage would be expected to increase amounts of soil inorganic N via residue decomposition, the biomass accumulated by clitoria 2 mo after planting was very low (avg. 0.1 Mg ha^{-1}), and would not have a significant N contribution to the systems. The greater N concentrations observed after 2 Sep in clitoria based systems were short lived. The increase in inorganic N concentrations between 10 Sep and 28 Dec may be related to greater microbial activity stemming from substrate inputs of clitoria and maize stover. Additionally, the rainfall received during the short rain periods was much less than that received during the long rain season, and likely led to reduced potential for NO_3.

Experiment 2

Initial mean soil inorganic N concentrations in the surface 20 cm and 20 to 40-cm depths were 5.2 and 2 mg kg^{-1}, respectively. By the end of the first yr, soil inorganic N in the surface 20 cm increased 102 % (5.2 to 10.5 mg kg^{-1}) in the surface 20 cm and 298 % (2.0 to 7.6 mg kg^{-1}) in the 20 to 40-cm depth from initial levels (data not shown). The increases in subsoil inorganic N could be a result of NO_3 leaching during the rain season. Increased amounts of NO_3-N in the subsoil were especially evident where dolichos and cassava had been part of the cropping system. Field observations showed that mature cassava plants dropped a substantial amount of leaves, which upon decomposition would release nutrients to the soil.

Generally, increased amounts of inorganic N were most evident during the long rain season, reflecting more favorable conditions for residue and soil N mineralization (Stanford and Smith, 1972). Table 2.22 shows the sampling dates when significant differences in soil inorganic N concentrations occurred among Exp2 treatments. Returning dolichos foliage as surface mulch two mo after planting led to significantly greater soil inorganic N concentrations in Jul 1999 compared to dolichos allowed to grow four mo (Fig. 2.6). Application of dolichos foliage mulch likely contributed to increased soil N. From the results of a companion paper reporting decomposition and nutrient release from legume residues, dolichos 2-mo cut residue had a C:N (13:1) ratio below 25:1, allowing for net soil N mineralization to occur. Dolichos supplied a high quality substrate for the microbes, while the tropical temperature regime and the moderate precipitation received in Jul were ideal for microbial activity. Also, with the moderate precipitation, the amount of soil N leached was likely to be low. This increased soil N concentration was short lived, however, as inorganic

N concentrations declined to original levels one mo later.

When dolichos was grown for four mo and then cut for mulch, soil inorganic N increased by 160% (4.5 vs. 11.6 mg ha^{-1}) compared to systems with no fertilizer inputs (Fig. 2.6). Unlike the two-mo harvest strategy, the greater soil N values obtained with the four mo cut were sustained for a longer period, at values 40 to 100% above systems with no fertilizer inputs. These increased N levels were associated with greater biomass production in the longer harvesting strategy, along with greater amounts of accumulated N in the decomposing foliage (Table 2.10). Averaged across cropping systems, dolichos cut at 4 mo accumulated 123 kg N ha^{-1}, compared to 41 kg N ha^{-1} in dolichos foliage cut at two mo. Its likely that some of the N released from the 2 mo dolichos foliage was taken up by the accompanying maize crop still at a growth stage with a high N demand. In contrast, dolichos cut at four mo in Aug of both yr coincided with a more mature maize-growth stage, consequently N demand was much less. Additionally, results from the nutrient decomposition and release study showed that N release from the four-mo dolichos foliage was much slower (0.3 wk^{-1}), compared to the 2.50 wk^{-1} rate for two-mo dolichos. Both the two and four-mo cut dolichos nutrient release curves fit an asymptotic model, but the readily available N (58%) was released within two wk after placement of two-mo dolichos residue, compared to over 6 wk taken to release a similar proportion from the four-mo dolichos residue.

Nutrient Balances

Nutrient balances were prepared to determine the occurrence of net gain or loss of nutrients resulting from a cropping system and/or management strategy. Inorganic fertilizers (N and P applications) and/or returned plant residues (legume foliage, cassava leaves, and maize stover) were the nutrient inputs, while crop harvests (maize grain, cassava tubers, and cassava stems) were the nutrient removals.

The nutrient balances results revealed that fertilizer application rates of 120 kg N ha^{-1} and 40 kg P ha^{-1} in Exp1, along with retaining maize stover in the respective cropping field, resulted in positive nutrient balances (8 kg N, 18 kg P, and 54 kg K ha^{-1}) after maize grain harvest (Appendix Table A2.2). These results indicate that the fertilizer recommendation would be suitable, because of the increased yields obtained while maintaining or increasing the soil nutrient status. Also, irrespective of clitoria harvest management strategy, intercropping of maize and clitoria resulted in positive nutrient balances with maize stover returned to the system. Mean nutrient balances for the 6 and 10 wk clitoria harvesting strategy were 19 kg N ha^{-1}, 14 kg P ha^{-1}, and 78 kg K ha^{-1}. Generally, most cropping systems had positive P balances, ranging from 1 kg P ha^{-1} in the cassava/maize system supplied with N and P fertilizer, to 28 kg P ha^{-1} in clitoria monoculture with a 6-wk cutting strategy. Negative P balance values were observed in maize monoculture (-11 kg P ha^{-1}), cassava monoculture (-14 kg P ha^{-1}), and cassava/maize (-13 kg P ha^{-1}) systems without fertilizer inputs.

The presence of cassava in a cropping system resulted in negative N and K balances. Generally, intercropping of cassava and clitoria would offset a big proportion of the N removed in cassava tuber and stems, resulting in greater N balance values. The large amounts of K removed in cassava tuber and stems were not replaced by the inputs in clitoria foliage, maize stover, and cassava leaves.

While fertilizer application rates and maize stover management were similar for both experiments, inorganic N fertilizer was inadequate for maize grain production in Exp2 Tables 2.3 and 2.4). The net result was a negative N balance (-18 kg N ha^{-1}) for the maize monoculture maize production system supplied with N and P fertilizer. Averaged over two yr, mean cumulative grain yield for long and short rain seasons in Exp2 was 0.8 Mg ha^{-1} greater than that measured in Exp1 (9.0 Mg ha^{-1}). However, positive P and K balances were observed. Intercropping of dolichos with maize, or delaying dolichos harvesting to 4 mo after planting, resulted in positive nutrient balances because of the relatively large amounts of nutrients supplied by dolichos foliage during the long rain season (Table 2.10). The trends for P and K were similar to those of Exp1, with positive P balances recorded due to P supplementation and cassava tubers and stems removing large amounts of K. Similar to Exp1, negative K balances occurred in all cropping systems of Exp2 with cassava as a component crop.

The nutrient balance results demonstrate the potential of clitoria foliage to supply adequate N and K from the decomposing mulch for maize grain production in the region. For P, an inorganic source of fertilizer would be required. Both legumes also supplied near adequate N for cassava production. To improve cassava tuber yields, the integrated use of legume foliage together with other sources of N and P is suggested. Also, the results of this study support the need for developing a K fertilizer recommendation to cassava cropping systems in the region.

Area by Time Equivalent Ratio

Land equivalency (LER) and area by time equivalency ratios (ATER) are the measure of the efficiency in the use of land area and/or time for monoculture compared to intercropping. Calculations of the LER and ATER were based on totals of long and short rain season's yields of maize, legume, and cassava (Tables 2.6 and 2.7). Compared to a maize/cassava cropping system, intercropping of clitoria with maize or cassava in Exp1 resulted in a greater land equivalency ratio (> 1.8). Intercropping of cassava and maize resulted in a mean LER of 1.3. Generally, the LER tends to overestimate the biological efficiency of the intercropping system because the time factor is not considered. Considering the growth characteristics of maize and cassava, the ATER would be a better estimator of the biological efficiency of maize and cassava intercropping. Only one crop of cassava was harvested during the two cropping seasons each year; while two crops of maize were harvested, one in each season. Intercropping of clitoria with maize or cassava resulted in the most efficient way of utilizing land area and time (ATER range 1.2 to 1.6). A longer cutting interval of clitoria resulted in greater ATER values.

Similar to Exp1, the LER in Exp2 were greatest for dolichos/maize and dolichos/cassava cropping systems. When use of time was considered, the dolichos/maize cropping systems would increase biological efficiency, particularly in situations where fertilizer inputs are not used. Generally, greater values of ATER were observed where the basis for the comparisons was the no fertilizer input control, implying that advantages of intercropping would be noticeable in situations where fertilizer inputs are a constraint, as is the case in coastal Kenya.

SUMMARY AND CONCLUSIONS

The study was designed to assess the merits of incorporating herbaceous forage legumes as intercrops in maize and/or cassava cropping systems, as sources of plant nutrients for increased food production. Considering that very few farmers can afford purchased fertilizer inputs, the use of legumes as nutrients sources would ensure that N removed in crop harvest is replenished, while recycling other nutrients.

Clitoria and dolichos demonstrated their potential as sources of plant nutrients. The legumes accumulated substantial amounts of nutrients (2-yr avg.), ranging from 36 to 101 kg N ha^{-1}, 3 to 8 kg P ha^{-1}, 26 to 83 kg K ha^{-1}, 5 to 32 kg Ca ha^{-1}, and 5 to 7 kg Mg ha^{-1} in both the long and short rain seasons. Increased maize grain yields and nutrient accumulation in grain and stover occurred as a result of intercropping with the forage legumes. During the long rain season, intercropping of clitoria with maize resulted in 50 to 80% more nutrients accumulated in grain and stover, compared to maize monoculture without fertilizer inputs. Dolichos demonstrated its potential to increase grain yield during the short rain season, when yield in the dolichos/maize system was 79% greater than in maize monoculture with no fertilizer inputs. Also, positive nutrient balances occurred in all maize/legume intercropping systems. Furthermore, intercropping of forage legumes in cassava and /or maize and cutting the legume for mulch indicated an improvement in biological efficiency in the use of space and time in the region, by showing ATER values greater than unity. Maize grain and cassava tuber yield increases occurred as a result of applying N and/or P fertilizer, also confirming that the soils were inadequate in these nutrients. It was also observed that cassava tubers and stems removed large amounts of nutrients, particularly N and K, and there is need to develop recommendations on how best to replenish the nutrients removed. To increase and sustain maize grain and cassava production in the region, integrated use of foliage from legumes, inorganic fertilizer sources (particularly P and K), and other organic sources of nutrients would be recommended. Also measures that would minimize nutrient losses from the different cropping systems merits further research, such as synchronizing nutrient release with principal crop demand.

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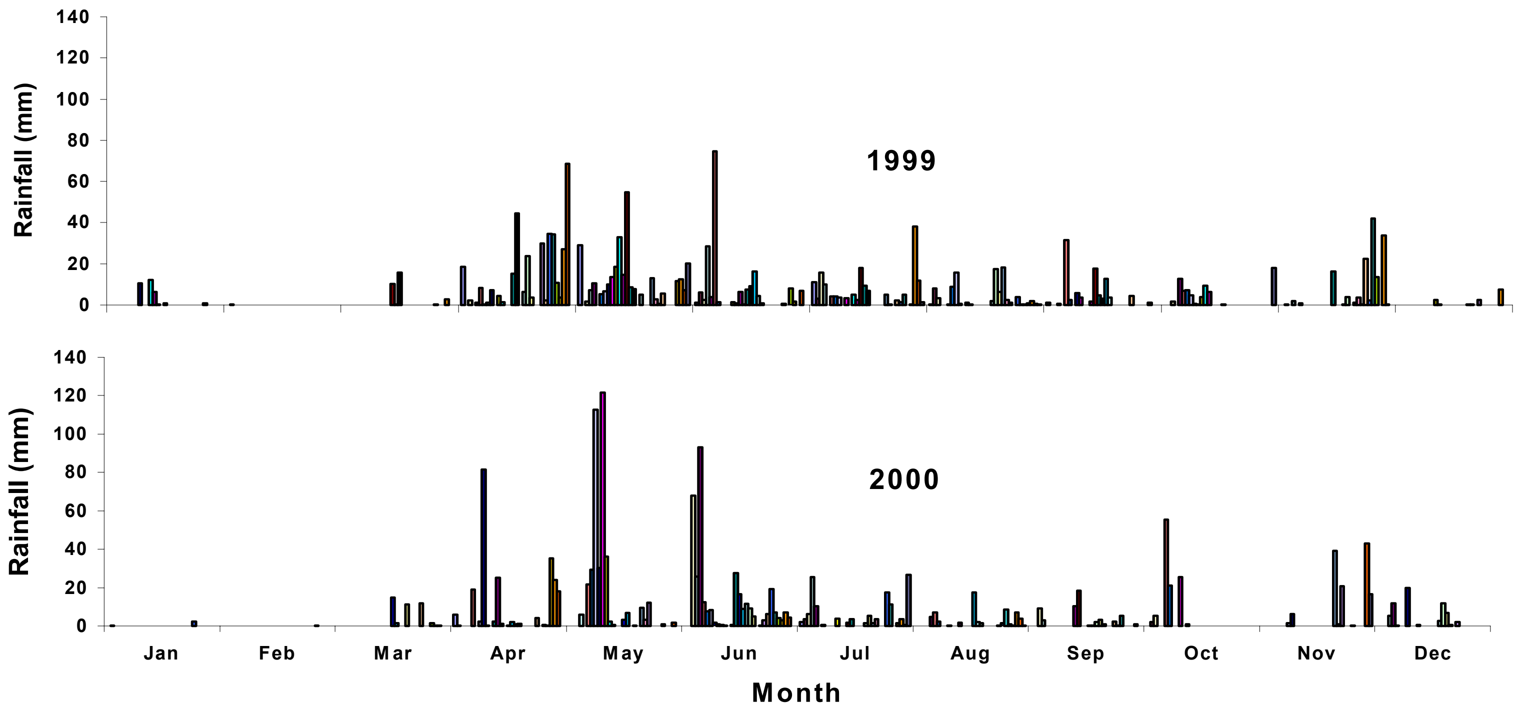


Fig.2.1. Rainfall distribution at the Mtwapa Research Station in Kenya during field experiments evaluating clitoria and dolichos for soil fertility improvement.

