American Journal of Experimental Agriculture
4(9): 1047-1071, 2014

SCIENCEDOMAIN *international*
www.sciencedomain.org

Biomass Production in the Short Rains and Its Influence on Crops in the Long Rains: A Systems Approach in Organic Farming

J. R. Birech[1], B. Freyer[2], J. K. Friedel[2], P. Leonhartsberger[2], J. K. Macharia[1] and C. O. Obiero[1*]

[1]Egerton University, Department of Crops, Horticulture and Soil Science, P.O. Box 536 – 20115, Egerton, Kenya.
[2]University of Natural Resources and Life Sciences (BOKU), Division of Organic Farming, Gregor Mendel Straße 33, 1180 Vienna, Austria.

Authors' contributions

This work was carried out in collaboration between all authors. Author JRB designed the study, carried out the actual field work under the supervision of authors BF, JF and PL while author JKM also carried out data collection and field experiment together with author JRB. Author COO and together with author JRB wrote the first draft, editing, formatting, statistical analysis. The final draft was read and approved by all authors.

Original Research Article

Received 10th December 2013
Accepted 16th February 2014
Published 18th April 2014

ABSTRACT

Production of legumes for purposes of obtaining biomass is often restricted to seasons that are less optimum for economic crops, thus limiting the possibility of accumulating substantial biomass. A three and half-year study was conducted at Egerton University, Kenya, with the aim of determining the biomass and grain yield production of lablab (*Dolichos lablab*) during the short rains and the effects of lablab biomass incorporation (LAB) or replacement with farm yard manure (FYM) (2.5 t ha^{-1} or 5 t ha^{-1}) on subsequent organic maize, potatoes and legume intercrops grown during the long rains. Results showed that the rainfall in the short rains season was highly variable and ranged from 164 mm (in 2005/06) to 744 mm (in 2006/07) and so did lablab biomass (0.04 - 2.41 t ha^{-1}). Lablab biomass and grain yield were closely related to the total amount of rainfall received. Moreover, it was shown that a minimum of 2 t ha^{-1} lablab biomass could provide sufficient N (60 kg ha^{-1}) removed by subsequent maize grains; yet to generate this amount of biomass; about 637 mm of rainfall is required under the trial conditions. Maize grain yields following

**Corresponding author: Email: otycha@gmail.com;*

LAB and FYM were 4.5 t ha^{-1} and 4.9 t ha^{-1} respectively (P = .05 in 2005), while potato tuber yields were 18.8 t ha^{-1} and 21.2 t ha^{-1} respectively (P = .05 in 2005) about 10% less yield in LAB compared to FYM. Both LAB and FYM increased the available N soon after incorporation, but reduced the soil pH over the trial period. Lablab grain yield and biomass were less by 17% and 14% respectively when planted after maize than after potatoes. The study concluded that rainfall largely affects the amount of green manure biomass which in turn affects the amount of N recycled, N availability and yield response of subsequent crops.

Keywords: Dolichos; rainfall; farmyard manure; maize; potatoes.

ACRONYMS

C – Carbon; C/N – Carbon to Nitrogen ratio; DAS – Days after sowing; g/kg – gram per kilogram; K – Potassium; kg/ha (kg ha^{-1}) – kilogram per hectare; N – Nitrogen; P – Phosphorus; SPSS – Statistical package for social scientists ; t/ha (t ha^{-1}) – tons per hectare.

1. INTRODUCTION

Soil fertility depletion is one of the leading factors responsible for low crop yields in sub-Saharan Africa. A change from shifting cultivation coupled with population increase in the last few decades has led to continuous cultivation of land with negligible nutrient returns to land [1]. There is widespread soil fertility depletion whose result is an overall low and declining crop yields, food deficits and hence continued food aid in the region [2]. In Kenya, for instance, maize yields in Trans-Nzoia district, the leading maize-producing district, has been declining from 5.4 t ha^{-1} in 1977, to 4.5 t ha^{-1} in 1987, to 3.6 t ha^{-1} in 1998 and to 2.25 t ha^{-1} in 2002 [2]. Research on the district has unveiled a list of factors responsible for yield decline, among them are: low application of nitrogen (N) fertilizer, soil erosion, declining farm sizes, field pests and nutrient mining [3].

Based on many fertilizer trials in Kenya, the general recommendation for maize is 60 kg Nitrogen (N) ha^{-1} + 26 kg Phosphorus (P) ha^{-1}, but these rates are often not feasible to capital constrained smallholder farmers, who make up 80% of the population. Therefore, in the last two decades, there has been a search for alternatives to soil fertility replenishment using organic resources that are commonly available to the smallholder farmers [4]. Furthermore, the potential for managed short-duration fallows to recycle nutrients particularly through biological N-fixation was explored [5,6].

Application of green manures derived from fast-growing legumes can add N to the systems owing to their ability to fix atmospheric N, and the relative ease with which this N is released for plant uptake [7]. Unlike synthetic fertilizers, legume green manures represent a potential renewable source of on-farm, biologically fixed N. It can also add substantial amounts of carbon to the soil [7]. In order to realize their potentials in a farm set up, green manure legumes have either to be produced within the crop-land or to be brought from outside the farm. In the case of on-farm production, green manures have to be slotted into an existing cropping system such as sequential cropping or intercropping, often with non-leguminous crops. In the former case, green manures are sown soon after the main crop is harvested (rotation) or just before harvesting (relay cropping).

Since green manures do not derive direct sales profit, the species should be those that require acceptably low levels of nutrients, moisture, and should fit into otherwise unplanted fallow periods. The growing season of a green manure must fit the demands of a particular crop rotation, which often means green manures are planted during fallow periods with weather unfavorable (low rainfall) for optimal production of economic crops [7]. For these reasons, climate is reported to be the most limiting factor to green manure species selection more than any other single factor [7]. In this era when a lot of variability in key weather elements are observed [8], there is an urgent need to identify resilient green manure cultivars, which perform well in a wide range of weather extremes, and to identify appropriate cropping systems (e.g. rotation, relay cropping), in order to curb vulnerability of farmers who depend on agriculture for livelihood.

This study therefore evaluates the utilization of the short rains to produce lablab (Dolichos lablab) green manures. Lablab is one of the few green manure legumes that are capable of producing a large bulk of green material that can be used for soil fertility improvement [9]. The herbage is equally an excellent fodder and protein source to livestock [10]. Its leaves are highly palatable when used as vegetables [11] and the protein-rich seeds are known to be a delicacy in some Kenyan cultures. In a legume research network in Kenya, lablab was found to be adapted to most sites in Central highland, South West highlands, Western region, Coastal lowland and the Lake Victoria basin, all with moderate to high rainfall levels, except is the semi-arid Eastern Kenya where (*Cajanus cajan*) was better adapted [9]. Lablab is also drought tolerant [11]. Lablab biomass grown in the short rains is reported to provide N for organically grown crops at Egerton [12], and for conventional crops at Egerton and Rongai [13], Kenya. Lablab is native to Africa and Asia but it is until recently that interest on the crop has been rekindled [11].

The general aim of the study was to evaluate the potential of utilizing the short, unpredictable rains to grow lablab for purposes of food production through the grains and for improving soil fertility through incorporation of its biomass into the soil. The specific objectives were: (1) to assess the effect of precipitation on lablab grown in the short rains and to predict lablab grain yield, biomass and nutrient accumulation based on rainfall scenarios; (2) to compare the effects of lablab biomass incorporation and farmyard manure application on the performance of maize, potatoes and legume intercrops grown in the long rains and (3) to compare the effect of lablab biomass and farmyard manure on selected soil properties in the long rains.

2. METHODOLOGY

2.1 Site Description

2.1.1 Climate

The field experiments were carried out at the Egerton University field station, Kenya (0º 13'S, 35º30'E; 2200 m above sea level) with an average annual temperature of 17.5ºC (average of 30 years) and annual rainfall of 1017 mm per annum (average of 44 years). The region experiences bimodal type of rainfall with two rainfall peaks; the long rains April to October (7 months) and the short rains November to March (5 months). Based on the 11-year data (1996-2006), the mean rainfall received in the short rains is 344 mm (5 months) while it is 679 mm in the long rains (7 months). Within the short rains, the month of February records the highest sunshine intensity (632 calcm^{-2} day^{-1}), least rainfall (39 mm), highest potential evaporation (5.2 mm day^{-1}) and highest average daily temperature (21.6ºC) compared to all other months. Within the long rains, the month of July is the coolest with the lowest values in sunshine intensity (500 cal cm^{-2} day^{-1}), average daily temperature (17.9ºC), and potential evaporation (3.3 mm day^{-1}), while the month of August records the highest rainfall (153 mm).

2.1.2 Soils

The soils at Egerton are classified as mollicandosol, which are described as a well-drained, deep to very deep, dark brown, friable and smeary, silty clay to clay, with humic top soils [14]. Top soil properties at the top 15 cm done before the start of the experiment were: pH (1:2.5 soil/water suspension) = 6.8. Total N = 3.2 g kg^{-1}, C/N ratio = 4.7, Extractable P (Melich-1 method) = 6.2 mg kg^{-1}, cations exchange capacity = 26.32 cmol kg^{-1}., bulk density = 1.04 g cm^{-3} [12].