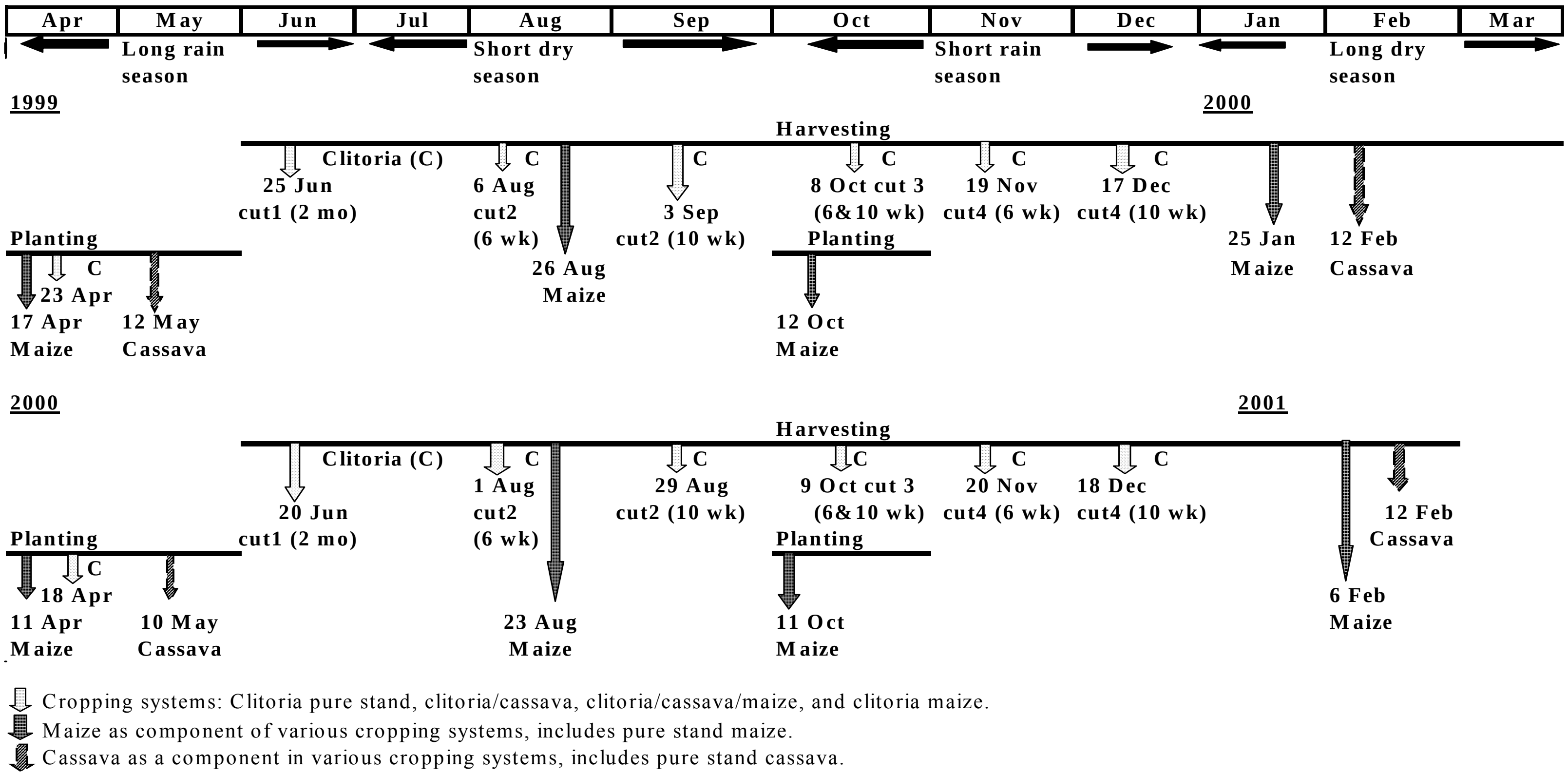
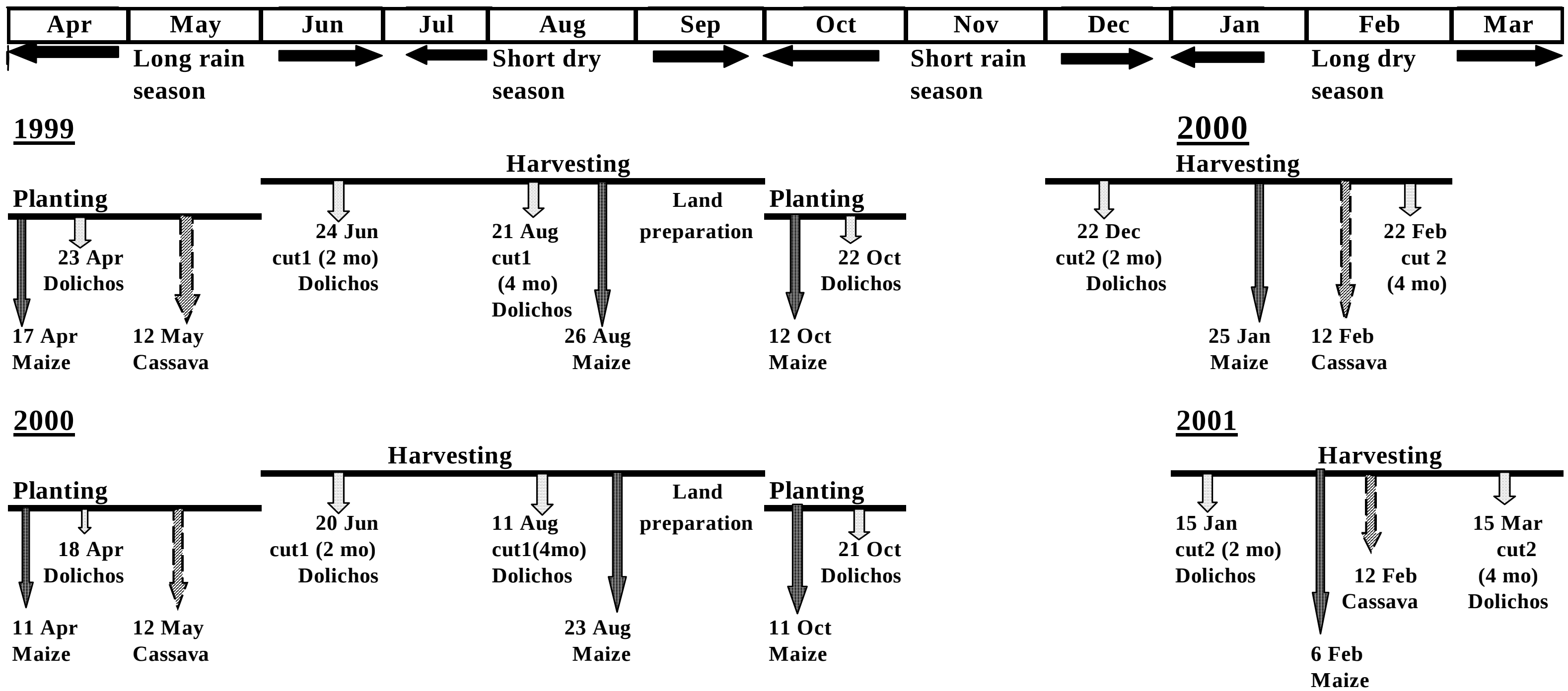


Fig. 2.2. Cropping sequence and cultural activities for clitoria/maize/cassava during the 1999 and 2000 cropping seasons in coastal lowland Kenya.



Cropping systems: Dolichos pure stand, dolichos/cassava, dolichos/cassava/maize, and dolichos maize.

Maize as component of various cropping systems, includes pure stand maize.

Cassava as a component in various cropping systems, includes pure stand cassava.

Fig. 2.3. Cropping sequence and cultural activities for dolichos/maize /cassava during the 1999 and 2000 cropping seasons in coastal lowland Kenya.

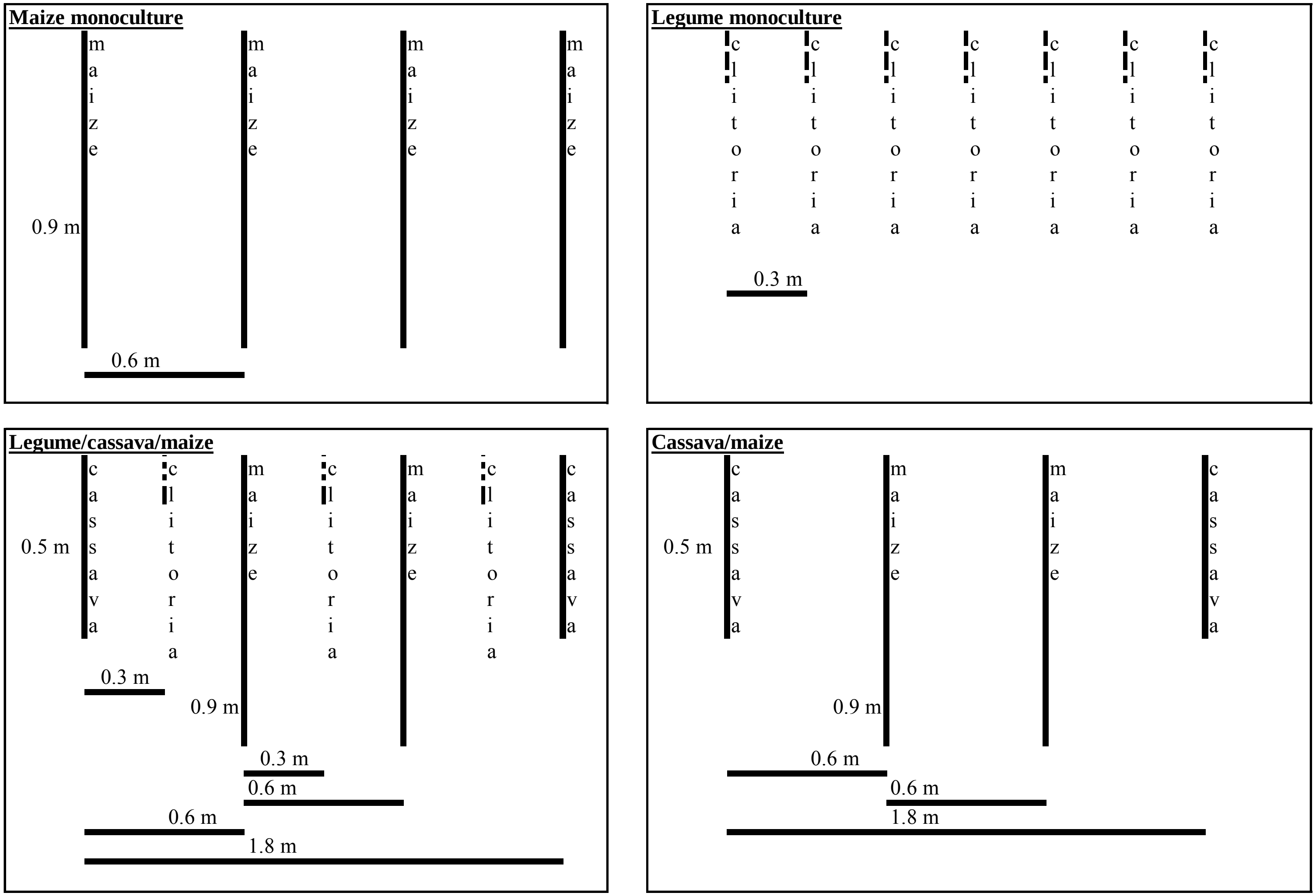
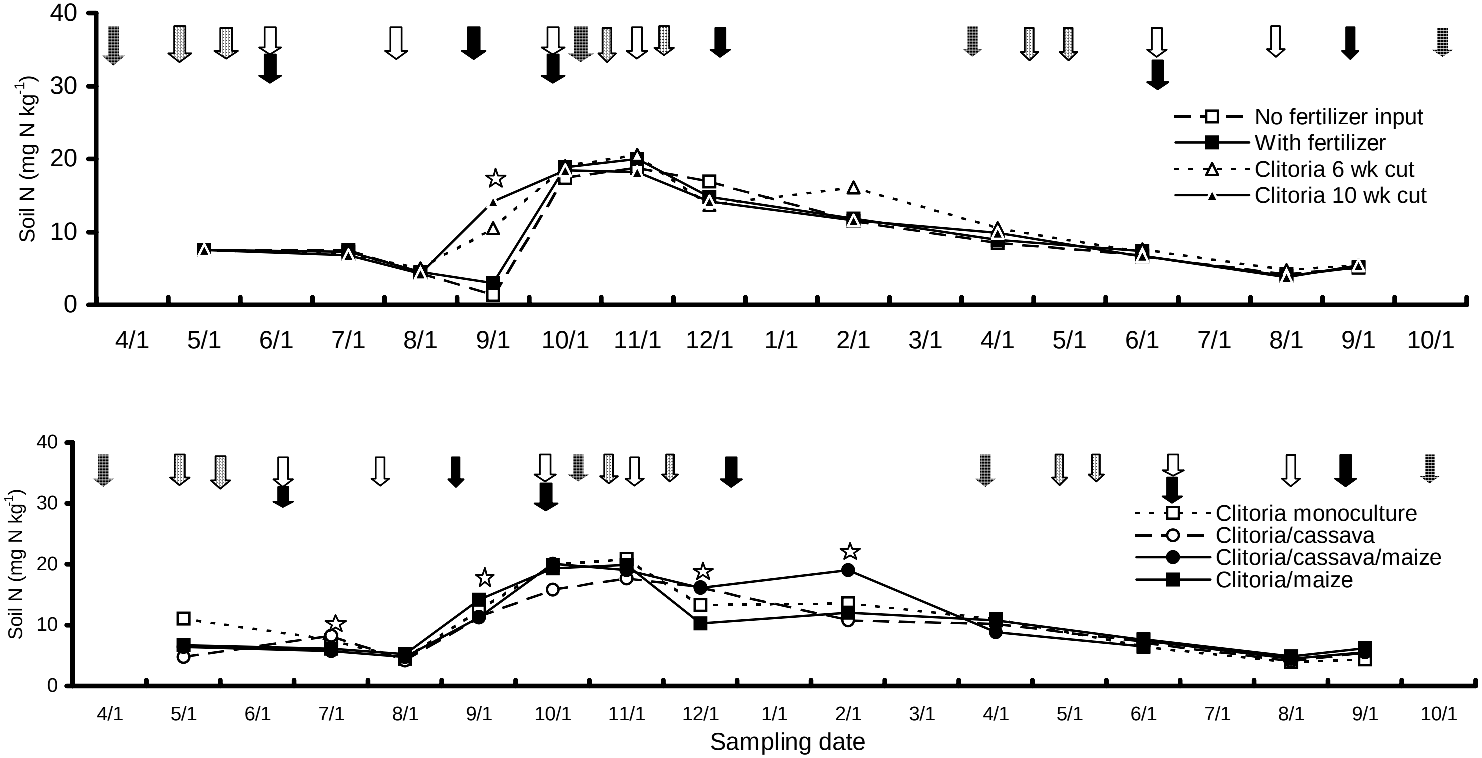


Fig. 2.4. Spatial arrangement of the crops planted in different subplots of maize, legume (clitoria or dolichos), and cassava/maize/legume for two experiments that evaluated legumes for soil fertility improvement in coastal lowland Kenya.



Fertilizer applied, 20 kg P ha^{-1}

Fertilizer applied, 60 kg N ha^{-1}

Fig.2.5. Soil inorganic N (0- 20 cm depth) as influenced by cropping systems, *Clitoria ternatea* harvest management and fertilizer supplementation in coastal lowland Kenya. An asterisk indicates significance at P<0.05. An ( ) unshaded arrow indicates a 6-wk clitoria cut, while a shaded arrow ( ) indicates a 10-wk cut

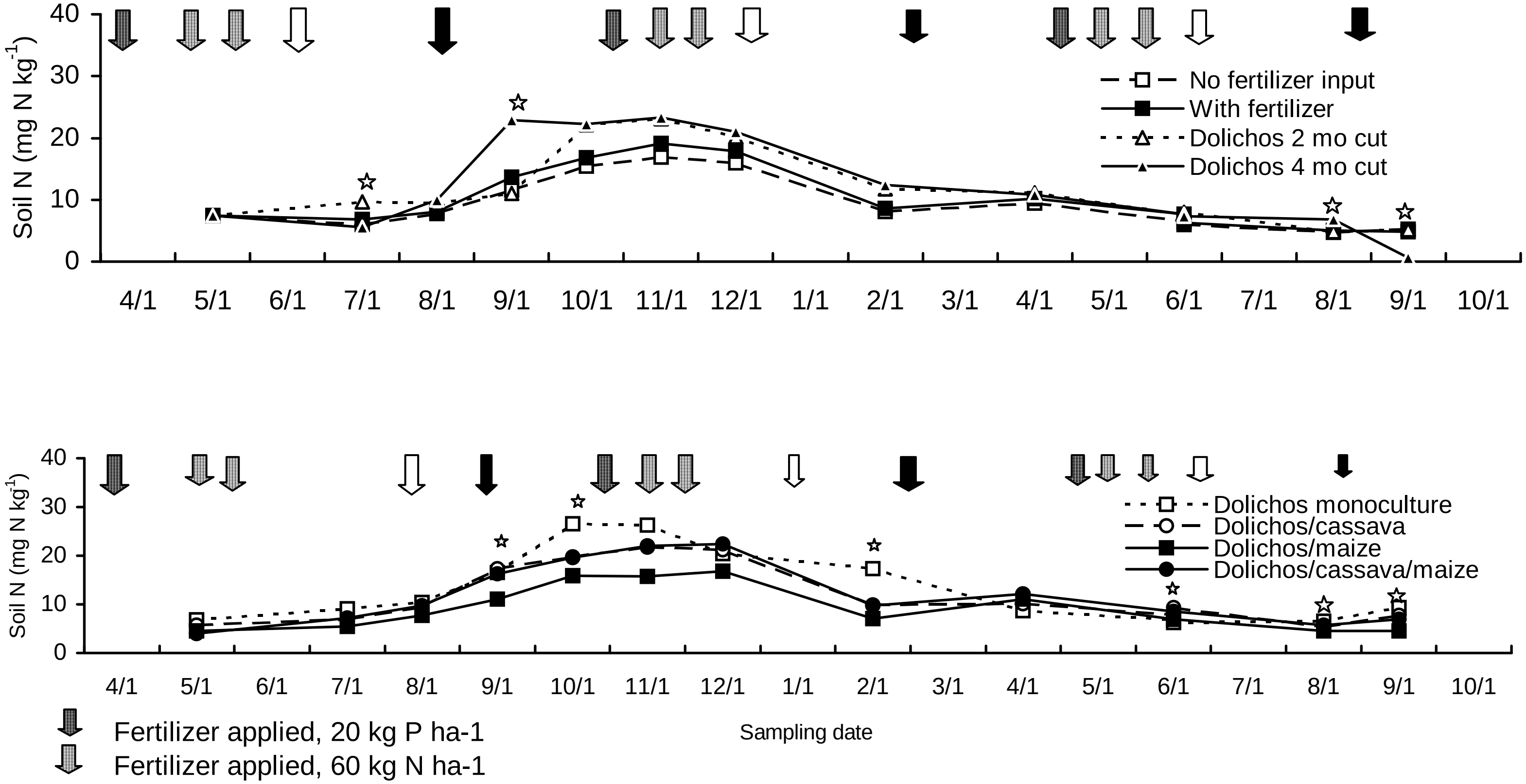


Fig.2.6. Soil inorganic N (0- 20 cm depth) as influenced by cropping systems, *Lablab perpureus* harvest management, and fertilizer supplementation in coastal lowland Kenya. An (☆) asterisk indicates significance at P<0.05. An (⇩) unshaded arrow indicate a 2 mo dolichos cut, while a shaded arrow (⬇) indicates a 4 mo cut.

Table 2.1. Initial soil characteristics for experiment evaluating clitoria for soil fertility improvement in coastal lowlands Kenya.

	Soil depth (cm)		
Parameter	0-40	40-70	70-80
pH†	6.3	6.5	5.4
Bulk density	1.2	nd	nd
Clay (%)	11	11	31
Silt (%)	6	2	4
Sand (%)	83	87	65
Organic C (g kg $^{-1}$)	7.4	4.9	4.6
Exch. K ($cmol_C kg^{-1}$)	0.2	0.2	0.4
Exch. Ca ($cmol_C kg^{-1}$)	1.3	0.8	1.3
Exch. Mg ($cmol_C kg^{-1}$)	0.3	0.3	1.4
Exch. acidity	0	0	1.8
Extractable P (mg kg^{-1})	0.7	0.2	0.6
Fe (mg kg^{-1})	74.3	58.7	55.0
Mn (mg kg^{-1})	170.0	52.0	4.6
Zn (mg kg^{-1})	8.7	3.2	4.6
ECEC	1.8	1.3	4.9
Base saturation (%)	100	100	63

† Soil:water (1:2.5)
nd = not determined

Table 2.2. Treatment combinations for experiment evaluating clitoria and dolichos for soil fertility improvement in coastal lowland Kenya during 1999 and 2000.

Cropping system	Legume cutting management
Exp1	
Clitoria	Cut clitoria at 2mo, then after 6 wk‡
Clitoria	Cut clitoria at 2mo, then after 10 wk‡
Clitoria/cassava	Cut clitoria at 2mo, then after 6 wk‡
Clitoria/cassava	Cut clitoria at 2mo, then after 10 wk‡
Clitoria/maize	Cut clitoria at 2mo, then after 6 wk‡
Clitoria/maize	Cut clitoria at 2mo, then after10 wk‡
Clitoria/cassava/maize	Cut clitoria at 2mo, then after 6 wk‡
Clitoria/cassava/maize	Cut clitoria at 2mo, then after 10 wk‡
Maize	No fertilizer input or legume‡
Maize	Fertilizer applied to maize †‡
Cassava/maize	Fertilizer applied to maize ‡
Cassava/maize	No fertilizer input or legume
Cassava	Fertilizer applied‡
Cassava	No fertilizer input or legume
Exp2	
Dolichos	Cut dolichos at 2-mo after planting‡
Dolichos	Cut dolichos at 4-mo after planting‡
Dolichos/cassava	Cut dolichos at 2-mo after planting‡
Dolichos/cassava	Cut dolichos at 4-mo after planting‡
Dolichos/maize	Cut dolichos at 2-mo after planting‡
Dolichos/maize	Cut dolichos at 4-mo after planting‡
Dolichos/cassava/maize	Cut dolichos at 2-mo after planting‡
Dolichos/cassava/maize	Cut dolichos at 4-mo after planting‡
Maize	No fertilizer input or legume
Maize	Fertilizer applied to maize†‡
Cassava/maize	Fertilizer applied to maize ‡
Cassava/maize	No fertilizer input or legume
Cassava	Fertilizer applied‡
Cassava	No fertilizer input or legume

† 60 kg N ha^{-1} applied in form of calcium ammonium nitrate (26% N) in two equal splits.
‡ 20 kg P ha^{-1} applied as triple super phosphate (20% P) before planting.

Table 2.3. Annual nutrient budgets in Exp1 for each cropping system, based on inputs from fertilizer and crop residues and removal by crop harvest in coastal lowland Kenya.

	Inputs†					Crop removal†						Balance		
	Fertilizer		Residue‡			Maize grain			Cassava stem and tubers					
Cropping system	N	P	N	P	K	N	P	K	N	P	K	N	P	K
	kg ha^{-1}													
Maize monoculture, no fertilizer	0	0	26	2	60	86	13	17	0	0	0	-60	-11	43
Maize monoculture, with fertilizer	120	40	38	4	86	150	26	32	0	0	0	8	18	54
Cassava monoculture, no fertilizer	0	0	22	2	10	0	0	0	109	16	193	-87	-14	-183
Cassava monoculture, with fertilizer	0	20	23	2	10	0	0	0	123	18	215	-100	4	-205
Cassava/maize, no fertilizer	0	0	40	5	36	47	13	10	74	11	168	-81	-13	-132
Cassava/maize, with fertilizer	60	20	42	5	46	65	18	14	70	13	167	-23	1	-121
Clitoria monoculture with P/ 6-wk cut	0	20	104	8	75	0	0	0	0	0	0	104	28	75
Clitoria monoculture with P/ 10-wk cut	0	20	95	5	48	0	0	0	0	0	0	65	25	48
Clitoria/maize with P/ 6-wk cut	0	20	105	9	107	69	16	20	0	0	0	18	16	87
Clitoria/maize with P/ 10-wk cut	0	20	86	8	85	53	13	16	0	0	0	20	13	69
Clitoria/cassava with P/ 6-wk cut	0	20	101	8	71	0	0	0	85	14	177	16	14	-106
Clitoria/cassava with P/ 10-wk cut	0	20	88	8	60	0	0	0	85	17	193	-9	10	-133
Clitoria/cassava/maize with P/ 6-wk cut	0	20	103	9	77	57	10	13	74	13	141	-28	6	-77
Clitoria/cassava/maize with P/ 10-wk cut	0	20	84	7	67	40	11	10	60	10	114	-16	6	-57

† Inputs and removals are the sum of long and short rain season.
‡ Residues additions were maize stover, cassava leaf, and clitoria foliage.

Table 2.4. Annual nutrient budgets in Exp2 for each cropping system based on inputs from fertilizer and crop residues and removal by crop harvest in coastal lowland Kenya.

	Inputs†					Crop removal†								
	Fertilizer		Residue‡			Maize grain			Cassava stem and tubers			Balance		
Cropping system	N	P	N	P	K	N	P	K	N	P	K	N	P	K
	kg ha^{-1}													
Maize monoculture, no fertilizer	0	0	22	2	51	91	11	15	0	0	0	-69	-9	36
Maize monoculture, with fertilizer	120	40	21	2	100	176	24	32	0	0	0	-18	18	68
Cassava monoculture, no fertilizer	0	0	18	1	7	0	0	0	105	12	156	-87	-11	-149
Cassava monoculture, with fertilizer	0	20	16	1	5	0	0	0	110	17	155	-94	4	-150
Cassava/maize, no fertilizer	0	0	36	3	32	44	6	44	95	11	163	-103	-14	-175
Cassava/maize, with fertilizer	60	20	42	3	36	65	11	65	107	15	175	-70	-3	-204
Dolichos monoculture with P/ 2 mo cut	0	40	70	6	52	0	0	0	0	0	0	70	26	52
Dolichos monoculture with P/ 4 mo cut	0	40	181	14	165	0	0	0	0	0	0	181	34	165
Dolichos/maize with P/ 2 mo cut	0	40	64	5	99	95	14	19	0	0	0	-31	11	161
Dolichos/maize with P/ 4 mo cut	0	40	145	10	178	87	14	17	0	0	0	58	16	52
Dolichos/cassava with P/ 2 mo cut	0	20	72	6	56	0	0	0	113	15	206	-41	11	-150
Dolichos/cassava with P/ 4 mo cut	0	20	153	10	127	0	0	0	92	10	147	61	20	-20
Dolichos/cassava/maize with P/ 2 mo cut	0	20	81	6	65	55	8	16	86	11	142	-60	7	-87
Dolichos /cassava/maize with P/ 4 mo cut	0	20	141	10	107	38	6	6	72	9	116	31	15	-19

† Inputs and removals are the sum of long and short rain season.
‡ Residues additions were maize stover, cassava leaf, and dolichos foliage.

Table 2.5. Inorganic nitrogen sampling dates in evaluating legumes for soil fertility improvement in coastal lowlands Kenya.

Date	Depth, cm	Field activity
1999 long rain season		
18 May	0-20; 20-40	Initial, before clitoria 6 and 10 wk (cut1)
3 Jul	0-20	After clitoria 6 and 10 wk (cut1)
3 Jul	0-20	Before clitoria 6 wk (cut2)
13 Aug	0-20	After clitoria 6 wk (cut2)
2 Sep	0-20	Before clitoria 10 wk (cut2)
10 Sep	0-20	After clitoria 10 wk (cut2)
2 Sep	0-20	Before clitoria 6 wk (cut3)
10 Sep	0-20	After clitoria 6 wk (cut3)
10 Sep	0-20	Before clitoria 10 wk (cut3)
1999 short rain season		
18 Oct, 1999	0-20	After clitoria 10 wk (cut3)
18 Oct, 1999	0-20	Before clitoria 6 wk (cut4)
24 Nov, 1999	0-20	After clitoria 6 wk (cut4)
10 Dec, 1999	0-20	Before clitoria 10 wk (cut4)
28 Dec, 1999	0-20	After clitoria 10 wk (cut4)
16 Feb, 2000	0-20	After clitoria 6 and 10 wk (cut4)
29 Feb, 2000	0-20	After clitoria 6 and 10 wk (cut4)
2000 long rain season		
10 April	0-20; 20-40	Initial, before clitoria 6 and 10 wk (cut1)
28 June	0-20	After clitoria 6 wk (cut1)
28 June	0-20	After clitoria 10 wk (cut1)
13 June	0-20	Before clitoria 6 wk (cut2)
14 Aug	0-20	After clitoria 6 wk (cut2)
14 Aug	0-20	Before clitoria 10 wk (cut2)
5 Sep	0-20	After clitoria 10 wk (cut2)

Table 2.6. Yields of maize, cassava tuber, and clitoria foliage dry matter, along with land equivalent ratio (LER) and area by time equivalent ratio (ATER), in various cropping systems and management strategies in coastal lowland Kenya.

Cropping system and management	Total ha days†	Yield: Cassava tuber	Yield: Maize grain	Yield: Legume foliage	LER	ATER
		Mg ha^{-1}				
No fertilizer						
Maize monoculture, no fertilizer	239	-‡	5.9	-	-	-
Clitoria monoculture, 6 wk	210	-	-	3.7	-	-
Maize/clitoria, 6 wk	292	-	5.5	3.0	1.7	1.3
Clitoria monoculture, 10 wk	245	-	-	2.3	-	-
Maize/clitoria, 10 wk	292	-	5.2	2.4	1.9	1.6
Cassava monoculture, no fertilizer	277	8.8	-	-	-	-
Maize/cassava, no fertilizer	298	5.8	3.6	-	1.3	1.1
Clitoria/cassava, 6 wk	304	6.9	-	2.8	1.5	1.2
Clitoria/cassava, 10 wk	304	8.0	-	2.3	1.9	1.6
With fertilizer						
Maize monoculture, with fertilizer	239	-	9.1	-	-	-
Clitoria monoculture, 6 wk	210	-	-	3.7	-	-
Maize/clitoria, 6 wk	292	-	5.5	3.0	1.4	0.9
Clitoria monoculture, 10 wk	245	-	-	2.3	-	-
Maize/clitoria, 10 wk	292	-	5.2	2.4	1.6	1.3
Cassava monoculture, with fertilizer	277	10.0	-	-	-	-
Maize/cassava, with fertilizer	298	6.7	4.5	-	1.2	1.0
Clitoria/cassava, 6 wk	304	6.9	-	2.8	1.4	1.2
Clitoria/cassava, 10 wk	304	8.0	-	2.3	1.8	1.5

† Number of days a crop occupied a hectare of land.
‡Calculations made for intercrops only.

Table 2.7. Yields of maize, cassava tuber, and dolichos foliage dry matter, along with land equivalent ratio (LER) and area by time equivalent ratio (ATER), in various cropping systems and management strategies in coastal lowland Kenya

Cropping system and management	Total ha days†	Yield: Cassava tuber	Yield: Maize grain	Yield: Legume foliage	LER	ATER
		Mg ha^{-1}				
No fertilizer						
Maize monoculture, no fertilizer	239	‡-	5.1	-	-	-
Dolichos monoculture, 2 mo	136	-	-	2.3	-	-
Maize/dolichos, 2 mo	258	-	7.6	1.4	2.5	2.0
Dolichos monoculture, 4 mo	252	-	-	7.7	-	-
Maize/dolichos, 4 mo	277	-	6.3	5.2	1.9	1.7
Cassava monoculture, no fertilizer	277	7.9	-	-	-	-
Maize/cassava, no fertilizer	298	5.8	3.1	-	1.3	1.1
Dolichos/cassava, 2 mo	304	8.3	-	1.6	1.7	1.1
Dolichos/cassava, 4 mo	304	5.1	-	2.4	1.7	1.0
With fertilizer						
Maize monoculture, with fertilizer	239	-	9.5	-	-	-
Dolichos monoculture, 2 mo	136	-	-	2.3	-	-
Maize/ dolichos, 2 mo	258	-	7.6	1.4	1.4	1.1
Dolichos monoculture, 4 mo	252	-	-	7.7	-	-
Maize/ dolichos, 4 mo	277	-	6.3	5.2	1.3	1.2
Cassava monoculture, with fertilizer	277	9.6	-	-	-	-
Maize/cassava, with fertilizer	298	7.8	4.2	-	1.2	1.1
Dolichos/cassava, 2 mo	304	8.3	-	1.6	1.6	0.9
Dolichos/cassava, 4 mo	304	5.1	-	2.4	1.6	0.9

† Number of days a crop occupied a hectare of land.
‡ Calculations made for intercrops only.

Table 2.8. Sources of variance and levels of significance for clitoria and dolichos forage yield and nutrient contents (2-yr avg.)

in two experiments that evaluated legumes for soil fertility improvement in coastal lowland Kenya.

	Exp1						Exp2					
		Nutrient content						Nutrient content				
Source†	Yield	N	P	K	Ca	Mg	Yield	N	P	K	Ca	Mg
						Long rain season						
Year	*	*	*	*	*	*	***	*	NS	**	**	NS
Cropping system	NS	NS	NS	NS	NS	NS	***	*	**	**	*	NS
Year x cropping system	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Management w/in cropping system	NS	NS	NS	NS	NS	NS	***	***	***	***	***	***
Year x management w/in cropping system	NS	NS	NS	NS	NS	NS	***	*	NS	**	**	NS
						Short rain season						
Year	**	**	**	**	**	**	NS	NS	NS	NS	NS	*
Cropping system	***	***	***	***	***	***	***	**	*	*	*	**
Year x cropping system	***	***	***	***	***	***	NS	NS	NS	NS	NS	***
Management w/in cropping system	***	***	***	***	***	***	*	NS	NS	NS	NS	*
Year x management w/in cropping system	***	***	***	***	***	***	NS	NS	NS	NS	NS	NS

† Forage yield and nutrient content; model [2].
*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.
NS=not significant.

Table 2.9. Forage yield and nutrient content (2-yr avg.) of *Clitoria ternatea* as influenced by cropping system and legume harvest management in coastal lowland Kenya.

	Long rain season						Short rain season					
Cropping system/management strategy	Forage yield†	N	P	K	Ca	Mg	Forage yield†	N	P	K	Ca	Mg
	Mg ha^{-1}	kg ha^{-1}					Mg ha^{-1}	kg ha^{-1}				
1. Clitoria monoculture, 6-wk cut	1.1	31	2	22	4	4	2.6	73	6	53	10	9
2. Clitoria monoculture, 10-wk cut	1.1	30	2	22	4	4	1.2	35	3	26	5	4
3. Clitoria/cassava, 6-wk cut	1.1	31	2	22	4	4	1.7	47	4	35	7	6
4. Clitoria/cassava, 10-wk cut	1.1	31	2	22	4	4	1.2	33	3	24	5	4
5. Clitoria/maize, 6-wk cut	1.0	29	2	21	4	4	2.0	58	4	42	8	7
6. Clitoria/maize, 10-wk cut	1.0	29	2	21	4	4	1.4	39	3	28	5	5
7. Clitoria/cassava/maize, 6-wk cut	1.0	29	2	21	4	4	1.3	37	3	27	5	5
8. Clitoria/cassava/maize, 10-wk cut	1.0	29	2	21	4	4	1.2	35	3	25	5	4
SE‡	0.02	0.7	0.1	0.5	0.1	0.1	0.1	2.8	0.2	2.1	0.4	0.4
Orthogonal contrasts												
Clitoria vs. intercrop (1 and 2 vs. 3,4,5,6, 7 and 8)	NS	NS	NS	NS	NS	NS	***	***	***	***	***	***
Clitoria vs. clitoria/cassava (1 and 2 vs. 3 and 4)	NS	NS	NS	NS	NS	NS	***	***	***	***	***	***
Clitoria vs. clitoria/maize (1 and 2 vs. 5 and 6)	*	NS	NS	NS	NS	NS	*	*	*	*	*	*
Clitoria/cassava vs. clitoria/cassava/maize (3 and 4 vs. 7 and 8)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Clitoria/maize vs. clitoria/cassava/maize (5 and 6 vs. 7 and 8)	NS	NS	NS	NS	NS	NS	***	***	**	***	***	***
Clitoria, 6-wk cut vs. clitoria/cassava (1 vs. 3 and 4)	NS	NS	NS	NS	NS	NS	***	***	**	***	***	***
Clitoria, 10-wk cut vs. clitoria/cassava (2 vs. 3 and 4)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Clitoria, 6-wk cut vs. clitoria/maize (1 vs. 5 and 6)	NS	NS	NS	NS	NS	NS	***	***	***	***	***	***
Clitoria, 10-wk cut vs. clitoria/maize (2 vs. 5 and 6)	NS	NS	NS	NS	NS	NS	***	***	***	***	***	***
Clitoria, 10-wk cut vs. clitoria 6 wk cut (1,3,5 and 7 vs. 2, 4, 6 and 8)	NS	NS	NS	NS	NS	NS	***	***	***	***	**	**

† Cumulative total yield of 2 cuts.
‡ Clitoria forage yield and nutrient content; model [2].
*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.
NS=not significant.
SE=standard error.