2.2 Treatments, Experimental Design and Agronomic Practices

Starting from mid-October 2003, the trial consisted of field experiments in the short and the long rains. Lablab seeds (of an early maturing dwarf lablab cultivar chosen from the local land-races because it could fit into a rotation system with subsequent crops) were inoculated with Rhizobium-specific bacteria (Biofix®) obtained from the Soil Science Laboratories of Nairobi University, Kenya. The seeds were then planted in plots of 3.6 m x 3.6 m at spacing of 60 cm x 15 cm. At the end of March, 2004, the lablab had produced mature seeds after which the grains were harvested followed by weighing the remaining plant material and either incorporating into the respective plots or removed and replaced with farmyard goat manure at a rate of 2.5 t dry matter (DM) ha^{-1} (37 kg N ha^{-1}, 5 kg P ha^{-1} and 83 kg K ha^{-1}). Ten days after incorporation, maize and potatoes were planted as main crops at a spacing of 75 cm x 30 cm. Three legumes namely garden pea, lima bean, and soybean were also planted as intercrops within the main crops after inoculating their seeds with Rhizobium-specific bacteria (Biofix®). Sole cropping of maize and potatoes was also done. Minjingu Rock Phosphate (MRP) (16% P_2O_5) was applied at a rate of 20 kg P ha^{-1} in all plots. The experiment was replicated 4 times in randomized complete block design (RCBD) with the field experiment carried out for three seasons as shown in Table 5 (Appendix 1).

Maize took 7-8 months while potatoes took 4-5 months to mature under Egerton conditions; they were harvested in mid-August and mid-November respectively. Another cycle of lablab was re-introduced into the mature maize in late-October as the maize grains were drying up before harvesting, a system referred to as relay cropping. This system allows maize and lablab to co-exist, each reaching a full biological cycle within a year. This work reports evaluation based on data from four seasons of lablab and three seasons of main crop plus legume intercrops. Thus, two short rains flanking both ends of the study. Since the 2004 maize crops showed signs of N deficiency (yellowing of leaves), the rate of farmyard manure was revised and increased to 5 DM tha^{-1} (74 kg N ha^{-1}, 10 kg P ha^{-1} and 166 kg K ha^{-1}) in the long rains of 2005 and 2006. Whereas farmyard manure rates were controlled, the lablab treatment was variable and depended on whatever lablab biomass that was harvested at the end of each season (no additional lablab biomass was brought from outside the plot). Maize straw, potato haulms, legume residues, and all weed biomasses were retained in their respective plots (after chopping to small pieces in the case of maize straw). Maize and potato plots were interchanged every other year to prevent possible buildup of pests and diseases specific to the crop species, particularly the notorious late blight of potatoes (*Phytophthora infestants*), which is spread by infected debris.

2.3 Data Collection

2.3.1 Objective 1

To assess biomass and grain production potential of lablab in the short rains and to predict lablab grain yield, biomass and nutrient accumulation based on rainfall scenarios, the following data was obtained from Egerton University weather station: long-term weather data, weather data during the experimental period, lablab grain yield (at 13% moisture content) and DM above-ground biomass (excluding grains) for four seasons. NPK concentrations in lablab tissues were determined after the nutrients were extracted by wet acid oxidation based on Kjeldahl digestion [15]. Thereafter, N was determined by steam distillation and titration [16], while colorimetry and flame photometry were used for P and K respectively [15]. NPK accumulation by lablab biomass was estimated by multiplying the NPK concentrations in the tissues by the total biomass obtained. NPK concentrations in goat manure were also done for comparison purposes.

2.3.2 Objective 2

To assess the impact of lablab biomass relative to that of farmyard manure on crops agronomic properties, the following data was collected: maize and potato plant height, maize grain yields, legume intercrops' grain yields (13% MC), potato tuber yield, maize, potato, and legume above-ground dry matter biomass. NPK content in maize grains was determined using the procedure in objective 1 above.

2.3.3 Objective 3

To compare the effect of lablab biomass and farmyard manure on selected soil properties in the long rains, soil sampling to a depth of 0-15 cm was done during the long rains at 30 days after sowing (DAS) and 160 DAS (grain filling stage for maize) in 2004 and 2006. Four random samples per plot were pooled to make a submitted sample for each plot. Soil moisture content was determined by gravimetric method [15]. The samples were air dried sieved through a 2 mm sieve and analyzed for pH (1:2.5 soil/water suspension) and to pass through a 0.5 mm sieve for total nitrogen, phosphorus and potassium and organic carbon analysis. Available N (Ammonium and Nitrate-nitrogen) was determined by 2 M KCl extraction, followed by steam distillation and acid titration [17]. Extractable P was determined by double acid extraction (0.1 N HCl and 0.025 N H_2SO_4) followed by colorimetry [18] and followed by flame photometry in the case of extractable K [19]. Organic carbon was determined by oxidation with potassium dichromate [20]. Assuming that the Walkey-Black method oxidizes 75% of the total organic carbon, the value obtained was corrected by multiplied with 1.33 [21].

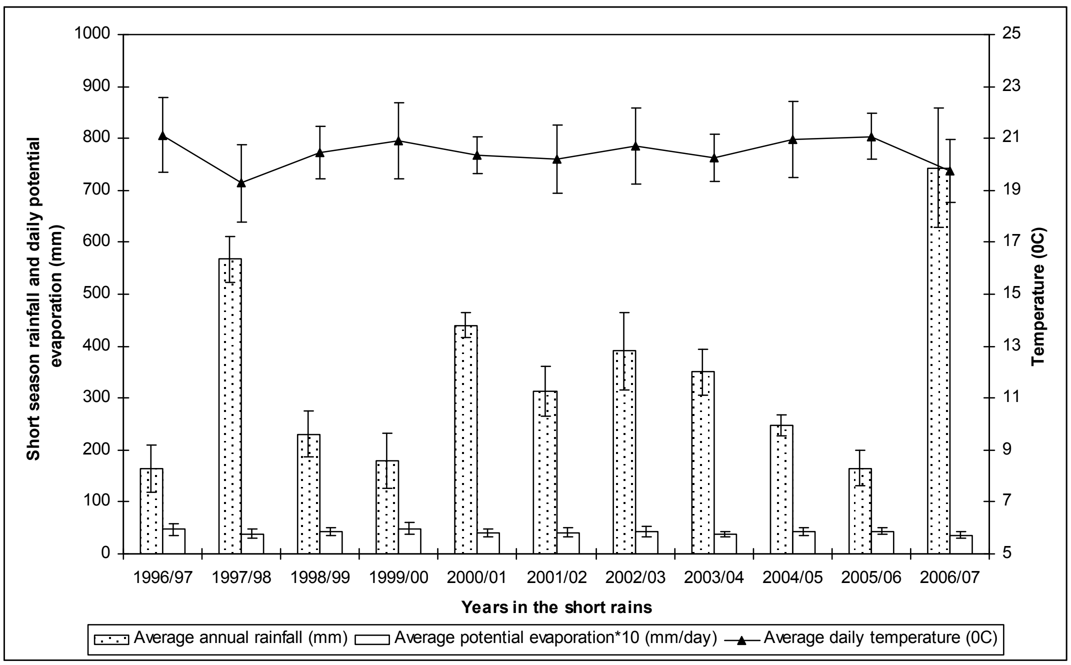
2.4 Data Analysis

All data were subjected to analysis of variance (ANOVA) using statistical Package for Social Scientists [22]. This experiment had four main factors: Blocks (4 levels), Biomass or manure type (farm yard manure and lablab green manure residues), Main crops (maize and potatoes) and Legume intercrops (lima bean, garden pea, soya bean, none or control).

3. RESULTS

3.1 Long-term Weather at Egerton

The weather pattern during the short rains at Egerton University over the recent 11 year period (1996–2006) (Fig. 1) indicates that rainfall during this period is highly variable from one season to another and can range from below 200 mm to just above 700 mm. Rainfall, temperature, potential evaporation and solar radiation are more variable in the short rains compared to the long rains, especially in the rainfall component (Table 1a), depicting a higher variability and thus unpredictability of rainfall in the short rain season. Furthermore, the daily temperature, potential evaporation, and rainfall show strong interdependence on each other in the short rains than in the long rains. For instance, the average daily temperature and potential evaporation in the short rains, are inversely related to rainfall (r = -0.846***, r = -0.837*** respectively), but these relationships are weaker in the long rains (Table 1b).



1

Fig. 1. Pattern of some weather elements in the short rains at Egerton (1996/07-2006/07)

Average potential evaporation has been multiplied by 10 to increase visibility
Bars represent the standard deviation (variance within the months)
Source: Data from Egerton University weather station

[1]Climatic data from Egerton Weather Station 9035092 Lat 0^0 23'S Long 35^o 55'E

Table 1a. Summary of climate in the long and short rains at Egerton (1996-2006)

Weather elements[a]	Short rains		Long rains	
	Mean	**Coefficient of variance (%)**	**Mean**	**Coefficient of variance (%)**
Radiation (cal/cm^2/day)	562.18 (28.03)	4.99	539.89 (13.19)	2.44
Potential E^0 (mm/day)	4.20 (0.38)	9.05	3.69 (0.20)	5.42
Rainfall (mm/season)	344.80 (183.10)	53.10	679.28 (199.80)	29.41
Temperature (^{0}C)	20.46 (0.58)	2.83	19.16 (0.02)	0.10

[a]All data based on data from 1996 to 2006 except for Radiation which is based on data from 1996 to 2001

Standard deviation in parenthesis (year-to-year variance: E^0=Evaporation: Source: Data from Egerton University weather station

Table 1b. Correlations between weather elements in the short and the long rains at Egerton

Weather elements[2]	Season	Rainfall (mm)	Temperature (^{0}C/day)	Potential evaporation (mm/day)
Temperature (ºC)	Short rains	-0.846***	-	-
	Long rains	-0.634*	-	-
Potential evaporation (mm day^{-1})	Short rains	-0.837***	0.827**	-
	Long rains	-0.252 ns	0.201 ns	-
Radiation (cal cm^{-2} day^{-1})	Short rains	-0.891*	0.838*	0.673 ns
	Long rains	-0.861*	0.548ns	0.632 ns

*ns *, **, *** Correlation is not significant at P = .05, significant at P = .05, P<. 01, P<.001 levels respectively: n=11 for all data Radiation where n = 6*

3.2 Rainfall Amounts and Distribution during the Experimental Period

Total rainfall in the long and the short rainy seasons had been dropping progressively since 2004 to 2006, but there was a sharp rise in the amount received from November 2006 to March 2007 (Fig. 2). The monthly distribution of rainfall during the short rains and the long rains are shown in Fig. 3 and Fig. 4 respectively.