Table 2.10. Forage yield and nutrient content (2-yr avg.) of *Lablab purpureus* as influenced by cropping system and legume harvest management in coastal lowland Kenya.

Cropping system/management strategy	Forage yield	Nutrient content N	P	K	Ca	Mg
	Mg ha-1	kg ha^{-1}				
		Short rain season				
1. Dolichos monoculture, 2-mo cut	1.5	48	4	33	12	2
2. Dolichos monoculture, 4-mo cut	6.2	154	12	133	52	12
3. Dolichos/cassava, 2-mo cut	1.6	50	4	46	16	3
4. Dolichos/cassava, 4-mo cut	5.3	130	8	111	39	9
5. Dolichos/maize, 2-mo cut	0.9	27	2	21	6	1
6. Dolichos/maize, 4-mo cut	4.6	104	7	92	33	6
7. Dolichos/cassava/maize, 2-mo cut	1.2	39	3	31	11	2
8. Dolichos/cassava/maize, 4-mo cut	4.1	104	7	79	35	9
SE†	0.2	11.7	1.0	9.3	3.3	1.3
Orthogonal contrasts						
Dolichos vs. dolichos/cassava (1 and 2 vs. 3 and 4)	*	NS	NS	NS	NS	NS
Dolichos vs. dolichos/maize (1 and 2 vs. 5 and 6)	***	**	**	**	**	**
Dolichos mono vs. dolichos intercrop	***	**	**	*	**	*
Dolichos 2-mo cut vs. dolichos/maize (1 vs. 3 and 4)	***	NS	NS	*	NS	NS
Dolichos 4-mo cut vs. dolichos/maize (2 vs. 5 and 6)	***	***	***	***	***	NS
Dolichos 2-mo cut vs. dolichos/cassava (2 vs. 3 and 4)	***	**	NS	***	**	***
Dolichos, 4-mo cut vs. dolichos/cassava (2 vs. 5 and 6)	***	***	***	***	***	*
Dolichos/cassava, 2mo cut vs. dolichos/cassava/maize (3 vs. 7 and 8)	***	NS	NS	NS	NS	***
Dolichos/cassava, 4-mo cut vs. dolichos/cassava/maize (4 vs. 7 and 8)	***	***	**	***	***	NS
Dolichos/maize, 2mo cut vs. dolichos/cassava/maize (5 vs. 7 and 8)	***	**	**	**	***	**
Dolichos/maize, 4-mo cut vs. dolichos/cassava/maize (6 vs. 7 and 8)	***	*	NS	**	*	NS
Dolichos, 2-mo cut vs. dolichos 4-mo cut (1,3,5 and 7 vs. 2,4, 6 and 8)	***	***	**	***	***	***
		Short rain season				
1. Dolichos monoculture, 2-mo cut	0.8	22	2	19	8	2
2. Dolichos monoculture, 4-mo cut	1.5	27	2	32	10	4
3. Dolichos/maize, 2-mo cut	0.5	12	1	10	4	1
4. Dolichos/maize, 4-mo cut	0.6	14	1	15	6	2
SE†	0.2	4.5	0.3	4.8	1.5	0.4
Orthogonal contrasts						
Dolichos 2-mo cut vs. dolichos/maize (1 and 2 vs. 3)	NS	NS	*	NS	NS	*
Dolichos 4-mo cut vs. dolichos/maize (1 and 2 vs. 4)	***	**	**	**	**	***
Dolichos, 2-mo cut vs. dolichos 4-mo cut (1 and 3 vs. 2 and 4)	NS	NS	NS	NS	NS	**

† SE=standard error; dolichos forage yield and long rain season nutrient contents based on model 2].

*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.

NS=not significant.

Table 2.11.Sources of variance and levels of significance for maize grain and stover yield (2-yr avg.) and their respective nutrient contents as affected by cropping system, *clitoria ternatea* and *lablab purpureus* harvest management, and fertilizer supplementation in coastal Kenya.

	Grain						Stover					
Source†	Yield†	N	P	K	Ca	Mg	Yield	N	P	K	Ca	Mg
Exp1												
						Long rain season						
Year	**	*	NS	NS	**	NS	NS	NS	*	NS	NS	NS
Cropping system	**	*	*	NS	NS	NS	***	**	**	*	**	**
Year x cropping system	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	*
Management within cropping system	***	***	***	***	*	***	***	**	NS	**	***	*
Year x management within cropping system	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS
						Short rain season						
Year	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cropping system	**	***	**	***	NS	**	***	***	*	***	***	***
Year x cropping system	**	**	**	**	NS	**	**	NS	**	**	*	**
Management w/in cropping system	*	NS	**	*	**	**	NS	*	**	NS	***	**
Year x management within cropping system	NS	NS	**	NS	NS	*	NS	NS	*	**	NS	NS
Exp2												
						Long rain season						
Year	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	**	NS
Cropping system	***	***	**	**	***	**	***	**	NS	**	***	**
Year x cropping system	***	**	**	*	NS	**	**	**	NS	**	NS	**
Management (cropping system)	***	***	***	***	*	***	**	***	*	***	*	*
Year x management within cropping system	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
						Short rain season						
Year	NS	*	NS	*	*	NS	NS	*	*	*	NS	NS
Cropping system	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Year x cropping system	*	*	NS	NS	*	*	NS	NS	NS	NS	NS	NS
Management within cropping system	***	***	***	***	***	***	***	**	***	**	***	***
Year x management within cropping system	***	**	**	**	**	**	NS	NS	**	NS	*	*

† Grain and stover yield for long and short rain seasons and their respective nutrient contents; model [1].

*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.

NS=not significant.

Table 2.12. Maize grain yield and nutrient contents (2-yr avg.) as influenced by cropping system, *Clitoria ternatea* harvest management, and fertilizer supplementation in coastal lowland Kenya.

Cropping system/management strategy	Grain yield	N	P	K	Ca	Mg
		Nutrient contents				
	$Mg\ ha^{-1}$	$kg\ ha^{-1}$				
		Long rain season				
1. Maize monoculture, no fertilizer	3.0	41	7	9	0.6	2.9
2. Maize monoculture, with fertilizer	5.4	90	15	19	0.9	5.7
3. Clitoria/maize, 6-wk cut	4.3	69	13	16	0.8	5.0
4. Clitoria/maize, 10-wk cut	4.3	53	11	13	0.8	4.3
5. Cassava/maize, no fertilizer	3.6	47	7	10	0.6	3.0
6. Cassava/maize, with fertilizer	4.5	65	11	14	0.7	4.5
7. Clitoria/cassava/maize, 6-wk cut	3.5	57	10	13	0.7	4.0
8. Clitoria/cassava/maize, 10-wk cut	2.5	40	11	10	0.6	3.0
SE†	0.3	5.7	1.2	1.2	0.1	0.4
Orthogonal contrasts						
Maize monoculture vs. clitoria/maize (1 and 2 vs. 3 and 4)	NS	NS	NS	NS	NS	NS
Maize monoculture vs. cassava/maize (1 and 2 vs. 5 and 6)	NS	NS	NS	NS	NS	NS
Cassava/maize vs. clitoria/cassava/maize (5 and 6 vs. 7 and 8)	**	**	NS	NS	NS	NS
Maize monoculture, no fertilizer vs. clitoria/maize (1 vs.3 and 4)	***	**	***	**	NS	**
Maize monoculture, with fertilizer vs. clitoria/maize (1 vs. 3 and 4)	**	***	NS	**	NS	NS
Cassava/maize, no fertilizer vs. clitoria/cassava/maize (5 vs. 7 and 8)	NS	NS	NS	NS	NS	NS
Cassava/maize, with fertilizer vs. clitoria/cassava/maize (6 vs. 7 and 8)	***	*	NS	NS	NS	NS
		Short rain season				
1. Maize monoculture, no fertilizer	2.9	45	6	8	0.2	2.5
2. Maize monoculture, with fertilizer	3.7	60	11	13	0.4	4.0
3. Clitoria/maize, 6-wk cut	1.2	18	3	4	0.2	1.2
4. Clitoria/maize, 10-wk cut	0.9	13	2	3	0.1	0.9
SE†	0.3	5.0	0.8	1.0	0.05	0.3
Orthogonal contrasts						
Maize monoculture, no fertilizer vs. clitoria/maize (1 vs. .3 and 4)	***	***	**	***	NS	**
Maize monoculture, with fertilizer vs. clitoria/maize (2 vs. 3 and 4)	***	***	**	**	NS	**

† SE=standard error; model [1].

*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.

NS=not significant.

Table 2.13. Maize stover yield and nutrient contents (2-yr avg.) as influenced by cropping system, *Clitoria ternatea* harvest management and fertilizer supplementation in coastal lowland Kenya.

Cropping system/management strategy		Stover yield	N	P	K	Ca	Mg
			Nutrient content				
		Mg ha^{-1}	kg ha^{-1}				
			Long rain season				
1. Maize monoculture, no fertilizer		2.1	10	1	21	5	3
2. Maize monoculture, with fertilizer		3.4	16	2	30	9	5
3. Clitoria/maize, 6-wk cut		3.0	11	2	28	7	4
4. Clitoria/maize, 10-wk cut		2.5	10	2	19	6	4
5. Cassava/maize, with fertilizer		2.9	14	1	31	8	4
6. Cassava/maize, no fertilizer		2.3	9	1	17	5	3
7. Clitoria/cassava/maize, 6-wk cut		1.7	8	2	16	4	3
8. Clitoria/cassava/maize, 10-wk cut		1.9	7	1	15	4	3
	SE‡	0.2	1.3	0.2	3.2	0.6	0.4
Orthogonal Contrasts							
Maize monoculture vs. clitoria/maize (1 and 2 vs. 3 and 4)		NS	**	NS	NS	NS	NS
Maize monoculture vs. cassava/maize (1 and 2 vs. 5 and 6)		NS	NS	NS	NS	NS	NS
Cassava/maize vs. clitoria/cassava/maize (5 and 6 vs. 7 and 8)		***	***	NS	**	***	**
Maize monoculture, no fertilizer vs. clitoria/maize (1 vs.3 and 4)		***	**	*	*	***	**
Maize monoculture, with fertilizer vs. clitoria/maize (1 vs. 3 and 4)		**	NS	***	NS	NS	NS
Cassava/maize, no fertilizer vs. clitoria/cassava/maize (5 vs. 7 and 8)		*	NS	**	NS	NS	NS
Cassava/maize, with fertilizer vs. clitoria/cassava/maize 6 vs. 7 and 8)		***	***	NS	***	***	**
			Short rain season				
1. Maize monoculture, no fertilizer		2.7	16	1	39	6.1	4.5
2. Maize monoculture, with fertilizer		3.6	22	2	56	8.9	6.3
3. Clitoria/maize, 6-wk cut		1.2	7	1	16	3.0	2.1
4. Clitoria/maize, 10-wk cut		1.3	8	1	17	2.9	2.2
	SE†	0.3	1.7	0.2	4.4	0.7	0.4
Orthogonal contrasts							
Maize monoculture, no fertilizer vs. clitoria/maize (1 vs.3 and 4)		***	**	NS	**	**	***
Maize monoculture, with fertilizer vs. clitoria/maize (2 vs. 3 and 4)		***	***	***	***	***	***

† SE=standard error; model [1]

*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.

NS=not significant.

Table 2.14. Maize grain yield and nutrient contents (2-yr avg.) as influenced by cropping system, *Lablab purpureus* harvest management, and fertilizer supplementation in coastal lowland Kenya.

Cropping system/management strategy	Grain yield	N	P	K	Ca	Mg
		Nutrient content				
	$Mg\ ha^{-1}$	$kg\ ha^{-1}$				
Long rain season						
1. Maize monoculture, no fertilizer	3.1	54	7	9	0.8	3.0
2. Maize monoculture, with fertilizer	5.5	99	14	18	1.5	5.8
3. Cassava/maize, no fertilizer	3.1	44	6	8	0.6	2.5
4. Cassava/maize, with fertilizer	4.2	65	11	13	0.8	4.3
5. Dolichos/maize, 2-mo cut	2.7	39	6	8	0.5	2.5
6. Dolichos/maize, 4-mo cut	2.5	38	6	8	0.5	2.6
7. Dolichos/cassava/maize, 2-mo cut	2.8	55	8	10	0.6	3.1
8. Dolichos/cassava/maize, 4-mo cut	3.0	39	6	8	0.4	2.4
SE†	0.4	5.3	0.8	1.0	0.1	0.3
Orthogonal contrasts						
Maize monoculture vs. cassava/maize (1 and 2 vs. 3 and 4)	**	**	NS	*	**	*
Maize monoculture vs. dolichos/maize (1 and 2 vs. 5 and 6)	***	***	***	***	***	***
Maize monoculture vs. dolichos/cassava/maize (1 and 2 vs. 7 and 8)	*	***	**	**	***	***
Cassava/maize vs. dolichos/cassava/maize (3 and 4 vs. 7 and 8)	NS	NS	NS	NS	NS	***
Maize monoculture, no fertilizer vs. dolichos/maize (1 vs. 5 and 6)	NS	**	***	NS	NS	NS
Maize monoculture, with fertilizer vs. dolichos/maize (2 vs. 5 and 6)	**	**	NS	***	***	***
Cassava/maize, no fertilizer vs. dolichos/cassava/maize (3 vs. 7 and 8)	NS	NS	NS	NS	NS	NS
Cassava/maize with fertilizer vs. dolichos/cassava/maize (4 vs. 7 and 8)	**	*	**	**	*	**
Short rain season						
1. Maize monoculture, no fertilizer	2.2	37	4	6	0.2	1.9
2. Maize monoculture, with fertilizer	4.3	77	10	14	0.4	4.3
3. Dolichos/maize, 2-mo cut	3.5	56	8	11	0.3	3.0
4. Dolichos/maize, 4-mo cut	3.0	49	8	9	0.4	3.0
SE†	0.3	5.3	0.6	0.9	0.04	0.3
Orthogonal Contrasts						
Maize monoculture, no fertilizer vs. dolichos/maize (1 vs. 3 and 4)	**	*	***	**	**	***
Maize monoculture, with fertilizer vs. dolichos/maize (2 vs. 3 and 4)	**	***	***	***	*	**

† SE=standard error; grain yield for long and short rain seasons and their respective nutrient contents; based model [1].

*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively; NS=not significant.

Table 2.15. Maize stover yield and nutrient content (2-yr avg.) as influenced by cropping system, *Lablab purpureus* harvest management, and fertilizer supplementation in coastal lowland Kenya.

		Nutrient content				
Cropping system/management strategy	Stover yield	N	P	K	Ca	Mg
	Mg ha^{-1}	kg ha^{-1}				
		Long rain season				
1. Maize monoculture, no fertilizer	2.3	11	0.8	26	6.0	3.9
2. Maize monoculture, with fertilizer	3.7	17	1.1	44	9.3	5.9
3. Cassava/maize, no fertilizer	1.9	7	1.1	16	3.7	2.7
4. Cassava/maize, with fertilizer	2.6	12	0.4	23	6.4	3.8
5. Dolichos/maize, 2-mo cut	1.8	8	0.8	20	3.7	2.6
6. Dolichos/maize, 4-mo cut	1.4	8	0.7	17	3.4	2.6
7. Dolichos/cassava/maize, 2-mo cut	1.8	8	0.6	17	4.4	2.9
8. Dolichos/cassava/maize, 4-mo cut	1.8	8	0.9	14	2.9	2.3
SE†	0.3	1.5	0.2	3.6	0.7	0.5
Orthogonal contrasts						
Maize monoculture vs. cassava/maize (1 and 2 vs. 3 and 4)	**	**	NS	**	**	**
Maize monoculture vs. dolichos/maize (1 and 2 vs. 5 and 6)	***	**	NS	**	***	***
Maize monoculture vs. dolichos/cassava/maize (1 and 2 vs. 7 and 8)	***	**	NS	***	***	***
Cassava/maize vs. dolichos/cassava/maize (3 and 4 vs. 7 and 8)	NS	NS	NS	NS	NS	NS
Maize monoculture, no fertilizer vs. dolichos/maize (1 vs. 5 and 6)	*	NS	NS	NS	*	*
Maize monoculture, with fertilizer vs. dolichos/maize (2 vs. 5 and 6)	***	***	NS	***	***	***
Cassava/maize, no fertilizer vs. dolichos/cassava/maize (3 vs. 7 and 8)	NS	NS	NS	NS	NS	*
Cassava/maize, with fertilizer vs. dolichos/cassava/maize (4 vs. 7 and 8)	*	NS	NS	NS	**	*
1. Maize monoculture, no fertilizer	1.8	11	0.6	25	3.9	3.5
2. Maize monoculture, with fertilizer	3.5	21	1.4	56	8.1	6.6
3. Dolichos/maize, 2-mo cut	3.1	17	1.1	48	6.1	5.2
4. Dolichos/maize, 4-mo cut	3.3	19	1.2	54	6.5	5.5
SE†	0.3	1.7	0.1	5.3	0.7	0.5
		Short rain season				
Orthogonal contrasts						
Maize monoculture, no fertilizer vs. dolichos/maize (1 vs. 3 and 4)	***	**	***	**	**	***
Maize monoculture, with fertilizer vs. dolichos/maize (2 vs. 3 and 4)	NS	NS	*	NS	*	**

† SE=standard error; maize stover yield long and short rain seasons; long rain season's nutrient contents based on model [1].
*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively;
NS=not significant.