3.3 Influence of Amounts and Temporal Distribution of Rainfall on Lablab Grain Yield and Biomass Production in the Short Rains

Rainfall amounts received in the short rains was an important factor in determining the amount of lablab grains and above-ground dry matter biomass obtained (Table 2a). When 351 mm of rain was received, lablab grain yield and dry matter biomass was 0.329 t ha^{-1} and 0.811 t ha^{-1} respectively. Lablab yields were lowest in the short rains of 2005/06 due to the low amount of total rainfall received and the poor distribution. During this season, only 164 mm in five months, furthermore 90 mm (55%) of this rain was received in the month of March when the crop was maturing ad therefore could not benefit much from the rain. Otherwise, only 74 mm of rainfall was received during the four critical months (November – February) of growth, flowering and podding. During this season, only 11 kg ha^{-1} and 42 kg ha^{-1} lablab grain and dry matter biomass was obtained respectively.

[2]Climatic data from Egerton Weather Station 9035092 Lat 0^0 23'S Long 35^o 55'E

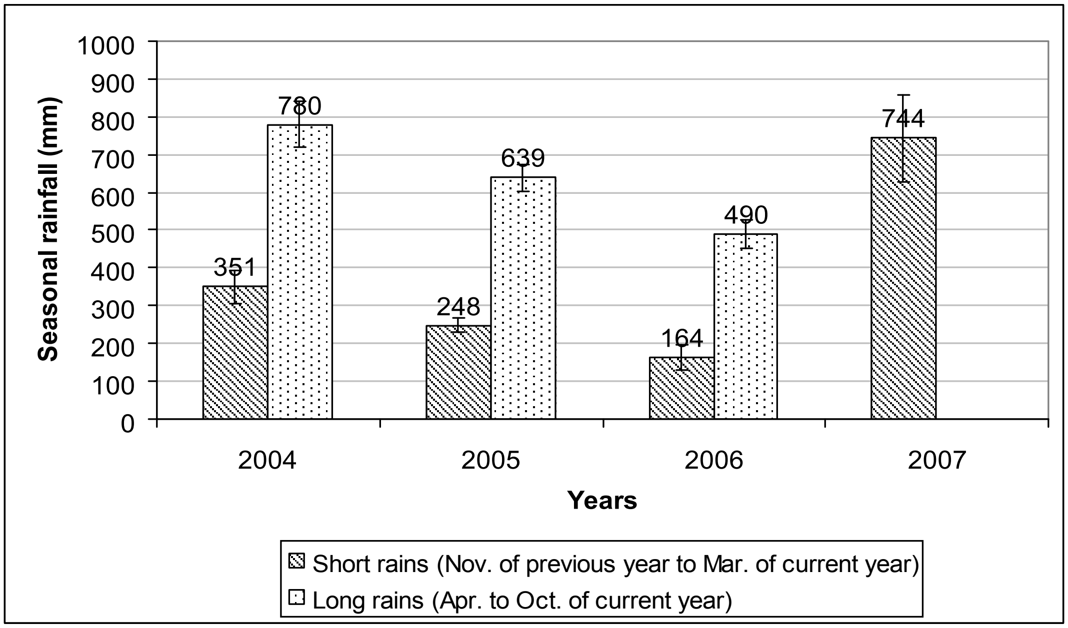


Fig. 2. Rainfall amounts in the short and long rains at Egerton during the experimental period

Source: Data from Egerton University weather station[2]

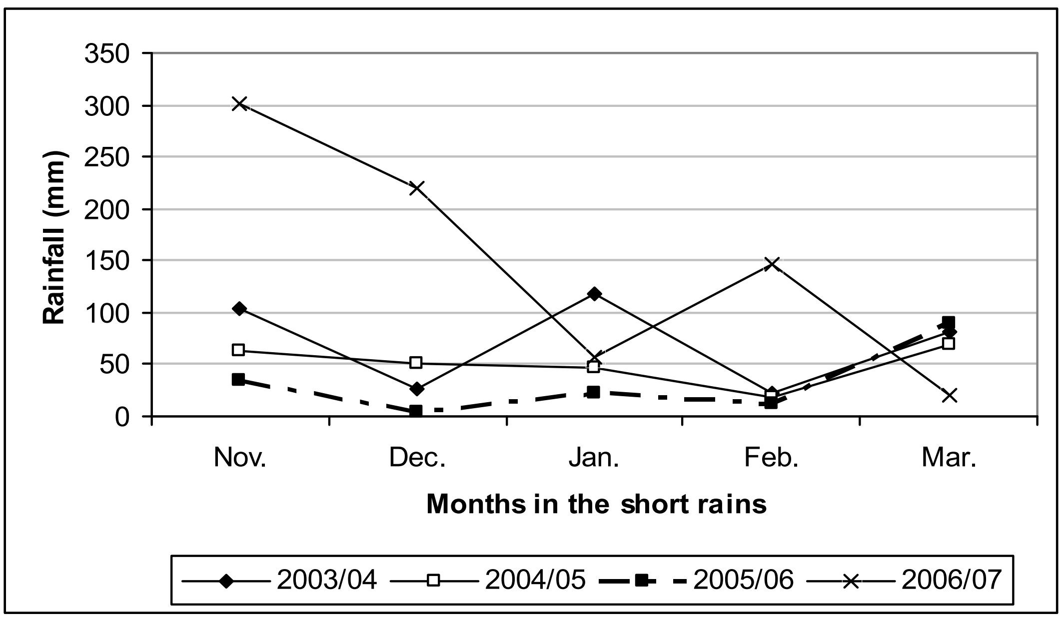
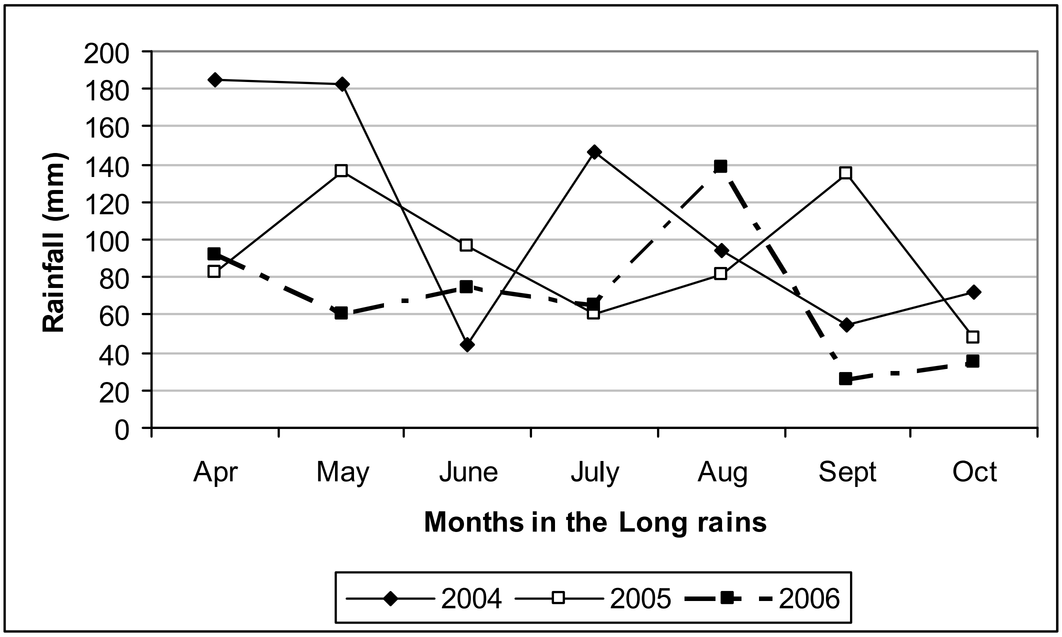


Fig. 3. Monthly rainfall distribution in the short rains at Egerton during the experimental period

Source: Data from Egerton University weather station[3]



[3]

Fig. 4. Monthly rainfall distribution in the long rains at Egerton during the experimental period
Source: Data from Egerton University weather station[3]

Table 2a. Lablab grain and biomass yield (t/ha) in the short rains

Lablab properties	2003/ 04	2004/ 05	2005/ 06	2006/ 07
Lablab grain[a] yield	0.329 (0.080)	0.341 (0.194)	0.011 (0.007)	0.931 (0.363)
Lablab dry matter biomass	0.811 (0.236)	0.782 (0.299)	0.042 (0.225)	2.414 (0.766)

[a]Lablab grains at 13% moisture content: Standard deviation in parenthesis

3.4 Relationship between Lablab Performance and Weather Elements

The total amount of biomass and grain yield of lablab obtained was proportional to the amount of rainfall received in the short rains. Using the 4-season data the total amount of rainfall received in the short rains was positively correlated to lablab grain yield (r = 0.989; *P* = .05) and dry matter biomass (r = 0.996; *P* = .01). The amount of rainfall in December and January also showed significant positive relationships, while the mean daily temperature and potential evaporation in the month of December had significantly negative relationships with lablab performance (Table 2b).