Table 2.16. Sources of variance and levels of significance for cassava leaf, stem and tuber yields, along with their respective nutrient contents, as affected by cropping system, clitoria and dolichos harvest management, and fertilizer supplementation in coastal lowland Kenya.

	Exp1						Exp2					
		Nutrient content						Nutrient content				
Source	Yield†	N	P	K	Ca	Mg	Yield	N	P	K	Ca	Mg
Leaf †												
Year	NS	NS	NS	NS	NS	NS	*	*	NS	NS	NS	NS
Cropping system	***	**	**	**	**	**	*	**	**	**	*	NS
Year x cropping system	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS
Management (cropping system	NS	NS	*	*	**	NS	NS	NS	NS	*	NS	NS
Year x management w/in cropping system	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Stem†												
Year	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
Cropping system	***	***	**	**	***	***	***	**	**	*	**	**
Year x cropping system	NS	NS	NS	NS	NS	NS	NS	**	**	NS	**	*
Management w/in cropping system	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Year x management w/in cropping system	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Tuber†												
Year	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cropping system	*	NS	NS	**	NS	NS	***	*	**	NS	**	***
Year x cropping system	NS	NS	NS	NS	NS	NS	*	**	***	*	**	NS
Management w/in cropping system	NS	**	**	NS	NS	*	**	*	***	**	NS	**
Year x management w/in cropping system	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS

† Cassava, leaf, stem and tuber yield; model [1].

*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.

NS=not significant.

Table 2.17. Cassava tuber and stem yield and nutrient content (2-yr avg.) as influenced by cropping system, *Clitoria ternatea* harvest management, and fertilizer supplementation in coastal lowland Kenya.

		Cassava tuber nutrient content						Cassava stem nutrient content				
Cropping system/management strategy	Tuber yield	N	P	K	Ca	Mg	Stem yield	N	P	K	Ca	Mg
	Mg ha^{-1}	kg ha^{-1}					Mg ha^{-1}	kg ha^{-1}				
1. Cassava monoculture, no fertilizer	8.8	49	8	96	21	8	6.8	60	8	97	48	15
2. Cassava monoculture, with fertilizer	10.0	60	11	127	27	10	6.5	63	7	88	44	15
3. Cassava/maize, no fertilizer	5.8	33	6	83	17	6	4.7	41	5	75	29	10
4. Cassava/maize, with fertilizer	6.7	35	7	92	15	5	4.6	35	6	61	27	10
5. Clitoria/cassava 6-wk cut	6.9	44	8	103	18	7	4.5	41	6	74	35	10
6. Clitoria/cassava 10-wk cut	8.0	52	10	115	20	7	4.7	45	7	78	40	12
7. Clitoria/cassava/maize 6-wk cut	6.2	34	7	79	17	6	4.2	40	6	62	28	10
8. Clitoria/cassava/maize 10-wk cut	5.7	34	6	72	13	5	3.4	26	4	42	21	7
SE†	0.5	5.4	1.1	10.3	2.0	0.7	0.5	6.1	0.7	9.3	3.4	1.3
Orthogonal contrasts												
Cassava mono vs. cassava/maize (1 and 2 vs. 3 and 4)	***	**	**	***	**	***	***	**	NS	NS	*	**
Cassava mono vs. clitoria/cassava (1 and 2 vs. 5 and 6)	***	NS	NS	NS	*	*	***	***	**	***	***	***
Cassava/maize vs. clitoria/cassava/maize (3 and 4 vs. 7 and 8)	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS
Cassava mono, no fertilizer vs. clitoria/cassava (1 vs. 5 and 6)	*	NS	NS	NS	NS	NS	***	*	NS	NS	*	**
Cassava mono, with fertilizer vs. clitoria/cassava (2 vs. 5 and 6)	***	NS	NS	NS	**	**	NS	NS	NS	*	NS	NS
Cassava/maize, no fertilizer vs. clitoria/cassava/maize (3 vs. 7 and 8)	NS	NS	NS	NS	NS	NS	**	*	**	***	**	*
Cassava/maize, with fertilizer vs. clitoria/cassava/maize (4 vs. 7 and 8)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† SE=standard error; model [1].

*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.

NS=not significant.

Table 2.18. Cassava leaf yield and nutrient content (2-yr avg.) as influenced by cropping system, C*litoria ternatea* harvest management, and fertilizer supplementation in coastal lowland Kenya.

Cropping system/management strategy	Leaf yield	Nutrient content N	P	K	Ca	Mg
	Mg ha^{-1}	kg ha^{-1}				
1. Cassava monoculture, no fertilizer	0.7	22	1.5	10	16	5
2. Cassava monoculture, with fertilizer	0.8	23	1.6	10	15	5
3. Cassava/maize, no fertilizer	1.0	31	2.2	19	20	7
4. Cassava/maize, with fertilizer	0.9	28	1.9	15	17	6
5. Clitoria/cassava 6-wk cut	0.7	23	1.5	14	17	6
6. Clitoria/cassava 10-wk cut	0.7	24	1.6	14	14	5
7. Clitoria/cassava/maize 6-wk cut	0.7	29	1.7	13	15	6
8. Clitoria/cassava/maize 10-wk cut	0.6	13	0.8	6	8	3
SE†	0.1	5.0	0.3	2.5	2.8	1.0
Orthogonal contrasts						
Cassava mono vs. cassava/maize (1 and 2 vs. 3 and 4)	NS	NS	NS	NS	NS	NS
Cassava mono vs. clitoria/cassava (1 and 2 vs. 5 and 6)	NS	NS	NS	NS	NS	NS
Cassava mono, no fertilizer vs. clitoria/cassava (1 vs. 5 and 6)	NS	NS	NS	NS	NS	NS
Cassava mono, with fertilizer vs. clitoria/cassava (2 vs. 5 and 6)	NS	NS	NS	NS	NS	NS
Cassava/maize vs. clitoria/cassava/maize (3 and 4 vs. 7 and 8)	**	*	**	**	**	*
Cassava/maize, no fertilizer vs. clitoria/cassava/maize (3 vs. 7 and 8)	**	*	**	***	**	*
Cassava/maize, with fertilizer vs. clitoria/cassava/maize (4 vs. 7 and 8)	*	NS	*	*	NS	NS

† SE=standard error, model [1].
*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.
NS=not significant.

Table 2.19. Cassava tuber and stem yield and their nutrient contents (2-yr avg.) as influenced by cropping system, dolichos harvest management and fertilizer supplementation in coastal lowland Kenya.

Cropping system/management strategy	Tuber yield	Cassava tuber nutrient content N	P	K	Ca	Mg	Stem yield	Cassava stem nutrient content N	P	K	Ca	Mg
	$Mg\ ha^{-1}$	$kg\ ha^{-1}$					$Mg\ ha^{-1}$	$kg\ ha^{-1}$				
1. Cassava monoculture, no fertilizer	7.9	44	6	75	16	9	7.1	61	6	81	33	16
2. Cassava monoculture, with fertilizer	9.6	54	10	89	20	12	7.5	56	7	66	34	17
3. Cassava/maize, no fertilizer	5.8	40	5	69	14	6	6.3	55	6	94	32	12
4. Cassava/maize, with fertilizer	7.7	50	9	91	15	8	6.2	57	6	84	34	14
5. Dolichos/cassava, 2-mo cut	8.3	58	9	117	18	8	6.0	55	6	89	36	14
6. Dolichos/cassava, 4-mo cut	5.1	42	6	75	13	5	5.2	50	4	72	28	11
7. Dolichos/cassava/maize, 2-mo cut	5.5	41	6	75	12	6	5.3	45	5	67	26	12
8. Dolichos/cassava /maize, 4-mo cut	4.4	34	5	62	9	4	4.4	38	4	56	18	9
SE†	0.6	5.2	0.6	8.1	1.5	0.9	0.5	4.7	0.5	8.3	3.2	1.3
Orthogonal contrasts												
Cassava mono vs. cassava/maize (1 and 2 vs. 3 and 4)	**	NS	*	NS	*	**	**	NS	NS	NS	NS	*
Cassava mono vs. dolichos/cassava (1 and 2 vs. 5 and 6)	**	NS	NS	NS	NS	**	*	NS	NS	NS	NS	*
Cassava/maize vs. dolichos/cassava/maize (3 and 4 vs. 7 and 8)	**	NS	NS	NS	*	*	**	**	**	**	**	NS
Cassava monoculture, no fertilizer vs. dolichos/cassava (1 vs. 5 and 6)	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	*
Cassava monoculture, with fertilizer vs. dolichos/cassava (2 vs. 5 and 6)	***	NS	**	NS	*	***	**	NS	*	NS	NS	**
Cassava/maize, no fertilizer vs. dolichos/cassava/maize (3 vs. 7 and 8)	NS	NS	NS	NS	NS	NS	*	*	*	**	*	NS
Cassava/maize, with fertilizer vs. dolichos/cassava/maize (4 vs. 7 and 8)	**	*	***	*	*	**	*	**	**	*	**	NS

† SE =standard error; based on model [1].

*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.

NS =not significant.

Table 2.20. Cassava leaf yield and nutrient content (2-yr avg.) as influenced by cropping systems, dolichos harvest management and fertilizer supplementation in coastal lowland Kenya.

Cropping system/management strategy	Leaf yield	Nutrient content N	P	K	Ca	Mg
	Mg ha^{-1}	kg ha^{-1}				
1. Cassava monoculture, no fertilizer	0.9	18	1.1	7	11	5
2. Cassava monoculture, with fertilizer	0.7	16	1.1	5	11	5
3. Cassava/maize, no fertilizer	1.0	29	2.0	16	16	6
4. Cassava/maize, with fertilizer	0.9	30	2.0	13	16	7
5. Dolichos/cassava, 2-mo cut	0.9	22	1.5	10	16	5
6. Dolichos/cassava, 4-mo cut	1.1	33	2.1	16	18	7
7. Dolichos/cassava/maize, 2-mo cut	1.1	34	2.2	17	19	8
8. Dolichos/cassava /maize, 4-mo cut	1.1	29	1.9	14	16	7
SE†	0.1	3.1	0.2	1.9	1.9	0.8
Orthogonal contrasts						
Cassava mono vs. dolichos/maize (1 and 2 vs. 3 and 4)	NS	**	***	**	*	NS
Cassava mono vs. dolichos/cassava (1 and 2 vs. 5 and 6)	*	**	**	**	**	NS
Cassava/maize vs. dolichos/cassava/maize (3 and 4 vs. 7 and 8)	NS	NS	NS	NS	NS	NS
Cassava monoculture, no fertilizer vs. dolichos/cassava (1 vs. 5 and 6)	NS	*	**	*	*	NS
Cassava monoculture, with fertilizer vs. dolichos/cassava (2 vs. 5 and 6)	*	**	**	**	*	NS
Cassava/maize, no fertilizer vs. dolichos/cassava/maize (3 vs. 7 and 8)	NS	NS	NS	NS	NS	NS
Cassava/maize, with fertilizer vs. dolichos/cassava/maize (4 vs. 7 and 8)	NS	NS	NS	NS	NS	NS

†SE=standard error, based on model [1].

*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.

NS=not significant.

Table 2.21. Sources of variance and levels of significance for soil inorganic N as influenced by cropping systems, *Clitoria ternatea* harvest management, and fertilizer supplementation in coastal lowland Kenya.

Source†	1999				2000
	3 Jul	2 Sep	10 Sep	28 Dec	16 Feb
Cropping system	**	**	NS	*	*
Management within cropping system.	NS	NS	**	NS	NS

† Model [3] for each date. Dates where neither cropping system nor management were significant are omitted from this table.

*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.

NS=not significant.

Table 2.22. Sources of variance and levels of significance for soil inorganic N (0 to 20-cm depth) as influenced by cropping system, dolichos harvest management, and fertilizer supplementation in coastal lowland Kenya.

	1999				2000				
Source†	3 Jul	2 Sep	10 Sep	18 Oct	16 Feb	29 Feb	28 Jun	14 Aug	5 Sep
Cropping system	NS	NS	**	*	**	**	**	*	***
Management within cropping system	***	***	***	NS	NS	NS	NS	*	***

† Model [3] for each date. Dates where neither cropping system nor management were significant are omitted from this table.
*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.
NS=not significant.

CHAPTER 3

Residue decomposition and nutrient release dynamics from two tropical forage legumes in a Kenyan environment

ABSTRACT

Soil fertility decline is one of the factors limiting food production on the east coast of Africa. Increased awareness by smallholder farmers of the role of legumes as food, fodder, and for soil fertility improvement has stimulated research on the influence of herbaceous legumes in various cropping systems. Decomposition and nutrient release from foliage of forage legume species clitoria (*Clitoria ternatea*) and dolichos (*Lablab purpureus*), planted in monoculture or as an intercrop with tropical food crops cassava (*Manihot esculenta*) and maize *(Zea mays*), were evaluated under field conditions in fine-loamy, kaolinitic, isohyperthermic, arenic Paleustalfs. Clitoria foliage was cut every 6 or 10-wk after the uniformity cut, while dolichos residue was cut at 2 and 4 mo after planting the legume. Following each legume harvest, three replicates of nylon mesh bags containing legume residue as intact plants were placed on the soil surface within their respective cropping system and legume management plots, and then retrieved at 0, 1, 2, 4, 8 and 16 wk after field placement. An asymptotic model best described clitoria and dolichos dry matter disappearance across different harvest management strategies, while legume residue decomposition rates were unaffected by cropping system. The rate coefficients for dry matter disappearance of clitoria and dolichos residues were 0.2 and 0.5 wk^{-1}, respectively. Similarly, nutrient release from clitoria and dolichos residues best fit an asymptotic model.

The *k*-values obtained for dolichos showed the greatest variation (0.2 to 2.5 wk^{-1}) compared to those obtained for clitoria (0.3 to 1.0 wk^{-1}). Nitrogen release was generally slowest in clitoria and in dolichos 4-mo cut foliage. Across harvest management strategies, the general order of nutrient release was K > P > Mg > N, while that of dolichos cut at 2 mo was K>Mg> N>P and K>N>P>Mg for dolichos cut at 4 mo. Generally, the N, P and Mg release resulted in the formation of a plateau at 40%, indicating that there were some factors reducing the release rate of the respective nutrients. Overall, clitoria and dolichos demonstrated their potential to release nutrients to cropping systems in the region. Nutrient pools from the shorter cutting interval were potentially available within relatively short periods, while a longer cutting intervals resulted in relatively large nutrient pools that were potentially available over a longer period, and were likely to be beneficial to a long duration crop like cassava, and maize in subsequent cropping seasons. Further research is needed to characterize the synchronization between residue nutrient availability and crop nutrient demand.

INTRODUCTION

Herbaceous legumes as green manure crops can play a major role in nutrient capture and cycling within plant soil systems (Wade and Sanchez, 1983; Becker and Ladha, 1995), as well as provide alternatives to shifting cultivation in replenishing soil fertility. Rebuilding soil fertility in traditional agricultural systems was achieved through long-duration fallow periods (Norman et al., 1995). Nutrients accumulated in the above ground vegetation were made available to subsequent crops when the vegetation was cut and then burned, however, soil fertility deteriorated rapidly after vegetation was removed. With increased human population and land pressure, long fallow periods are no longer feasible. However, it is possible to fallow the land for shorter periods with high yielding legume cover crops and successfully produce adequate yields of annual crops (Becker and Ladha, 1995; Luna-Orea and Wagger, 1996). Planting of legumes with food crops ensures better ground cover and reduces nutrient loss through erosion and runoff. Application of the legume as mulch rather than soil incorporation ensures a slower release of plant nutrients and may improve the synchrony of nutrient release from legume residue with the subsequent crop requirements (Fischler, 1997).

Legume residue decomposition and nutrient release rates are influenced by resource quality parameters such as polyphenolics, C:N ratio, and lignin/polyphenol:N ratios (Villis and Jones, 1973; Palm and Sanchez, 1990; Tian et al., 1992). Harvesting the foliage at a short growth interval rather than a long interval is likely to influence the residue quality (Wagger, 1989), and in turn, the rate of decomposition and release of nutrients. Also, variation in climatic conditions can influence decomposition and nutrient release rates.

Wagger (1989) found that under moisture limiting conditions microbial decomposition appeared slower and more constant, while weekly rainfall events during the sampling intervals resulted in more rapid decomposition and N release from rye (*Secale cereale*), crimson clover (*Trifolium incarnatum*)and hairy vetch (*Vicia villosa*) cover crops. The influence of environmental factors was demonstrated in a study by Luna-Orea et al., (1996), whereby the authors noted that a sandier soil with better drainage and alternating wetting and drying of surface residue favored abiotic rather than biotic decomposition.

Coastal Kenya farmers are aware of the problem of declining soil fertility caused by continuous cropping without returning nutrients, soil erosion, burning of plant residues, short fallow intervals in food crop production plots, and overgrazing (Mureithi et al., 1996). The common methods used by farmers for managing soil fertility include the use of farmyard manure, plant residues, and intercropping with grain legumes. The use of farmyard manure is limited by its availability, while few farmers use inorganic fertilizer because of its limited availability and high cost. The grain legume cowpea (*Vigna unguiculata)*, which is commonly intercropped with maize (*Zea mays*), is efficient in translocating nutrients to the grain and thus may result in net nutrient removal from the field (Karlen et al., 1994). In such situations, the potential contribution of improved management of crop residues and legume green manure to improve soil fertility assumes great importance.

The use of green manures (or cover crops) as a nutrient source has been advocated as an alternative to expensive fertilizers and farmers in coastal Kenya have shown interest in planting herbaceous and tree leguminous species that were recommended through past research conducted within the region. Though the legumes were primarily screened to supply fodder for livestock, the growth habits of some promising species indicated their potential for cover cropping and soil fertility improvement (Saha *et al.,* 1997). *Lablab purpureus* (dolichos) and *Clitoria ternatea* (clitoria) are among the more promising herbaceous legumes that were evaluated on smallholder, mixed crop and livestock farms for fodder and soil fertility improvement (Mwatate *et al.,* 1997). The evaluation of these legumes as components of livestock feed has been conducted (Muinga et al., 2000), but information is required on how these legumes may be used for soil fertility improvement. In order to develop effective green manure techniques acceptable by smallholder farmers, it is necessary to know the decomposition and nutrient release dynamics to better synchronize the periods of maximum supply from the decomposing mulch with that of maximum demand by the principal crop (Myers et al., 1994). With these factors in mind, the objectives of this study were to evaluate the effects of harvest frequency and stage of development of an annual (dolichos) and a perennial (clitoria) forage legume on legume biomass, nutrient accumulation and the rate of nutrient release from legume residues.

MATERIALS AND METHODS

The studies were conducted over a two-year period from 1999 to 2001 at the Regional Research Center in Mtwapa, Kenya. The experimental site is within the coconut/cassava agro-ecological zone (Jaetzold and Schmidt, 1983), about 3:36 ^{o}S, 39:44 ^{o} E. The soils at the experimental site were fine-loamy, kaolinitic, isohyperthermic, arenic Paleustalfs. The topsoil texture is sandy loam to sandy clay loam with low organic matter content. These soils are deep and moderately well-drained, with low nutrient status and moisture storage capacity. There are two distinct rainfall patterns in the area, a long rainy season from April to June (430 to 750 mm), and a short rainy season from October to December (220 to 260 mm). The annual average rainfall range is 1050-1230 mm. The mean monthly temperature is 28^{o} C during the warmer period from December to March and 24-26^{o} C from June to mid September.

Two experiments were conducted concurrently. The design for the first experiment (Exp1) was a split-plot with five replications, consisting of combinations of the perennial forage legume, clitoria, planted in monoculture or as an intercrop with food crops. Main plot treatments were the combinations of the forage legume and two tropical food crops cassava (*Manihot esculenta*) and maize. Main plot dimensions were 5.4 by 8.1 m, with 2-m spacing between main plots. The subplot treatments were two cutting strategies for clitoria. Clitoria was first cut at two mo after planting, and subsequently every 6 and 10-wk after the first cut. The harvested foliage was applied to the respective plots as surface mulch.

The design of the second experiment (Exp2) was similar to the first one, but evaluated the annual legume dolichos. The cutting management strategy for dolichos occurred two and four mo after planting the legume. The subplots dimensions were 5.4 by 4 m. Clitoria planted in monoculture was drilled along rows at a rate of 10 kg ha^{-1}. Clitoria in maize and cassava intercropping systems was planted at seeding rate of 5.5 and 8 kg ha^{-1}, respectively. In Exp2, dolichos was planted at a spacing of 0.6 by 0.2 m.(three seeds per hole and thinned to two seeds per hole), leaving a plant density of 166,700 plants ha^{-1}. Dolichos in maize and cassava intercropping systems was planted at a density 83,300 and 133,300 dolichos plants ha^{-1}, respectively. The two experiments were conducted in the same plots for two years (1999 and 2000). Treatment combinations are shown in Table 3.1.

To monitor residue decomposition and nutrient release from the two legumes, nylon mesh bags containing legume residue were placed on the soil surface within their respective cropping system and legume management plots. There were two placement dates for clitoria 6 and 10-wk cuts in 1999 and one placement in 2000. There was one placement date each year for dolichos cut at two and four mo.

Representative samples of the legume foliage were harvested from respective legume treatments about one wk prior to the legume cutting date. These samples were spread on plastic sheeting to dry. The air-dried plant material was placed in nylon mesh bags (50μm openings, 20-cm wide and 40 cm long) as intact plants. Approximately 15 g of clitoria and 25 g of dolichos were placed into the nylon bags, corresponding to loading rates of 2 and 4 Mg ha^{-1}, respectively. Three replicates of the mesh bags containing the legume residues were placed in the field following each harvest management and then retrieved at 0, 1, 2, 4, 8 and 16 wk in the field. The nylon mesh bags containing the remaining plant residue at each retrieval date were oven dried at 65^{o}C to a constant weight. In order to minimize the effects of soil contamination, soil adhering to the residue was carefully removed by gentle rubbing between fingers. The remaining plant material was then weighed and ground. Duplicate samples (0.5 to 1g) of the ground residue were placed in a muffle furnace to determine the ash-free content by drying at 550^{o}C for two hr. Subsamples of residue remaining at each retrieval date were analyzed for total C and N [Perkin Elmer 2400 CHN elemental analyzer), and P, K, Ca, and Mg by inductively coupled spectrometry.

Nonlinear regression equations for percentage of original ash-free dry weight, N, P, K, Ca, and Mg remaining at each retrieval date were determined by cropping system and legume cutting strategy. Data was fit to single, double, and asymptotic models using the Marquardt options of NLIN procedure developed by SAS (SAS, 1998). A single exponential model [1] assumes one rate of plant material decomposition or nutrient release. The double exponential model [2] separates the decomposing material or nutrient into two pools; one that quickly mineralizes and a second pool that mineralizes slowly. The asymptotic model [3] tends towards a positive constant rate of decomposition or nutrient release. The general forms of the equations are:

[1] Single exponential: $Y = \theta_o \exp(-k_1 x)+\varepsilon$

[2] Double exponential: $Y = \theta_o \exp(-k_1 x)+(100-\theta_0)\exp(-k_2 x)+ \varepsilon$

[3] Asymptotic: $Y= \theta_o+(100-\theta_o)\exp(-k_1 x)+ \varepsilon$

where Y is the percent of original plant material or nutrient remaining at time x, θ_0 is the dry weight or nutrient pool, k_1 and k_2 are the dry matter disappearance or nutrient release rate constants, and ε is random error for uncontrolled factors.

An appropriate model was selected for each legume harvest date based on the lowest error mean square value and positive confidence limits. For the purpose of model comparisons, data from different placement dates were pooled and a common model was fitted in order to test the hypothesis that the curves for the different placement dates (and harvest management strategies) are the same, using an F-test. A similar procedure was followed to carry out F-tests to compare effects of different cropping systems.

RESULTS AND DISCUSSION

Legume Dry Matter Production and Chemical Composition

In a companion paper reporting principal crop production results, legume establishment and biomass accumulation were discussed in detail (Chapter 2). These results are briefly reviewed for the convenience of the reader. Clitoria cumulative dry matter, averaged across cropping systems in these experiments, was 2.8 and 3.6 Mg ha^{-1} for the 6 and 10-wk harvesting strategy, respectively; while dolichos accumulated 2.2 and 8.0 Mg ha^{-1} for the 2 mo and 4 mo harvest strategies, respectively (Table 3.2). Monoculture clitoria in Exp1 resulted in the greatest dry matter accumulation, while intercropping of clitoria with cassava and/or maize resulted in dry matter yields ranging from 25 to 51% of monoculture clitoria in 1999, and 56 to 105% of the monoculture in 2000. Compared to 6-wk, harvesting clitoria at 10-wk intervals led to 29% greater cumulative biomass production. Similar to results with clitoria, monoculture dolichos in Exp2 accumulated the greatest dry matter, while intercropping of dolichos with cassava and/or maize resulted in dry matter yields ranging from 56 and 71% of monoculture dolichos in 1999, and 46 to 64% of monoculture dolichos in 2000. Dolichos cut at 4 mo after planting produced nearly 260% more dry matter than dolichos cut 2 mo after planting.

The C:N ratio of the legume residues averaged 15:1 for all cropping systems of Exp1, and 16:1 for Exp2 (Table 3.2). The longer cutting interval resulted in a slightly higher C:N ratio. The highest C:N ratio (19:1) was observed during 1999 for dolichos cut 4 mo after planting. Regardless of cropping system or harvest strategy, legume residues had C:N ratios below the theoretical value (25:1) where net mineralization would occur (Heal, et al., 1997). Overall, cropping systems did not significantly influence nutrient concentration of clitoria and dolichos foliages (Table 3.2). Averaged across all cropping systems and years, nutrient concentrations in clitoria foliage were 28.6 g N kg^{-1}, 2.1 g P kg^{-1}, 20.7 g K kg^{-1}, 4.0 g Ca kg^{-1}, and 3.5 g Mg kg^{-1}, while those of dolichos foliage were 27.4 g N kg^{-1}, 2.1 g P kg^{-1}, 23.0 g K kg^{-1}, 8.5 g Ca kg^{-1}, and 2.1 g Mg kg^{-1}. Magnesium concentrations were generally greater in clitoria foliage, while Ca concentrations were greatest in dolichos foliage. Compared to nutrient concentrations of other foliage materials for soil fertility improvement in the region, the capacity of clitoria and dolichos to supply nutrients are nearly similar to leaf prunings of pigeon pea (*Cajanus cajan)*, with the exception that K concentrations were greater in the herbaceous legumes while Ca concentrations were greater in the tree prunings (Schroth et al., 1992).

Clitoria harvested at shorter interval between cuttings resulted in greater N and K concentrations in clitoria foliage in 1999, while N, P, K, and Ca concentrations in dolichos foliage were greater for the short compared to the long duration harvesting strategy. Only N and K concentrations were significantly influenced by the dolichos management strategy during 2000. Variations in nutrient concentrations would ultimately affect the nutrient content of the legume residues and the quantity of nutrients available for release. On the basis of dry matter yield, potential nutrient contributions of clitoria residues ranged from 37 to 114 kg N ha^{-1}, 3 to 8 kg P ha^{-1}, 27 to 83 kg K ha^{-1}, 5 to 16 kg Ca ha^{-1} and 5 to 14 kg Mg ha^{-1}, while dolichos residues would contribute 60 to 137 kg N ha^{-1}, 5 to 10 kg P ha^{-1}, 51 to 115 kg K ha^{-1}, 19 to 42 kg Ca ha^{-1} and 5 to 11 kg Mg ha^{-1}. However, the nutrient availability would depend on the dry matter decomposition and nutrient release rates from the legume residues.

Legume Residue Decomposition

The cropping systems in which legume residues were applied as surface mulch did not have a significant influence on their decomposition rates. Across all cropping systems, cutting dates, and legume cutting strategy, the asymptotic model provided the best fit for clitoria and dolichos residue decomposition (Table 3.3). Clitoria harvested at 6 or 10-wk, or dolichos harvested at 2 or 4 mo after planting did not differ in rate of dry matter disappearance, so reduced models were used to represent clitoria and dolichos decomposition (Fig. 3.1). The use of reduced models suggests that clitoria or dolichos may be harvested at various growth stages without compromising the decomposition rate. Thus the timing of harvesting can conveniently be targeted to minimize competition with main crops, while recycling substantial amounts of nutrients back to the system.

Generally, dolichos residue disappeared faster than clitoria. The rate coefficient (k wk^{-1}) for clitoria and dolichos dry matter disappearance were 0.2 and 0.5 wk^{-1}, respectively. Estimated values for dry matter remaining from clitoria surface residue placement, averaged across 6 and 10-wk cutting intervals, were 67% at 2 wk, 45% at 4 wk, and 30% at 8 wk. The percentage of initial dolichos dry weight remaining during the same periods averaged 54, 35, and 25% (Fig. 3.1). A more rapid dry matter loss of dolichos residues was observed in a study carried out in a tropical derived savanna environment in West Africa (Ibewiro et al, 1999). Dolichos residue, with a C:N ratio of 11:1, lost 63% of the initial dry weight by 4 wk, with a further 10 to 21% loss by 20 wk after placement. This rapid loss could make for an attractive strategy under intercropping conditions, providing the accompanying crop would be able to utilize the released nutrients in a timely manner. In the absence of an accompanying crop, this rapid loss of dry matter may expose the soil surface to erosion processes, with potential loss of released nutrients. Clitoria's dry matter disappearance in the first two wk averaged 33% of the initial dry weight, providing a greater proportion of surface residue ground cover. If accompanied by a slower release of nutrients, the intercrops would have a greater opportunity to utilize the nutrients released from clitoria foliage.

The effects of soil macrofauna were not measured directly in this study. Nevertheless, localized presence of termites was noted and termites accessed the residues by cutting into the mesh bags. Care was taken not to lose any of the residue during retrieval of the mesh bags. Across all placement dates and treatments, termites were present in about 11% of the bags. In mesh bags that were attacked by termites, the residue material was greatly reduced, indicating that termites may be important contributors to the residue loss process. Schroth et al. (1992) studied mulch decomposition under agro-forestry conditions in a sub-humid tropical savanna environment. Direct observations in the field and feeding marks on collected samples indicated that termites were an important factor of mass loss from the more lignified woody branches, while bark and leaves were less affected. In our study, the greatest proportion of mesh bags attacked by termites was from for the dolichos residues cut 4 mo after planting (19%). With the exception of dolichos 4 mo cut foliage, other foliage material used in the litter bags were most probably not lignified enough to attract the termites. Apart from termites, earthworms and millipedes are also common in the area. In later studies, it may be worthwhile studying the role of these macrofauna on the decomposition and nutrient release process.

Nutrient Release from Legume Residue

The parameter coefficients used to describe nutrient release, as affected by harvest management, are summarized in Table 3.4. Both clitoria and dolichos foliages harvested on different dates during 1999 and 2000 fit reduced models, with the exception of one clitoria 10-wk cut that coincided with a dry period (Fig. 3.2). The cut during this dry period was characterized by the slowest rate of N, P, and K release.Nutrient release data for this same cut was fit to include the 8-wk retrieval date, because retrieval at 16 wk coincided with the beginning of the 2000 long rain season and the extremely high values obtained were treated as outliers. A similar increase in nutrients (K, Ca, and Mg) remaining was observed in another decomposition study of a perennial forage legume (Kalburtzi et al, 1999). The authors suggested that nutrient release was dependent on microbial activity, and was thus constrained under moisture limiting conditions. Another alternative explanation was that soluble nutrient compounds were precipitated on the residue material from other sources. Legume residues harvested on all other dates reflected nutrient release patterns that were similar to dry matter decomposition. Both clitoria and dolichos foliages best fit an asymptotic model. Across all cropping systems in Exp1, N, P and K release from the 6 and 10-wk cutting strategies best fit reduced models, such that single curves represented the amounts of each nutrient remaining at different times after litterbag placement in the field (Fig. 3.2). The only exception was noted for Mg release, where Mg in the 10-wk cutting strategy was released much slower compared to the 6-wk cutting strategy. Across harvest management strategies, the general order of nutrient release was K > P > Mg > N.

Similar to Exp1, nutrient release from dolichos foliage in Exp2 fit the asymptotic model (Table 3.4). Unlike clitoria, a shorter harvesting strategy resulted in faster nutrient release rates from dolichos foliage. The order of nutrient release from dolichos cut at 2 mo was K>Mg> N>P, and K>N>P>Mg for dolichos cut at 4 mo. The N, P, and Mg release curves resulted in the formation of a plateau at 40%, indicating that there were some factors reducing the release rate of the respective nutrients. It is likely that the readily available C and N in cell contents had been consumed by microorganisms, leaving the more resistant structural compounds. Results for Ca release did not fit any of the NLIN regression models, thereby not allowing an estimate of *k*-values. Slow release of Ca was observed in other studies (Luna-Orea *et al*., 1996; Kalburtji *et al.*, 1998), being primarily related to its role as a structural component of plant tissue and therefore less susceptible to release during decomposition.