[3]Climatic data from Egerton Weather Station 9035092 Lat 0^0 23'S Long 35^o 55'E

Table 2b. Correlations between lablab grain yield, biomass and weather elements in the short rains

Lablab properties	Total rainfall (short rains) (mm)	Rainfall (December) (mm)	Rainfall (January) (mm)	Mean daily Temp(^{0}C) (December)	Potential evaporation (mm/day) (December)
Lablab grain yield (kg/ha)	0.989*	0.970*	0.969*	-0.959*	-0.971*
Lablab dry matter biomass (kg/ha)	0.996**	0.982*	0.975*	-0.953*	-0.962*

**, ** Correlation is significant at P=*.05, *P<*.01 *respectively: n=4*

Based in the strong relationship with lablab properties, weather elements reported in Table 1a (rainfall, mean daily temperature, and potential evaporation) can be used to develop a multiple regression model to predict lablab properties based on a unit change in any one of the variables. However, in this study, only total rainfall in the short rains was used in the prediction model because the linear regression between the lablab traits and the total amount of rainfall in the short rains generated the highest R^2 values compared to other weather variables. Furthermore, rainfall itself influenced the temperature over the last 11 years (r = -0.846***; n=11), while the temperature partly influenced the potential evaporation (r = +0.827**, n=11) (Table 1b), such that the relationship of temperature and potential evaporation with lablab traits could be an indirect effect of rainfall. Considering the high variability of rainfall in the short rains, (CV = 53%), Table 1a it is evident that the total amount of rainfall is the most varying weather element at Egerton compared to the other elements observed during this period. The difference between the lowest (164 mm; short rains of 2005/06) and the highest (744 mm; short rains of 2006/07) total rainfall recorded during this period is 580 mm. The fact that both rainfall extremes occurred within in the last two years of the trial could confirm concerns of current changing rainfall patterns in the last decade. On the contrary, the widest temperature variation in the short rains 11 years is 1.8^{0}C, with a low coefficient of variation (2.8%). Being the most likely element to vary from one season to another, total rainfall in the short rains was used to predict lablab grain and above-ground biomass yields with the following linear regression models:

Lablab grain yield (kg ha^{-1}) = 1.52 x Rainfall in the short rains (mm) - 190.63 (R^2=0.98; *P* = .05, n=4) (Fig. 5). 98% of the observed grain yield can be accounted for by the fitted model.

3.5 Nutrient Contents and Contributions from Lablab Biomass and Farmyard Manure

The NPK concentrations in Lablab tissues and farmyard manure are shown in (Table 3a). The above-ground biomass obtained from lablab (Table 2a) was all applied on the respective plot in the case of lablab incorporation treatment (LAB), and since the amounts obtained were variable from one year to another, it follows that the nutrients incorporated at the start of each long rainy season were variable. Farmyard manure rates were constant at 5 t ha^{-1} in all years except at the long rains of 2004 when 2.5 t ha^{-1} was applied. Table 3b therefore estimates the amount of nutrients applied in each case.

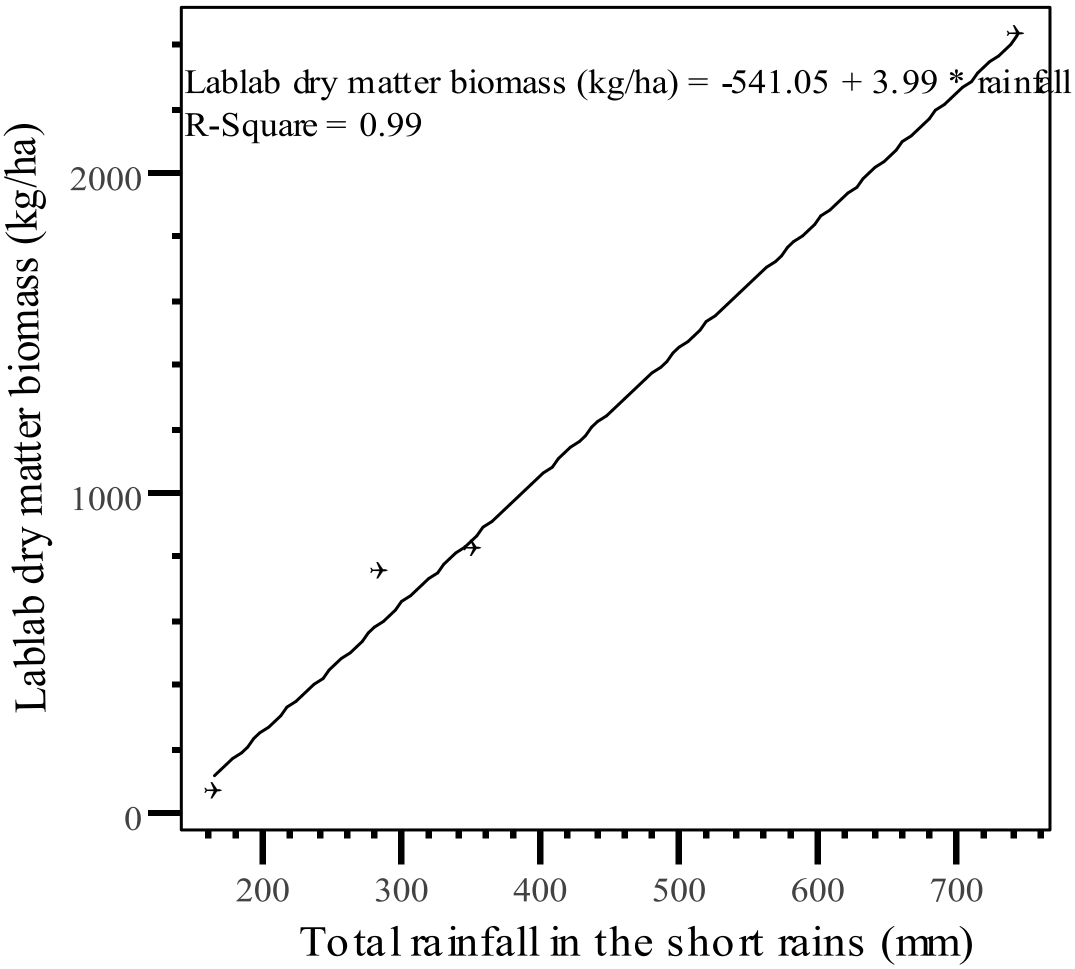


Fig. 5. Regression curve predicting lablab dry matter biomass from total rainfall in the short rains at Egerton

Lablab dry matter weight (kg ha^{-1}) = 3.99 x Rainfall in the short rains (mm) - 541.05 (R^2=0.99; *P*=.01, n=4) (Fig. 6). 99% of the variation in dry matter can be accounted for by the fitted model.

Table 3a. NPK concentrations (g kg^{-1} DM) in lablab residues and farmyard manure

Elements	Lablab	Farmyard manure (goat manure)
N	31.6 (2.5)	14.8 (2.1)
P	2.1 (0.2)	2.0 (0.2)
K	15.7 (1.4)	33.1 (3.1)

Standard deviation in parenthesis

Table 3b. Estimated nutrients recycled (kg/ha) by lablab incorporation (considering above-ground contributions) compared to those from farmyard manure

	Lablab				Farmyard manure			
Nutrients	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2003/ 04**	**2004/05**	**2005/06**	**2006/07**
N	26.0	25.0	1.3	77.2	37.0	74.0	74.0	74.0
P	1.7	1.6	0.1	5.1	5.0	10.0	10.0	10.0
K	12.7	12.3	0.7	37.9	82.8	165.5	165.5	165.5

3.6 Effect of Lablab Biomass Incorporation and Farmyard Manure on Growth of Maize, Potatoes and Legume Intercrops in the Long Rains

3.6.1 Plant height of maize and potatoes

Maize plant height was higher in all the three years with the application of farmyard manure than with the incorporation of lablab residues. This effect was statistically significant *(P*<.01) in 2005 only. Potatoes height followed a similar trend as higher figures were obtained in the farmyard manure than the lablab incorporated treatments (Table 4a). The effect was significant only in 2004 (*P* = .05).

3.6.2 Maize grain and potato tuber yields

Farmyard manure application recorded on average 10% more maize grain yields compared to lablab application across all the years. However, this effect was statistically significant (*P* =.05) in the year 2005 when maize grain yield was about 5.9 t ha^{-1} in the lablab incorporation treatment compared to about 6.6 t ha^{-1} in the farmyard manure treatment (Table 4a). The yield of potatoes tubers was also higher in the farmyard manure treatment than in the lablab incorporation. In 2004 potato tubers weighed on average 22.6 t ha^{-1} in after lablab incorporation and it weighted 29.5 t ha^{-1} after farmyard manure application (*P*<.01). Though potato tuber yields were slightly lower in 2005, the trends were similar to 2004, where farmyard manure recording higher yields than lablab incorporation (*P* = .05). In the long rains of 2006 when an average of 0.04 t ha^{-1} lablab dry matter was applied against 5 t ha^{-1} of dry farmyard manure, no significant variation was observed in the grain yield of maize and tuber yield of potatoes. There was certainly a poor response to application of soil amendments, which was caused, to a large extend, by limited rainfall during the long rains (490 mm) (Fig. 2).

3.6.3 Above-ground biomass of maize and potatoes

Above-ground biomass of both maize and potatoes (excluding seeds) was higher after farmyard manure application than after lablab incorporation in all the three years but the degree of significances varied with the crops and from year to year (Table 4a). In 2005, maize dry matter straw was higher after farmyard manure application (10.3 t ha^{-1}) than lablabbiomass application (9.14 t ha^{-1}) (*P*=.05). In 2006, straw yield was also higher (9.79t ha^{-1}) in farmyard manure than in lablab residue application (8.57 t ha^{-1}). Potato dry matter biomass followed a similar pattern but the effect was only significant in 2005 (*P* = .05). Though most parameters did not respond to manure management in the year 2006, maize stover yield was significant (*P*<.001) in the farmyard manure treatment, a factor that was attributed to rainfall pattern, which affected the two main crops differently. Maize and potatoes differed in critical rainfall periods and longevity in the field. The high rainfall received in August 2006 (138 mm) was therefore beneficial to maize and not potatoes since potatoes were already mature by this time. Correlation analysis within plots which received lablab biomass showed a positive relationship between the dry matter of lablab harvested and grain yield of maize (r = 0.696**, n = 16) in 2004 and potato tuber yield (r = 0.522**, n = 16) in 2005.

3.6.4 NPK concentration in maize grains

The concentration of N and K in mature maize grains did not differ for the two manure types, however, P content was only slightly higher (*P* = 0.062) after application of farmyard manure (1.57 g/kg) than after lablab biomass incorporation (1.2 g/kg) (Table 4b).

3.6.5 Effect of biomass type on legume intercrops

Manure type had little influence of the properties of legume intercrops. Except in 2005 when lablab application increased the grain yield of legumes (*P* = .05), the two biomass types generally did not vary the yields of legume intercrops in 2004 and 2006 nor biomass in all the years (Table 4c).

3.6.6 Effect of lablab biomass and farm yard manure on some soil properties

Soil analysis done during the last year of the trial revealed an overall improvement in the total N from 3.2 to 3.63 g kg^{-1}. However, the soil pH had reduced from 6.8 to 6 in the plots which received farmyard manure and to 5.8 in the plots applied with lablab biomass.

Soil available N (NH4 + NO_3^{-1}) was higher at the beginning than at the end of the long-rain season in both 2004 and 2006. Available N was higher in the farmyard manure treatment in all cases but these differences were not statistically significant (Table 4d). Notably, extractable P taken in September 2006 (160 DAS) was significantly higher (*P* = .05) in the farmyard manure (25 mg kg^{-1}) than the lablab incorporation (19.5 mg kg^{-1}) treatment. Extractable K was 503 mg kg^{-1} and 573 mg kg^{-1} in the lablab incorporation and the farmyard manure treatments respectively. Total N, total P and organic carbon in soils were not different for the two biomass types.

Table 4a. Plant height, yield and dry matter biomass (t ha^{-1}) of maize and potatoes after lablab biomass (LAB) and farmyard manure (FYM) applications in the long rains

Crop	Biomass type	Plant height (cm) at 100% flowering/tasseling				Grain yield of maize / tuber yield of potatoes(t ha^{-1})				Above-ground biomass/straw yield (t ha^{-1})			
		2004	**2005**	**2006**	**Mean**	**2004**	**2005**	**2006**	**Mean**	**2004**	**2005**	**2006**	**Mean**
Maize	LAB	167.5a (31.61)	220.3a (16.4)	217.4a (10.08)	201.7	4.28a (1.26)	5.90a (1.63)	3.30a (0.44)	4.49a	5.09a (2.17)	9.14a (2.25)	8.57a (1.47)	7.59
	FYM	180.6a (39.7)	233.5b (13.8)	216.3a (13.0)	210.1	4.71a (0.84)	6.56b (1.74)	3.55a (1.02)	4.94a	5.23a (2.07)	10.30b (2.33)	9.79b (1.44)	8.44
P values		*ns*	**	*ns*		*Ns*	*	*ns*		*ns*	*	***	
Mean		174.1	226.9	216.9	205.9	4.50	6.23	3.43	4.72	5.16	9.72	9.18	8.02
Potatoes	LAB	80.5a (8.0)	79.0a (8.5)	60.5a (5.2)	73.3	25.55a (6.03)	22.55a (5.43)	8.29a (1.15)	18.80	1.38a (0.46)	1.14a (0.21)	0.77a (0.10)	1.10
	FYM	86.7b (7.6,)	82.8a (10.0)	62.7a (6.5)	77.4	29.49b (7.08)	25.04b (4.59)	9.14a (1.14)	21.22	1.48a (0.30)	1.49b (0.46)	0.83a (0.13)	1.27
P values		*	(*P*=0.052)	*ns*		**	*	*ns*		*ns*	**	*ns*	
Mean		83.6	80.9	61.61	75.4	27.52	23.80	8.72	20.01	1.43	1.32	0.80	1.19

*ns, *, **, *** -Treatments are not significant, or significant at P = .05, P<.01, P<.001 respectively: Means followed by the same letter in a column within a crop type are not significantly different at P = .05: Standard deviation in parenthesis: Maize grains at 13% moisture content; potato tubers at 77% moisture content*

Table 4b. NPK concentrations in mature maize grains after lablab biomass (LAB) and farmyard manure (FYM) applications in 2006

Biomass type	Total N content in maize grains (g/kg)	Total P content in maize grains (g/kg)	Total K content in maize grains (g/kg)
LAB	18.42a (2.39)	1.34a (0.56)	5.72a (0.54)
FYM	18.24a (2.79)	1.75a (0.60)	6.01a (0.61)
P values	ns	(*P* = 0.062)	*ns*
Mean	18.33	1.54	5.87

ns means are not significantly different, significant at P = .05, P<.01 respectively
Means followed by the same letter in a column are not significantly different at P = .05
Standard deviation in parenthesis

Table 4c. Grain yield and above-ground biomass of legume intercrops following lablab biomass (LAB) and farmyard manure (FYM) applications in the long rains

Biomass type	Legume grain yield (t ha^{-1})				Legume above-ground biomass/straw yield (t ha^{-1})			
	2004	2005	2006	Mean	2004	2005	2006	Mean
LAB	0.470a (0.210)	0.649b (0.363)	0.148a (0.117)	0.427	1.035a (0.483)	1.791a (1.352)	0.367a (0.255)	1.064
FYM	0.414a (0.186)	0.521a (0.264)	0.144a (0.131)	0.396	1.083a (0.574)	2.048a (1.259)	0.332a (0.258)	1.154
P values	*ns*	*	ns		ns	ns	ns	
Mean	0.442	0.585	0.146	0.412	1.059	1.920	0.350	1.109

*ns, *, **, *** -Treatments are not significant, or significant at P = .05, P<.01, P = .001 respectively: Means followed by the same letter in a column are not significantly different at P = .05: Legume grains at 13% moisture content: Standard deviation in parenthesis*

.

Table 4d. Effect of lablab residue (LAB) and farmyard manure (FYM) application on some soil properties in 2004 and 2006

	Soil pH (1:2.5 soil / water) at 30 DAS, 2004	Soil pH (1:2.5 soil / water) at160 DAS, 2004	Soil Available N (mg/kg) at 30 DAS, 2004	Soil available N (mg/kg) at 160 DAS 2004	Soil pH (1:2.5 soil / water) at30 DAS, 2006	Soil pH (1:2.5 Soil / water) at 160 DAS, 2006	Soil Available N (mg/kg) at 30 DAS, 2006	Soil available N (mg/kg), at 160 DAS, 2006	Extractable P (Mehlich) (mg/kg), at 160 DAS, 2006	Extractable K (mg/kg), at 160 DAS, 2006	Soil total N (g/kg), at 160 DAS, 2006	Soil total P (g/kg), at 160 DAS, 2006	Soil organic carbon (%) ,at 160 DAS, 2006	C/N ratio, at 160 DAS, 2006
LAB	6.9a (0.2)	6.5a (0.2)	30.9a (15.2)	14.4a (5.3)	5.6a (0.2)	5.8a (0.2)	198a (37)	65a (15)	20a (9)	503a (134)	3.58a (0.19)	0.61a (0.27)	2.57a (0.56)	6.63a (1.73)
FYM	7.1b (0.2)	6.6a (0.1)	44.9a (13.2)	11.8a (3.4)	5.8b (0.2)	6.0a (0.3)	202a (39)	68a (17)	25b (11)	573a (129)	3.63b (1.27)	0.54a (0.23)	2.69a (0.55)	7.32a (2.28)
P values	*	ns	ns	ns	***	*	Ns	ns	*	0.075	ns	ns	ns	ns
Mean	7.0	6.6	37.9	13.12	5.7	5.9	200.00	66.83	22.25	537	3.61	0.57	2.63	7.0

*ns, *, ***- means are not significantly different, significant at P = .05, P<.001 respectively: Means followed by the same letter are not significantly different at P = .05 Standard deviation in parenthesis*