The slower release of nutrients with delayed harvests of legumes can be attributed to significantly lower N concentrations associated with these foliages residues (Table 3.2). Nitrogen concentrations in the 4 mo harvests of dolichos were 21 % lower than the 2 mo harvests. Nevertheless, the lower N concentrations associated with delayed cuts were still above the critical value (18 to 22 g N kg^{-1}) for the transition between net N immobilization and net mineralization. Also, the low P concentration observed in the 4 mo cut during 1999 for dolichos (Table 3.2) may have affected the decomposition rate, as it was below the value of 2.5 g P kg^{-1} required for net P mineralization in plant residue (Palm *et al.*, 1997). The *k*-values obtained for dolichos showed the greatest variation (0.2 to 2.5 wk^{-1}) compared to those obtained for clitoria (0.3 to 1.0 wk^{-1}) (Table 3.4). Nitrogen release was generally slowest in clitoria, and in the dolichos 4 mo foliage cut. Though the dolichos two-mo cut released N rapidly (k=2.50 wk^{-1}), almost all the N release occurred during the first wk after litterbag placement (Fig.4.3), before forming a plateau with over 40% N still remaining in the residue. One possible explanation is that lignin and polyphenolic compounds may have influenced the decomposition and nutrient release rates of these legumes (Vallis and Jones, 1973). These constituents were not measured in this study, but clitoria foliage was reported to be low in polyphenolics (Mwendia, 1997).

Based on the observed nutrient release patterns, the potentially available nutrient pools were quantified with time based on initial nutrient contents. Estimates of percentage nutrients released at each time interval were multiplied by the initial nutrient content of the respective legumes. With few exceptions, the estimated nutrient pools differed in the time taken to achieve their maximum potential availability (Table 3.5). Nitrogen, P, K, and Mg nutrient pools maxima were achieved with the shorter harvesting strategies of dolichos and clitoria. The fastest release was observed for N and P from the clitoria 10-wk cut and dolichos harvested at 2 mo after planting, where the maximum N and P pools were achieved only two wk after litter placement in the field. Nitrogen release from dolichos agrees with the work conducted in West Africa (Ibewiro, et al., 2000), whereby 64% of the N in dolichos residue was released within a period of four wk. Other maximum pool levels occurred at four wk for K release from the dolichos 2 mo cut, eight wk for P and K released from the clitoria 6-wk cut, and eight wk for P and Mg from the dolichos 2-mo cut. If competition for light and moisture are minimized, N, P, and K released from the shorter harvesting intervals of the two legumes are likely to benefit an accompanying crop. In the absence of any crop, however, losses of N and K by leaching may be high, especially in sandy soils. A crop like cassava with a long growing season before harvesting (9 to 12 mo), is likely to benefit from both the shorter and longer harvest strategies in the long rain season, since released nutrients would encounter a well developed cassava root system. In a companion paper (Chapter 2), it was noted that cassava removed large amounts of N and K in the stems and tubers (a total of 85 kg N ha^{-1} and 185 kg K ha^{-1} in cassava from the clitoria/cassava cropping system). The total nutrients returned to the soil in the legume foliage and cassava leaves indicated the potential to supply N removed in cassava, but resulted in a negative K balance. Though P release was also fast compared to N, the total amounts accumulated in the legume residues were generally low (8 kg ha^{-1} annually) and would not have major agronomic impact on the accompanying crop.

SUMMARY AND CONCLUSIONS

Dry matter disappearance patterns of clitoria and dolichos residues followed an asymptotic model, with dolichos residue decomposing faster than clitoria. Residue decomposition and nutrient release patterns were affected more by legume harvest management strategy than the cropping systems in which the residue material was produced and placed as surface mulch. Clitoria and dolichos demonstrated their potential to release N, P, K, Ca, and Mg to cropping systems in the region. Nutrient pools from the shorter cutting interval were potentially available within relatively short periods, however, a longer cutting interval resulted in relatively large nutrient pools that were potentially available over a longer period, and were likely to be beneficial to a long duration crop like cassava, and maize in subsequent cropping seasons.

The relatively slow release of N from clitoria and dolichos residues 4 wk after placement could result in N being available the following season. Approximately 50% of the N in the clitoria cut at 6 and 10-wk, and over 40% of N in dolichos foliage had not been released by 16-wk after placement. While the N and P supplied by decomposing clitoria residue was low, the nutrients would make a modest contribution towards the requirements for maize in the region. Commercial fertilizer adoption in coastal lowland Kenya is very low (< 4%), applying an average of less than 3 kg ha^{-1} (Mose, 1998). Clitoria foliage had the potential to supply 40 and 20 % of the recommended N and P, respectively. The relatively higher nutrient pools contained in dolichos residue, and more rapid nutrient release rates, were likely to benefit the accompanying maize or cassava crop. Dolichos foliage would supply 50 and 20% of the recommended N and P, respectively. Finally, the relatively slow N release observed with clitoria and dolichos 4-wk after placement suggest that factor(s) other than the C:N ratio, perhaps polyphenolics, were governing release. Further research is needed to characterize the synchronization between residue nutrient availability and crop nutrient demand.

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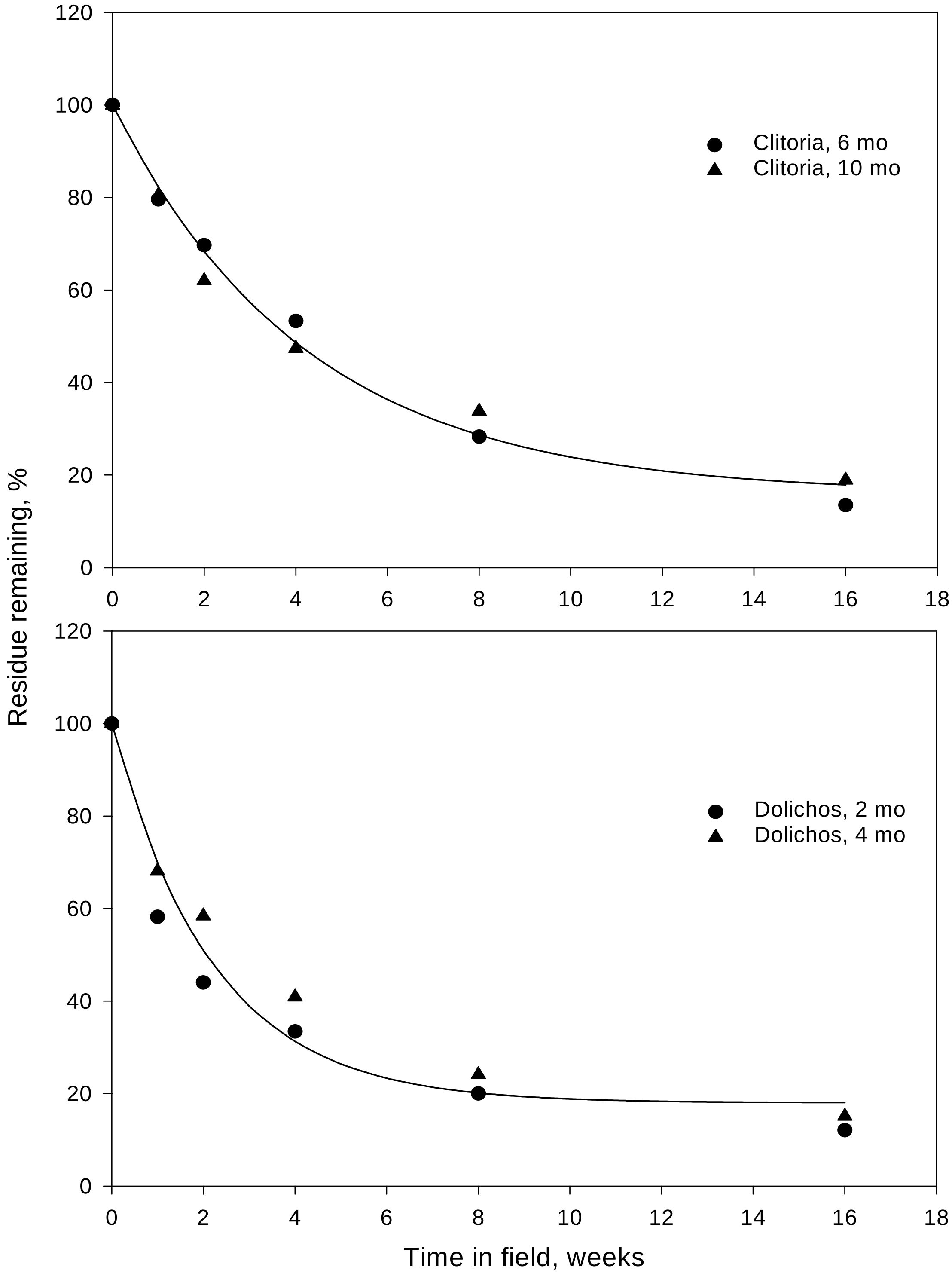

Fig. 3.1. Percentage of initial dry matter remaining in clitoria and dolichos residue litterbags as a function of time after placement in the field. Symbols correspond to mean values across four croppping systems, and the lines correspond to the prediction models in Table 3.3. Each line represents a reduced model of the 1999 and 2000 growing seasons.

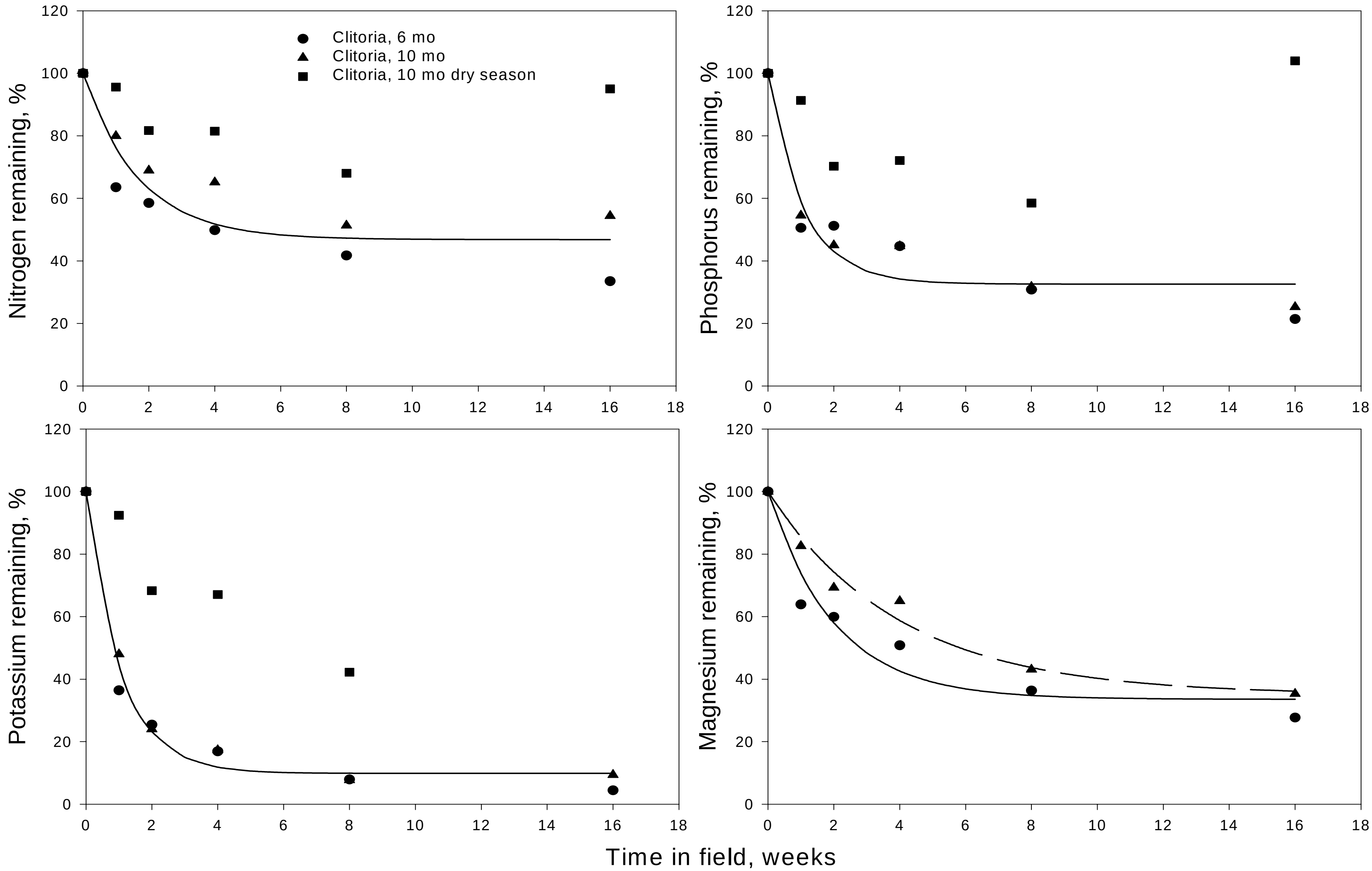

Fig.3.2. Percentage of N, P, K, and Mg remaining in clitoria residue literbags as a function of time after placement in the field. Symbols correspond to mean values across four cropping systems, and the lines correspond to the prediction models in Table 3.4. Each line represents a reduced model of the 1999 and 2000 growing seasons.

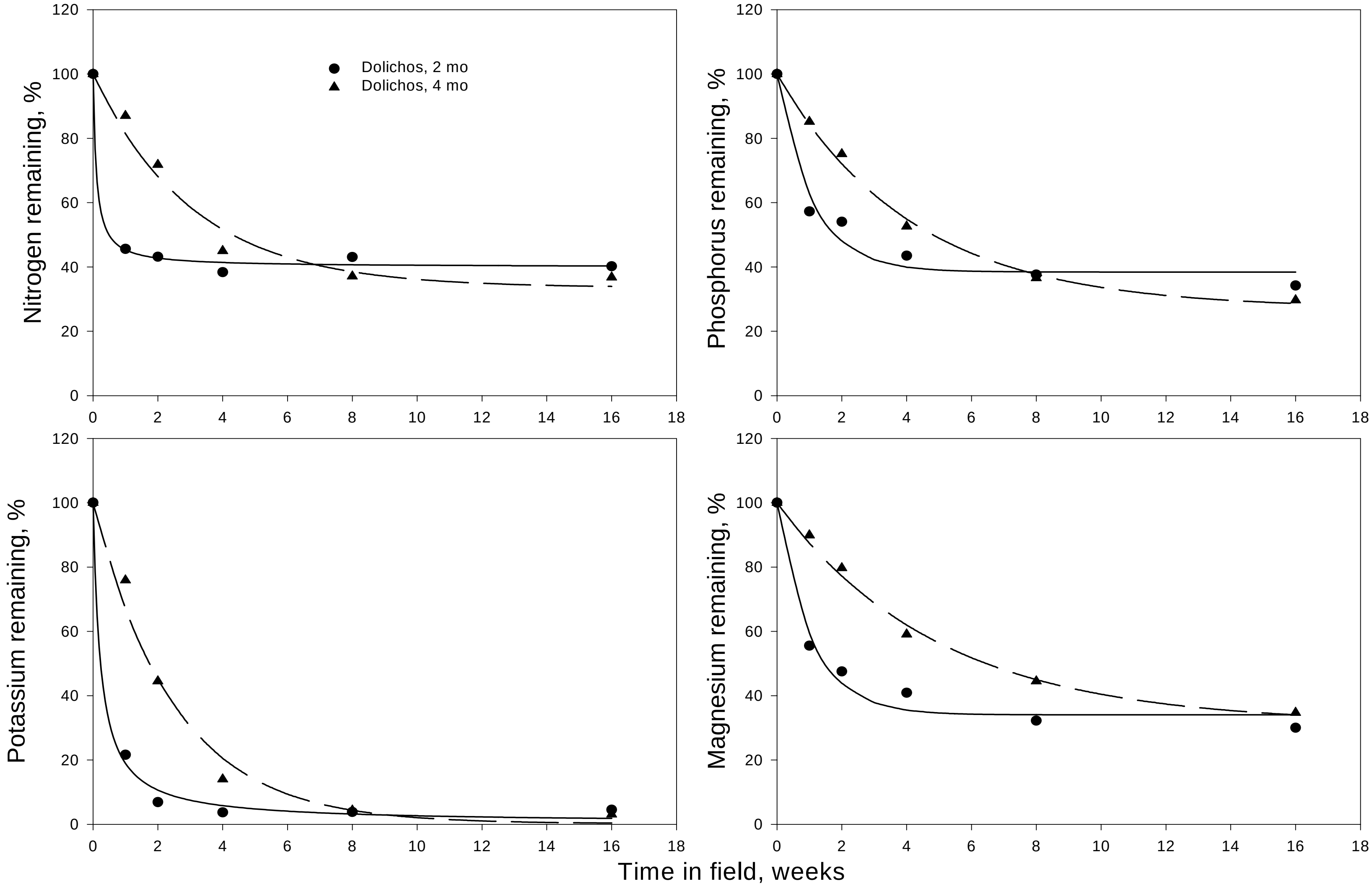

Fig. 3.3. Percentage of N, P, K, and Mg remaining in dolichos residue literbags as a function of time after placement in the field. Symbols correspond to mean values across four cropping systems, and the lines correspond to the prediction models in Table 3.4. Each line represents a reduced model of the 1999 and 2000 growing seasons.