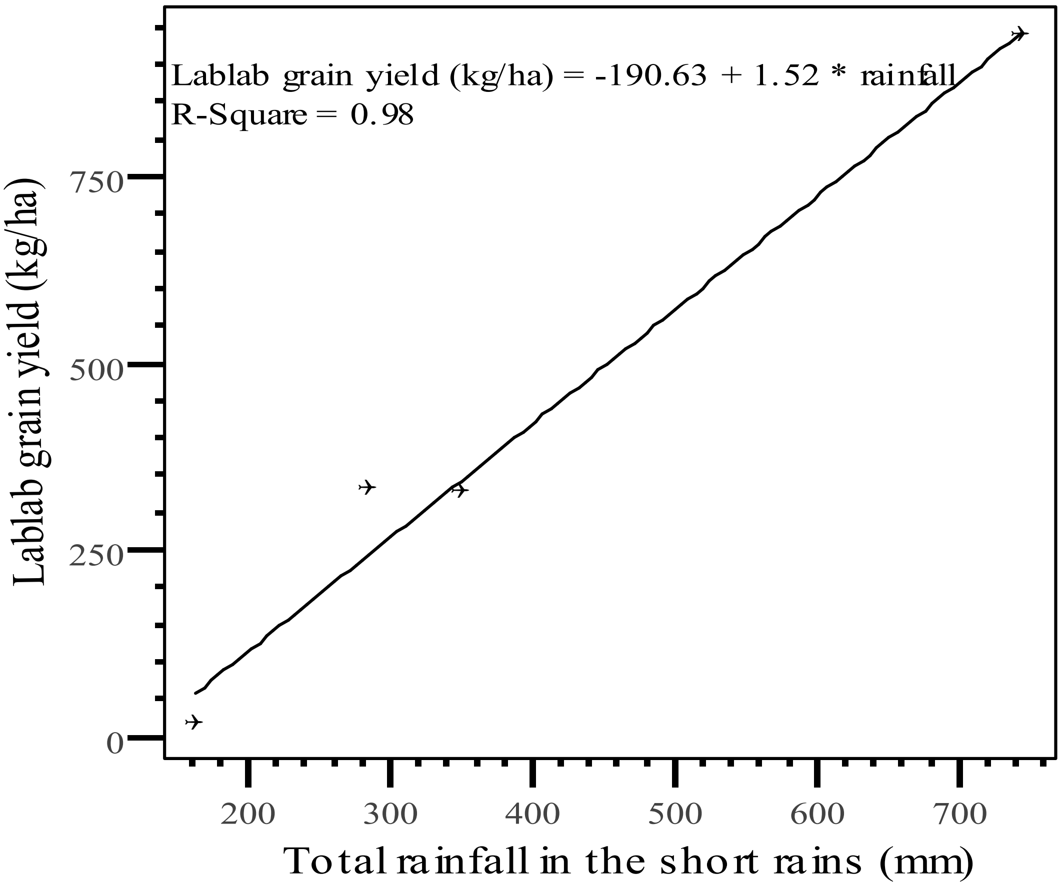


Fig. 6. Regression curve predicting lablab grain yield from total rainfall in the short rains at Egerton

4. DISCUSSION

4.1 Predicting Lablab Productivity from Rainfall

Rainfall seems to be the single most important factor influencing the development of lablab in the short rains. Though total rainfall in the short rains was important, the direct relationship between lablab grain and biomass yield with rainfall, mean daily temperature, mean potential evaporation in the month of December (5-9 WAS [weeks after sowing]) (Table 2b) confirms the critical need for water at flowering and podding [23].

Weather elements can be used to develop a multiple regression model to predict the productivity of the particular lablab variety based on a unit change in any one of the variables. Cherr et al. [24] suggested the use of temperature and solar radiation data coupled with leaf area index and light interception to predict green manure productivity in temperate regions. This is largely because temperature and solar radiation are the most limiting weather factors to plant growth in temperate regions. Our results however suggest that, in the sub-humid climates of the tropics where rainfall is most limiting, it is most appropriate to use rainfall to build predictive models for green manure growth and yield. Based on the four year data, 98% and 99% of the variation in grain yield and dry matter could be accounted for by the fitted models respectively (Fig. 5 and Fig. 6). While these models are applicable to the lablab variety in question, and specific to Egerton and similar climates in the tropics, it demonstrates the potential of such models as decision making tools in the choice of green manure species that are productive at given climatic conditions.

By applying our model to Egerton situation, which often receives less than 400 mm of rainfall in the short rains (Fig. 1), it is observed that the grain yield and dry matter biomass from the early maturing dwarf variety of lablab will seldom exceed 420 kg ha^{-1} and 1050 kg ha^{-1} respectively. By implication, N contributions from above-ground biomass of lablab will seldom exceed 33 kg N ha^{-1} under the climate and cropping systems scenarios. A question of interest is whether this amount of biomass can provide sufficient N to support subsequent organically produced crops without any other external inputs! In an unlikely event where rainfall exceeds 700 mm in the short rains (it happened only once in the last 11 years), lablab dry matter biomass from the early maturing dwarf cultivar, may reach 2.5 t/ha at Egerton. At this production potential, lablab above-ground biomass will provide about 80 kg Nha^{-1}, 5 kg P ha^{-1} and 40 kg K ha^{-1}.

Though, lablab is known to be generally drought tolerant [11], the rainfall threshold below which crop failure would occur is unclear. From this study, it can be stated that rainfall below 160 mm/season, and having a similar distribution as that observed, under similar fertility levels and cropping systems, may lead to crop failure in lablab, both in terms of grain yields and dry matter biomass. Screening for drought tolerance coupled with grain and biomass yield potential is recommended.

Studies in Western Kenya confirm the linkage between rainfall and lablab productivity. The ability of lablab for grain yields, shoot N accumulation, N-fixation and net N input into the soil has been shown to follow a rainfall gradient [25]. Our findings confirm the fact that variable weather or other environmental patterns may also alter year-to-year profitability of green manure approaches [26] and the impact of legumes as soil improving green manures is likely to diminish with reducing rainfall. In West Africa lablab produced a dry matter biomass of 1.9 t/ha to 2.0 t/ha in 13-19 weeks, contributing to 71 kg N/ha, in loamy sand at 1350 mm/year [27]. Lablab productivity is therefore site-specific as per the dictates of the climatic conditions a region.

4.2 Nutrient Contributions from Farmyard Manure and Lablab Biomass

4.2.1 NPK out-flow in maize grains

The average biomass out-flow from the farm for the 3 years in form of dry matter of potato tubers was 4.323 t/ha and 4.881 t/ha in lablab incorporation and farmyard manure respectively. The average dry matter of maize grains removed during this period was on average 3.909 t/ha and 4.297 t/ha in lablab incorporation and farmyard manure respectively. The NPK content was not done in potato tubers and therefore nutrient outflows from potato plots was not estimated. Basing on the NPK contents in maize grains in the lablab incorporation treatment, harvests of maize grains potentially removes 64.7 kg N/ha, 4.7 kg P/ha and 20.1 kg K/ha. In the farmyard manure treatment, NPK removed in form of maize grain harvest was 70.53 kg N/ha; 6.8 kg P/ha and 23.2 kg K/ha.

4.2.2 NPK contribution from FYM and lablab

On the supply side, nutrient inflows from FYM in 2004 when 2.5 t/ha was applied was 37 kg N/ha, 5 kg P/ha and 82 kg K/ha. This rate could not offset out-flows. Assuming a high nutrient recovery, farmyard manure applied at a rate of 5 t/ha in both 2005 and 2006 supplied 74 kg N/ha, 10 kg P/ha and 165 kg K/ha. These rates are sufficient N and K inflows to offset the outflows.

On the contrary, nutrients recycled to the system in these 3 years from above-ground lablab biomass (below-ground not included) were far less than that removed (Table 3b). In 2004 and 2005 when lablab dry matter biomass of about 0.8 t/ha was applied, the N inputs corresponded to about 26 kg N/ha. The N content supplied by this amount of biomass was less than half of the N removed in maize harvests. Our estimates reveal that a lablab dry matter biomass of about 2 t/ha (with 3.2% N) could replenish a similar amount of N removed in maize grains (64 kg N/ha) and lablab biomass application rates below 2 t/ha could lead to net N mining (assuming all N is derived from biological fixation). This is in agreement with [28] who gave a general rule of thumb that only legumes producing above 2 t/ha of biomass would be expected to provide better yield response for maize in the following season. For this variety of lablab to reach this tonnage, Egerton needs about 637 mm of rainfall in the short rains based on our prediction model. Yet there is 20% probability of getting this amount of rainfall in the short rains based on 11-year data (1996-2006).

It was not clear from the study how much of the tissue N could have been derived from biological N-fixation. However, [25] observed a relatively high N fixation by lablab in Western Kenya considering only above-ground input (101 kg N ha^{-1}) and relatively low N export in form of grain N (25 kg N ha^{-1}), leaving a high net N input (76 kg N ha^{-1}), across rainfall and fertility gradients. Most grain legumes in the above study, e.g. soya beans mined soil N. While testing lablab as a fodder legume, Hardason and Atkins [29] found that between 55 to 72% of its tissue N was derived from the atmosphere depending on the climate, being lower in drier regions.

Lablab also recycled 1.7 kg P/ha and 13 kg K/ha when applied at a rate of 0.8 t/ha. This is not an external contribution per se but a mere recycling of soil P and K. Legumes have the potential to mobilize P in the soil that is otherwise sparingly available to non-legumes. They do so by releasing organic acids, phosphatases and reducing the soil pH in the Rhizosphere, which influence P availability [30,31] demonstrated that more P was available to the following maize crop when rock P was applied to lablab compared to when it is applied directly to maize. This shows that lablab has the potential to increase the availability of P from otherwise sparingly available forms.

It is worth noting that besides the quantified amounts of lablab and farmyard manures applied, additional organic materials were equally available to both treatments in the form of lablab root biomass. Lablab had been planted in all plots in the short rains, the above-ground biomass was later cut and either reapplied in the case of LAB or replaced with farmyard manure in the case of FYM. Below ground nutrient deposits accruing from growing lablab in the short rains was not quantified and therefore not included in the estimation of nutrient contributions.

Our results confirm other findings that organic inputs cannot provide the recommended P rates due to low P concentrations [32]. In anticipation of this deficit, Minjingu rock phosphate at the rate of 20 kg P/ha was applied at the beginning of the long rains in all the 3 years. The general recommendation for nutrient application in most Kenya soils in 60 kg N and 26 kg P/ha, most soils are deemed to be sufficient in K [33]. Based on the estimated nutrient balances, the following minimum inputs are proposed to provide sufficient N and P for organic maize production: (i) Lablab biomass at a minimum rate of 2 t/ha + rock P of 20 kg P/ha, or (ii) Farmyard manure at a minimum rate of 5 t/ha + rock P of 20 kg P/ha. Both rates meet the minimum fertilizer recommendation for maize Kenyan soils (60 kg N + 26 kg P/ha). Whenever the lablab biomass obtained is less than 2 t/ha, it is important to provide other organic supplements (e.g. FYM) in order to make main crop-lablab rotation to be sustainable. Though Kenyan recommendations are silent of K needs for most crops, it is postulated that a crop like potatoes which have high K demands could benefit more from farmyard manure compared to lablab biomass even when application at similar N rates. Our conclusion agrees with on-farm studies in western Kenya where incorporation of residues from *Crotalaria grahamiana* and *Tephrosia vogelii* fallows at a rate of 2 t/ha in conjunction with 20 kg P ha^{-1} as Minjingu phosphate rock increased the levels of nitrate in soils, resulting in better yields and economic viability of maize [34].

4.2.3 Crop responses to lablab and farmyard manure applications

The disparity in the amounts of nutrients recycled by lablab and farmyard manure was responsible for a general lower performance of main crops following lablab incorporation. Lablab supplied lesser nutrients in most years because its biomass production was limited by low rainfall. Therefore, plant growth as measures by the height of maize and potatoes was higher following farmyard manure application than following lablab incorporation. Maize grain yield, potato tuber yields and above-ground biomass from the two main crops were higher in the farmyard manure treatment in all the three year. However, there were hardly any effect of biomass type on the yield and biomass of legume intercrops, leading to the conclusion that N was responsible for positive main crop response. This is in agreement with the work of Ghaley and others [35] who reported that, whereas wheat yields increased with increasing N application rates, the yields of associated legume intercrop reduced. Based on our observed variable responses by legumes and non-legumes, it is concluded that N was largely responsible to main-crop responses.

The lower rainfall received in the long rains of 2006 (490 mm) compared to the previous two years could explain the generally lower crop performance during this year. Despite the high difference in biomass amounts from lablab residues (0.04 t/ha) and farmyard manure (5 t/ha), there was a narrow gap between crop responses to these inputs in this drier year. All crop observations were not significantly different except the above-ground biomass of maize, which was higher following farmyard manure application (P<.001). These observations leads to two conclusions: that drought limited crop response to soil amendments; and that drought reduced organic matter decomposition and nutrient mineralization. A direct relationship has been established between soil moisture and nutrient mineralization [36]. N recoveries of legume residues are lower at low rainfall regions [7] and lack of rainfall leads to absence of response to applied N [37]. Water availability is therefore reported to be second most important factor affecting decomposition of organic matter in tropics, where leaf-chemistry (N, P, K, cellulose, lignin, polyphenols and tannins) remains a major determinant [38].

4.2.4 Influence of lablab and farmyard manure on soil properties

Generally, the biomass types tended to affect available nutrients (NPK) with varying degrees of significances. Available NPK were higher in the farmyard manure treatment and this attests to the fact that more nutrients were supplied by the farmyard manure than the lablab treatment. The two biomass types however did not differ in total N and P. Farmyard manure application lead to a slightly higher soil available P and P uptake as measured by the P concentrations in maize grains. As was the case with crop responses, it is possible that nutrient availability patterns varied in a dry and wet a year. There was a lower available N in April 2004 than April 2006 (30 DAS) (Table 4d). This could be due to a high initial rainfall in April 2004 (Fig. 4), which may have caused leaching and/or fast crop uptake. Year-to-year variations in the chemical status are not reported in our tests because most measurements were done only in 2006.

The organic carbon at the end of the trial was 2.63% (41 t C ha^{-1}) at the top 15 cm soil layer. Over 65% of the soils in Kenya have less than 2% organic carbon, a critical cut-off level for nitrogen fertilization recommendation [39]. Practices such as burning of crop residues, erosion on sloping lands, lower litter inputs, removal of crop residues associated with the continuous cropping was reported to lead to nutrient mining and depletion of soil organic matter in 5 years [39]. These practices, couples with higher topsoil temperatures and increased aeration and aggregate breakdown during cultivation increase deplete the soil organic matter. In 24 fertilizer trial sites in Kenya initial C stocks at the sites ranged between 30.2 and 44.1 t C ha^{-1} in the surface layer. After 7 years of continuous cropping without any fertilization, the overall annual loss was 0.69 t C $ha^{-1}yr^{-1}$ across sites [33]. In the current trial, retention of all crop residues at the end of the short rains and the long rains as well as all weed biomass for the last 3 years supported high soil organic matter levels.

At the end of the third year of our trial, soil pH had dropped for both manure types compared to the initial value. Fallowing with lablab could be partly responsible for this change. During N fixation, legumes release a net excess of protons into their rhizosphere, which markedly lowers the soil pH [40]. *Tephrosia candida* was reported to reduce the soil pH after 2 years of fallow in humid tropics of Nigeria [41]. Our studies indicate that the incorporation of lablab residues further lowered the pH as compared to removal and application of farmyard manure. This could be due to the release of organic acids during the residue decomposition process [42], but seemingly decomposing plant materials acidify the soil more than do decomposing animal manures. Nonetheless, lower soil pH is conducive for the dissolution of rock phosphate [37].

4.2.5 Fitting lablab green manures into existing cropping systems

There are two major lablab varieties in Kenya; an early maturing determinate cultivar (4-5 month to mature) and late maturing indeterminate cultivar (6-7 months). Most of these are farmers' collections and have not been documented. The early maturing lablab cultivar was therefore chosen for this purpose, and though it typically fitted into the maize cropping system, it emerged that the cultivar is a poor biomass producer and can barely support the nutrition of the following maize crop. Furthermore, relay cropping reduced the yield and biomass of lablab. Had the late-maturing cultivar been used, it would not have produced seed on time. The late-maturing lablab cultivar, sown on a previously fallow land in mid-October, 2003 at Egerton did not produce seeds by early April but had attained 4.9 t/ha of dry matter biomass [43]. Certainly, favorable rainfall in the short rains (391 mm), previously fallow land, and prolificacy of the cultivar for biomass production contributed to this outcome but it is unclear whether an outcome of high biomass and no seeds or low biomass with seed would be economically viable in a farmers' context.

A potato-based rotation system is likely to accommodate a long-duration lablab cultivar. Potatoes take 5 months to mature leaving an open 6-7 months for possible insertion of fallow crop. In this case, it is possible to introduce the late maturing lablab variety which takes 6 months to produce seeds as well as substantial amount of biomass. The long-duration lablab cultivar can also fit well in to a wheat-based system. Wheat takes 5-6 months to mature and in most parts of Kenya.

To enhance viability of lablab for soil fertility management, there is need to evaluate lablab accessions for suitability to different soils and climate and particularly for high biomass and seed production with different farming systems. Selection for multiple uses including fodder, vegetable production, and palatability tests could be done. Alternative farming systems such as crop-livestock integration could be explored. Our positive results with farmyard manure application suggest that the use of legume biomass as animal fodder could enhance production of milk, meat and drought power, while secondarily improving soil fertility through the application of animal manures.

This paper agrees with other work that crop-green manure cropping systems are complex [7]. There is need for proper assessment of the site-specific relationships between the life cycles of the green manure plant and the subsequent economic crops; for an understanding of the production environment (e.g. climate), management options (e.g. soil fertility) as well as production goals or expected benefits from a green manure. The understanding of such interrelationships could lead to the development of decision support systems for farmers.

5. CONCLUSION

The utilization of legumes as green manures has benefits beyond the addition of N into a system, leading to increase in yields of subsequent crops. However, their production potential is intricately linked to the amount of rainfall and cropping system adopted. The study evaluating lablab biomass production potential and their effect on subsequent crops vis-à-vis that of farmyard manure led to the following conclusions:

1. Biomass and grain yield of lablab fallows in the short rains is closely related to the amount of rainfall received during the season such that it is possible to design prediction models for lablab growth based on rainfall. The prediction model derived from this study is valid for the lablab genotype used, and under similar rainfall distribution, soils, and cropping systems in the tropics. Weather elements are more variable in the short rains and crop species with greater resilience and able to adjust favorably to low and high rainfall extremes need to be sought.
2. Under organic management, main crop performance is proportional to the amount of green manure applied. Whenever on-site legume biomass are less than 2 t DM /ha, additional organic manures, such as farmyard manures have to be supplied to top up for crop requirement and to avoid nutrient mining.
3. Organic manures generally affected season-to-season availability of extractable nutrients (NPK), but total nutrients may not be altered in the first three years of organic management. Organic farming practices such as fallowing with legumes and residue incorporation, farm yard manure application and retention of crop residues have the potential to attain organic carbon content above a critical level of 2%, but it reduces the soil pH. They do have the potential to sustain reasonable crop yields in the sub-humid tropics, but external P may be mandatory.
4. Relay-cropping lablab into maize suppresses the grain yield and above-ground biomass of lablab as compared to rotating lablab with potatoes, partly due to lower residual N and soil moisture spared by the previous maize. There is a need to select

legume green manure species for compatibility with main crops and with existing cropping systems in Kenya as well as to provide multiple products.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support granted towards this work by the Austrian Exchange Service (ÖAD) through the North-South-Dialogue Scholarship Programme. Secondly, the University of Natural Resources and Life Sciences (BOKU), Vienna, through the Division of Organic Farming and the Department of Crops, Horticulture and Soil Sciences Egerton University for the supervision support.

COMPETING INTEREST

Authors have declared that no competing interests exist.