Table 3.1. Treatment combinations for two experiments evaluating legumes for soil fertility improvement in coastal lowland Kenya during 1999 and 2000.

Cropping system	Legume cutting management
Exp1	
Clitoria	Cut clitoria at 2 mo, then after 6 wk
Clitoria	Cut clitoria at 2 mo, then after 10 wk
Clitoria/cassava	Cut clitoria at 2 mo, then after 6 wk
Clitoria/cassava	Cut clitoria at 2 mo, then after 10 wk
Clitoria/maize	Cut clitoria at 2 mo, then after 6 wk
Clitoria/maize	Cut clitoria at 2 mo, then after10 wk
Clitoria/cassava/maize	Cut clitoria at 2 mo, then after 6 wk
Clitoria/cassava/maize	Cut clitoria at 2 mo, then after 10 wk
Exp2	
Dolichos	Cut dolichos at 2 mo after planting
Dolichos	Cut dolichos at 4 mo after planting
Dolichos/cassava	Cut dolichos at 2 mo after planting
Dolichos/cassava	Cut dolichos at 4 mo after planting
Dolichos/maize	Cut dolichos at 2 mo after planting
Dolichos/maize	Cut dolichos at 4 mo after planting
Dolichos/cassava/maize	Cut dolichos at 2 mo after planting
Dolichos/cassava/maize	Cut dolichos at 4 mo after planting

Table 3.2. Effect of cropping system on dry matter production and initial nutrient concentrations of C*litoria ternatea* and *Lablab purpureus* residues used in the decomposition and nutrient release study in coastal Kenya.

Treatment		1999							2000						
		DM†	N	P	K	Ca	Mg	C:N	DM†	N	P	K	Ca	Mg	C:N
		Mg ha^{-1}	——— g kg^{-1} ———						Mg ha^{-1}	——— g kg^{-1} ———					
Exp1															
Cropping system															
Clitoria monoculture		6.1	29.3	2.1	20.6	3.9	3.6	15	1.8	28.2	2.2	20.5	4.2	3.7	15
Clitoria/cassava		2.1	28.5	2.2	21.5	4.3	3.6	15	1.5	28.5	2.0	20.5	3.7	3.5	15
Clitoria/cassava/maize		1.5	28.5	2.3	20.7	4.2	3.6	15	1.0	28.8	1.7	20.2	3.4	3.2	15
Clitoria /maize		3.1	28.5	2.2	20.9	4.1	3.4	15	1.6	28.6	2.0	20.6	3.8	3.6	14
	SE	0.2	0.4	0.1	0.3	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.3	0.3	0.2
Clitoria cutting management ‡															
6 wk cut		2.8	29.4	2.2	21.3	4.2	3.6	15	1.1	28.8	2.1	20.5	4.0	3.7	15
10 wk cut		3.6	28.0	2.2	20.6	4.0	3.5	16	1.9	28.3	1.9	20.3	3.6	3.3	15
	SE	0.2	0.3	0.1	0.2	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.2
Exp2															
Cropping system															
Dolichos monoculture		6.9	27.4	1.9	23.7	9.1	2.7	17	3.1	26.1	2.2	20.9	8.3	2.1	16
Dolichos/maize		4.8	27.4	1.7	24.7	8.6	2.3	16	1.7	26.1	2.0	21.3	8.0	2.0	16
	SE	0.3	2.1	0.2	2.2	0.5	0.5	1.2	0.3	0.9	0.2	1.3	0.3	0.4	0.5
Dolichos/cassava		5.0	25.5	1.8	22.7	8.5	1.0	16	2.0	29.5	2.6	26.4	8.1	2.7	14
Dolichos/cassava/maize		3.9	28.3	2.1	22.5	8.5	1.3	15	1.4	28.6	2.4	21.7	8.5	2.9	15
	SE	0.3	2.6	0.2	2.5	0.8	0.7	1.5	0.3	1.5	0.3	1.8	0.5	0.5	0.5
Dolichos cutting management ‡															
2 mo cut		2.2	31.6	2.4	29.4	9.7	1.8	13	0.9	29.6	2.7	23.7	8.4	2.2	14
4 mo cut		8.0	22.7	1.4	24.4	7.7	1.9	19	3.2	25.6	2.3	21.4	8.1	2.6	16
	SE	0.2	1.7	0.2	1.5	0.5	0.4	1.2	0.2	0.9	0.2	1.1	0.3	0.4	0.5

SE= Standard error.

‡ Clitoria was initially cut at 2 months after planting, then at 6 or 10-wk intervals; dolichos was cut at 2 or 4 mo after planting.

† Cumulative yield of four cuts for clitoria, or 2 cuts for dolichos in 1999 and 2000.

Table 3.3. Parameter coefficients for asymptotic (Eq.[3]) model used to describe dry matter decomposition from C*litoria ternatea* and *Lablab purpureus* residues.

Treatment	Coefficient		
	$\boldsymbol{\theta}_o$	k_1	$S_{y.x}$†
Exp1			
Clitoria, reduced model for 6 and 10-wk cuts	16.0	0.2	3.5
Exp2			
Dolichos, reduced model for 2 and 4-mo cuts	18.0	0.5	6.4

Eq.[3] is $Y = \boldsymbol{\theta}_o + (100 - \boldsymbol{\theta}_o) \exp(-k_1 x) + \varepsilon$; where Y is the percent of original plant material remaining at time x, $\boldsymbol{\theta}_o$ is the dry weight pool, k_1 is the rate constant, x is time (weeks), and ε is random error for the uncontrolled factors.

† $S_{y.x}$ = root mean square error.

Table 3.4. Parameter coefficients for the asymptotic (Eq. [3]) model used to describe nutrient release from *Clitoria ternatea* and *Lablab purpureus* residues.

		Coefficient		
Treatment	Nutrient	$\boldsymbol{\theta}_o$	k_1	Sy.x[†]
Exp1				
Clitoria, reduced model for 6 and 10-wk cuts [‡]	N	46.8	0.6	8.3
Clitoria, 6 wk	P	31.8	0.9	9.7
Clitoria, 10 wk	P	33.2	1.0	6.9
Clitoria, reduced model for 6 and 10-wk cuts [‡]	K	9.8	1.0	4.2
Clitoria, 6-wk	Mg	33.6	0.5	7.2
Clitoria, 10-wk	Mg	35.0	0.3	4.3
Exp2				
Dolichos, 2 mo	N	41.0	2.5	1.9
Dolichos, 4 mo	N	33.6	0.3	4.9
Dolichos, 2 mo	P	38.4	0.9	4.9
Dolichos, 4 mo	P	27.1	0.2	2.1
Dolichos, 2 mo	K	3.9	0.4	0.4
Dolichos, 4 mo	K	0.2	0.4	5.6
Dolichos, 2 mo	Mg	34.0	1.0	4.4
Dolichos, 4 mo	Mg	31.3	0.2	2.3

Eq. [3] is $Y= \boldsymbol{\theta}_o+ (100-\boldsymbol{\theta}_o) \exp(-k_1 x) + \varepsilon$; where Y is the percent of original plant nutrient remaining at time x, $\boldsymbol{\theta}_o$ is the nutrient pool, k_1 is rate the constant, x is time (weeks), and ε is random error for the uncontrolled factors.

† $S_{y.x}$ = root mean square error.

‡ Combined across cropping systems and harvest management.

Table 3.5. Estimated cumulative nutrient release by *Clitoria ternatea* and *Lablab purpureus* residues as affected by foliage harvesting management strategies based on the long rain season foliage yield.

Crop (harvest strategy)	N	P	K	Mg
	kg ha^{-1}			
Exp1				
Clitoria (6 wk)				
0†	30.6	2.3	22.1	4.0
1	7.3	0.9	12.6	1.0
2	11.4	1.3	17.2	1.7
4	14.8	1.5	19.5	2.3
8	16.1	1.6	19.9	2.6
16	16.3	1.6	19.9	2.6
Clitoria (10 wk)				
0†	31.0	2.3	22.1	3.7
1	7.4	1.0	12.6	0.6
2	11.5	1.3	17.2	1.1
4	15.0	1.5	19.6	1.7
8	16.4	1.5	19.9	2.2
16	16.5	1.5	19.9	2.4
Exp2				
Dolichos (2 mo)				
0†	40.3	2.3	35.1	2.6
1	21.8	0.9	11.1	1.1
2	23.6	1.2	18.6	20.0
4	23.8	1.4	26.9	22.7
8	23.8	1.4	32.4	23.2
16	23.8	1.4	33.7	23.2
Dolichos (4 mo)				
0†	201.5	9.1	113.6	11.6
1	34.7	1.2	37.4	1.4
2	60.4	2.2	62.4	2.6
4	93.5	3.6	90.5	4.4
8	121.6	5.3	108.8	6.4
16	132.7	6.4	113.2	7.7

†Time zero values represent initial nutrient contents based on dry matter accumulation from two harvests each of clitoria and dolichos (2-yr avg.) during the long rain cropping season in coastal Kenya.

APPENDIX

Table A2.1. Parameter coefficients† from linear regression analysis of nutrient content and yield of clitoria, dolichos, maize grain and stover for predicting nutrient contents in the respective plant for Exp1 which chemical analyses was not conducted.

Exp.1				Exp.2			
Nutrient	b	SE	R^2	Nutrient	b	SE	R^2
Legume foliage							
C	432.1	2.1	1.00	C	405.6	2.0	1.00
N	28.2	0.5	0.98	N	23.8	0.7	0.95
P	2.2	0.1	0.97	P	1.6	0.8	0.88
K	20.6	0.2	0.99	K	20.1	0.6	0.96
Ca	3.9	0.1	0.96	Ca	7.6	0.2	0.97
Mg	3.6	0.1	0.95	Mg	1.4	0.1	0.66
Maize stover							
C	419.2	0.8	1.00	C	420.6	0.6	1.00
N	5.1	0.2	0.93	N	5.0	0.2	0.95
P	0.5	0.0	0.69	P	0.3	0.0	0.87
K	11.7	0.5	0.88	K	13.0	0.5	0.91
Ca	2.6	0.1	0.97	Ca	2.2	0.1	0.95
Mg	1.6	0.0	0.97	Mg	1.6	0.0	0.97
Maize grain							
C	403.6	1.6	1.00	C	402.6	2.0	1.00
N	14.2	0.2	0.98	N	15.2	0.3	0.98
P	2.4	0.1	0.96	P	2.1	0.0	0.97
K	3.1	0.0	0.99	K	2.8	0.0	0.98
Ca	0.2	0.0	0.69	Ca	0.2	0.0	0.56
Mg	1.0	0.0	0.98	Mg	0.9	0.0	0.98

† y=bx; where y=nutrient content (kg ha^{-1}), b=slope, and x=dry matter yield (Mg ha^{-1}).
SE=Standard error.

Table A2.2. Sources of variance and levels of significance for soil chemical properties as influenced by cropping systems, clitoria and dolichos harvest management, and fertilizer supplementation in coastal lowland Kenya.

	Exp1					Exp2				
Source†	pH	P	K	Ca	Mg	pH	P	K	Ca	Mg
Year	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cropping system	NS	***	**	NS	NS	*	***	***	NS	NS
Year x cropping system	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Management within cropping system	*	***	NS	NS	NS	NS	**	**	**	*
Year x management within cropping system	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Model [1].

*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.

NS=not significant.

Table A2.3. Soil chemical properties (0-20 cm depth) as influenced by cropping systems, clitoria harvest strategy, and fertilizer supplementation in coastal lowland Kenya.

Source	pH	P	K	Ca	Mg
		mg kg^{-1}	—— $cmol_c$ kg^{-1} ——		
1. Clitoria monoculture, 6-wk cut	6.2	0.4	0.3	2.6	0.7
2. Clitoria monoculture, 10-wk cut	6.2	0.4	0.3	2.1	0.6
3. Cassava monoculture, no fertilizer	6.4	0.2	0.2	2.4	0.6
4. Cassava monoculture, with fertilizer	6.3	0.4	0.2	2.4	0.7
5. Maize monoculture, no fertilizer	6.2	0.3	0.3	2.1	0.5
6. Maize monoculture, with fertilizer	6.5	1.0	0.3	2.2	0.6
7. Cassava/maize, no fertilizer	6.3	0.3	0.2	2.6	0.6
8. Cassava/maize, with fertilizer	6.3	0.4	0.2	2.8	0.7
9. Clitoria/cassava, 6-wk cut	6.4	0.3	0.2	2.2	0.6
10. Clitoria/cassava, 10-wk cut	6.2	0.3	0.2	2.3	0.6
11. Clitoria/maize, 6-wk cut	6.4	0.4	0.3	2.4	0.7
12. Clitoria/maize, 10-wk cut	6.4	0.4	0.3	2.4	0.6
13. Clitoria/cassava/maize, 6-wk	6.4	0.3	0.2	2.4	0.6
14. Clitoria/cassava/maize, 10-wk cut	6.4	0.3	0.2	2.3	0.6
SE†	0.1	0.04	0.02	0.2	0.1
Orthogonal contrasts					
Clitoria vs. cassava (1 and 2 vs. 3 and 4)	*	NS	**	NS	NS
Clitoria vs. maize (1 and 2 vs. 5 and 6)	*	***	NS	NS	NS
Cassava vs. clitoria/cassava (3 and 4 vs. 9 and 10)	NS	NS	NS	NS	NS
Maize monoculture vs. clitoria/maize (5 and 6 vs. 11 and 12)	**	***	NS	NS	NS
Cassava/maize vs. clitoria/cassava/maize (7 and 8 vs. 13 and 14)	NS	NS	NS	*	NS
Cassava monoculture, no fertilizer vs. clitoria/cassava/maize (3 vs. 13 and 14)	NS	NS	NS	NS	NS
Cassava monoculture, with fertilizer vs. clitoria/cassava/maize (4 vs. 13 and 14)	NS	NS	NS	NS	NS
Maize monoculture, no fertilizer vs. clitoria/maize (5 vs. 11 and 12)	NS	NS	NS	NS	NS
Maize monoculture, with fertilizer vs. clitoria/maize (6 vs. 11 and 12)	NS	***	NS	NS	NS

† SE=standard error; model [1].

*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.

NS=not significant.

Table A2.4. Soil chemical properties (0-20 cm depth) as influenced by cropping systems, dolichos harvest strategy, and fertilizer supplementation in coastal lowland Kenya.

Source		pH	P	K	Ca	Mg
			mg kg^{-1}	——	$cmol_c$ kg^{-1}	——
1. Dolichos monoculture, 2-mo cut		5.9	0.9	0.3	2.3	0.6
2. Dolichos monoculture, 4-mo cut		5.9	0.8	0.3	2.7	0.8
3. Cassava monoculture, no fertilizer		6.0	0.2	0.2	2.1	0.7
4. Cassava monoculture, with fertilizer		6.0	0.4	0.2	2.5	0.8
5. Maize monoculture, no fertilizer		6.1	0.2	0.2	2.3	0.6
6. Maize monoculture, with fertilizer		6.3	0.7	0.2	2.5	0.6
7. Cassava/maize, no fertilizer		6.2	0.2	0.2	2.2	0.8
8. Cassava/maize, with fertilizer		6.1	0.2	0.2	2.2	0.7
9. Dolichos/maize		6.1	0.7	0.3	2.4	0.7
10. Dolichos/maize		6.2	0.5	0.3	2.4	0.7
11. Dolichos/cassava, 2-mo cut		6.1	0.3	0.3	2.4	0.7
12. Dolichos/cassava, 4-mo cut		6.2	0.3	0.3	2.4	0.7
13. Dolichos/cassava/maize, 2-mo cut		6.2	0.3	0.2	2.4	0.7
14. Dolichos/cassava/maize, 4-mo cut		6.2	0.3	0.3	2.3	0.7
	SE†	0.1	0.1	0.0	0.2	0.1
Orthogonal contrasts						
Dolichos mono vs. cassava mono (1 and 2 vs. 3 and 4)		NS	***	***	NS	NS
Dolichos vs. maize (1 and 2 vs. 5 and 6)		**	NS	***	NS	NS
Cassava vs. dolichos /cassava (3 and 4 vs. 11 and 12)		NS	NS	***	NS	NS
Cassava/maize vs. dolichos/cassava/maize (7 and 8 vs. 13 and 14)		NS	NS	NS	NS	NS
Maize monoculture, no fertilizer vs. dolichos/maize (5 vs. 9 and 10)		NS	NS	NS	NS	NS
Maize monoculture, with fertilizer vs. dolichos/maize (6 vs. 9 and 10)		NS	NS	NS	NS	NS
Cassava monoculture, no fertilizer vs. dolichos /cassava (7 vs. 11 and 12)		NS	NS	NS	NS	NS
Cassava/maize, with fertilizer vs. dolichos/cassava/maize (8 vs. 13 and 14)		NS	NS	NS	NS	NS

† SE=standard error for soil chemical properties based on model [1].

*, **, *** Indicates significance at 0.05, 0.01and 0.001 levels of probability, respectively.

NS=not significant.