REFERENCES

1. Smaling EMA, Nandwa SM, Janssen BH. Soil Fertility in Africa at Stake. In: Buresh RJ, Sanchez PA, Calhoun (eds.). Replenishing soil fertility in Africa. SSSA Special publication No. 51.SSSA, Madison, WI. 1997;47-79.
2. Okalebo JR, Othieno CA, Woomer PL, Karanja NK, Semoka JRM, Bekunda MA, Mugendi DN, Muasya RM, Batino A, Mukhwana EJ. Available technologies for replenishing soil fertility in Africa. Nutrient Cycling in Agroforestry Systems. 2006;76:153-170.
3. Wanyama JM, Nkonge C, Serem A, Mose LO, Rono SC, Masinde AA, Mwarey, Murithi. Determinants of declining maize yield in Kenya: A bio-economic analysis for Trans-nzoia district. Proceedings of the 3rd annual international conference held on 31st July 2007 - 4th August 2007 at Moi University, Kenya; 2007.
4. Woomer PL, Karanja NK Okalebo JR. Opportunities for improving integrated nutrient management by small-holder farmers in the central Highlands of Kenya. African Crop Science Journal. 1999;4:503-518.
5. Jama B, Swinkles RA, Buresh RJ. Agronomic and economic evaluation of organic and inorganic sources of phosphorus in Western Kenya. Agronomy Journal. 1997;89:597-604.
6. Gathumbi SM, Cadisch G, Giller KE. Improved fallows: Effects of species interaction on growth and productivity in monoculture and mixed stands. Forest Ecology and management. 2004;187:167-280.
7. Cherr CM, Scholberg JMS, McSorley R. Green manure approach to crop production: A synthesis. Agronomy Journal. 2006;98:302-319.
8. Brown O, Hammill A, Mcleman R. Climate change as the 'new' threat: Implications for Africa. International Affairs. 2007;83(6):1141-1154.
9. Mureithi JG, Gachene CKK, Ojiem J. The role of green manure legumes in small-holder farming systems in Kenya: The legume research network project. Tropical and Sub-tropical Agroecosystems. 2003;1:57-70.
10. Nyambati EM. Management and nutritive evaluation on *Mucuna pruriens* and Lablab purpurea-maize intercrops in the sub-humid highlands of North Western Kenya. PhD. thesis. University of Florida; 2002.
11. Pengelly BC, Maass BL. *Lablab purpureus* (L.) Sweet – diversity, potential use and determination of a core collection of this multi-purpose tropical legume. Genetic Resources and Crop Evolution. 2001;48:261-272.

12. Lelei JN. Impact of soil amendments on maize performance and soil nutrient status in legume maize intercropping and rotation systems in Central Rift Valley Province of Kenya. Ph.D. Thesis, University of Natural Resources and Applied Life Sciences, Austria; 2004.
13. Cheruiyot EK, Mumera, LM, Nahone LN, Mwonga SK. Effect of legume-managed fallow on weeds and soil nitrogen in following maize (*Zea mays* L.) and wheat *(Triticum aestivum* L.) crops in Rift Valley Highlands of Kenya. Australian Journal of Experimental Agriculture. 2003;43(6):597-604.
14. Jaetzold R, Schmidt H. Farm management handbook of Kenya. Volume 2 Part B. Central Kenya. Ministry of Agriculture in co-operation with GAT and GTZ. 1983;379-404.
15. Okalebo JR, Gathua KW, Woomer PL. Laboratory Methods of Soil and Plant Analysis: A working manual. KARI, SSSEA, TSBF, UNESCO-ROSTA; 1993.
16. Bremner JM, Mulvaney CS. Nitrogen-total. In: Page AL, Miller RH, Keeney DR. (eds). Methods of Soil Analysis. Part 2 Chemical and microbial properties, 2nd edition. Madison, Wisconsin, USA: ASA, SSSA. 1982;595–624.
17. Keeney DR, Nelson DW. Nitrogen-inorganic forms. In: Methods of soil analysis, Part 2. Second edition. Page et al. (Eds). Agronomy Monogr. 9. ASA and SSSA, Madison, WI. 1982;643-698.
18. Mehlich A, Pinkerton A, Robertson W, Kempto. Mass analysis methods for soil fertility evaluation. National Agricultural Laboratories, Nairobi, Kenya; 1962.
19. Olsen SR, Sommers LE. Phosphorus. In: Methods of soil analysis. Part 2.2nd edition. Agronomy monograph 9. Page AL, et al. (eds). ASA and SSSA Madison, WI. 1982;403-429.
20. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of chromic acid titration method. Soil Science. 1934;37:29-38.
21. Hinga G, Muchena FN, Njihia CN. Physical and Chemical Methods of Soil Analysis. A publication of the Ministry of Agriculture, National Agricultural Laboratories, Kenya; 1980.
22. SPSS Incorporated. Applications Guide, SPSS Base 11.5. SPSS Inc., Chicago, IL, USA; 1999.
23. Thomson BD, Siddique KHM, Barr MD, Wilson JM. Grain legume species in low rainfall Mediterranean-type environments I. Phenology and seed yield. Field Crops Research. 1997;54:173-187.
24. Cherr CM. Improved use of green manure as a nitrogen source for sweet corn. M.S. Thesis. University of Florida, Gainesville; 2004.
25. Ojiem JO, Vanlauwe B, Ridder N, Giller KE. Niche-based assessment of contributions of legumes to the nitrogen economy of Western Kenya small-holder farms. Plant and Soil. 2007;292:119-135.
26. Vigil MF, Nelson DC. Winter wheat yield depression from legume green fallows. Agronomy Journal. 1998;90:727-734.
27. Carskey RJ, Oyewole B, Tian G. Integrated soil management for the savannah zone of West Africa: Legume and fertilizer N. Nutrient Cycling Agroecosystems. 1999;55:95-105.
28. Gilbert RR. Best-bet green manures for smallholder maize-based cropping systems of Malawi. In: Ritchie JM, (eds). Proceedings of the Final Workshop of the Farming System Integrated Pest Management Project, Club Makohola, Mangochi, Malawi. National Resource Institute. 2000;239–255.
29. Hardason G, Atkins C. Optimizing biological N2 fixation by legumes in farming systems. Plant and Soil. 2003;252:41-54.

30. Pypers P. Isotopic approaches to characterize P availability and P acquisition by maize and legumes in highly weathered soils. Ph.D. Dissertation, Catholic University of Leuven, Belgium; 2006.
31. Vanlauwe B, Nwoke OC, Diels J, Sanginga N, Carsky RJ, Deckers J, Merckx R. Utilization of rock phosphate on a representative toposequence in the Northern Guinea savanna zone of Nigeria: response by Mucunapruriens, Lablab purpureus and maize. Soil Biology and Biochemistry, 2000;32:2063-2077.
32. Palm CA. Contribution of Agroforestry trees to nutrient requirements of intercropped plants. Agroforestry Systems. 1995;30:105-124.
33. FURP (Fertilizer Use Recommendation Project). Fertilizer use recommendations. Vols. 1-22. Kenya Agricultural Research Institute (KARI). Ministry of Agriculture, Nairobi, Kenya; 1994.
34. Ndungu KW. Effects of Minjingu Phosphate Rock on maize yield and changes in soil phosphorus under improved fallows in Western Kenya. M.Ph. Thesis, Moi University, Eldoret, Kenya; 2002.
35. Ghaley BB, Hauggaard-Nielsen H, Hogh-Jensen H, Jensen ES. Intercropping of wheat and peas as influenced by nitrogen fertilizers. Nutrient Cycling in Agroecosystems. 2005;73:201-212.
36. Hagedorn F, Steiner KG, Sekayange L, Zech W. Effect of rainfall pattern on nitrogen mineralization and leaching in a green manure experiment in South Rwanda. Plant and Soil. 1997;195:365-375.
37. Vanlauwe B, Palm C, Murwira HK, Merckx R, Delve R. Organic resource management in sub-Saharan Africa: Validation of a residue quality-driven decision support system. 17th WCSS conference held in Thailand; 2002.
38. Teklay T. Decomposition and nutrient release from pruning residues of two indigenous Agroforestry species during the wet and dry seasons. Natural Cycles Agroecosystems. 2007;77:115-126.
39. Nandwa SM. Soil Organic Carbon (SOC) management for sustainable productivity of cropping and agro-forestry systems in Eastern and Southern Africa. Nutrient Cycling in Agroecosystems. 2001;61:143–158.
40. Fan XH, Tang C, Rengel Z. Nitrate uptake, nitrate reductase distribution and their relation to proton release in five nodulated grain legumes. Annals of Botany. 2002;90:315-323.
41. Ikpe FN, Owoeye LG, Gichuru MP. Nutrient cycling potential of *Tephrosia candida* in cropping systems of Southeastern Nigeria. Nutrient Cycling in Agroecosystems. 2003;67:129-136.
42. Brady NC, Weil RR. The Nature and Properties of Soils.13th Edition. Prentice Hall, New Jersey, USA; 2002.
43. Leonhartsberger C. Effect of short-term fallow systems and organic amendments on soil fertility properties in Njoro, Kenya. MS. Thesis, University of Natural Resources and Applied Life Sciences, Austria; 2006.

APPENDIX 1

Table 5. Treatment structure

Main Plot Factors (Maize*Potatoes)			
Maize		**Potatoes**	
Sub-plot factors			
Trt. No.		**Trt. No.**	
1	FYM + S1 (garden Pea)	1	FYM + S1 (garden pea)
2	IN + S1 (garden Pea)	2	IN + S1 (garden pea)
3	FYM + S2 (lima bean)	3	FYM +S2 (lima bean)
4	IN + S2 (lima bean)	4	IN + S2 (lima bean)
5	FYM + S3 (soy bean)	5	FYM + S3 (soy bean)
6	IN + S3 (soy bean)	6	IN + S3 (soy bean)
7	FYM + S4 (potatoes)	7	IN + S4 (maize)
8	FYM + S5 (maize)	8	FYM + S5 (potatoes)
9	IN + S5 (maize)	9	IN + S5 (potatoes)

*FYM = Farm yard manure (goat); IN = Incorporation of lablab; S1 – S5 cropping systems where; S1 = Garden*Maize intercrop or Garden pea*Potatoes intercrop under FYM or IN respectively,S5 = sole crop of either maize or potatoes under FYM or IN respectively*

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=485&id=2&aid=4358