Towards Sustainable Banana Production in Central Uganda: Assessing four alternative banana cropping systems

Name student: Songyos Kongkijthavorn

Period: 2 - 6

Farming Systems Ecology Group
Droevendaalsesteeg 1 – 6708 PB Wageningen - The Netherlands

WAGENINGEN UNIVERSITY
WAGENINGEN UR

Towards Sustainable Banana Production in Central Uganda: Assessing four alternative banana cropping systems

Name student: Songyos Kongkijthavorn
Registration number student: 881113459070
Credits: 36
Code number: FSE-80436
name course: MSc Thesis Farming Systems Ecology
Period: 2 - 6
Supervisor(s): Dr.ir. Jeroen Groot (WUR), Dr. Charles Staver (Bioversity International)
Professor/Examiner: Prof.dr.ir. Pablo Tittonell

Table of Contents

Preface

First of all, this project is a part of my MSc Plant Sciences study. I came to this thesis project with several thoughts in mind: a desire for a crisp new adventure, a thirst for knowledge, and a drive to steer clear of never-ending repetitive laboratory analyses in other projects. This project has offered me all those aspects. However, along my journey working in Uganda, I found a new thought. This thought arose when I was collecting soil samples in a field. A farmer girl with her child on her arms came up to me offered me help and said thank you for doing this for us. Such a simple word yet it was very powerful. It was the most sincere thank you I have ever heard. At that moment, I was dazed with a mixed feelings of gratitude, shame, and hope. Gratitude as I knew I was doing something that could improve their livelihood; shame as I have been living a spoiled comfortable carefree life; and hope as I may have found an additional new purpose in life. And that is why I would like to dedicate this dissertation to the farmer girl, her child, and Ugandan farmers who are struggling with their lives to make ends meet. Even though, this is only a small part of a bigger project and the thesis may be far from perfect, I sincerely hope that this work could be of help and possibly make a difference in their lives.

I would like to thank Dr.Charles Staver from Bioversity International for giving me a chance to do the thesis project, providing me a lot of ideas, and advising me on how to approach project problems. This project also would not have run smoothly without the help in regard to ideas, data analysis and report writing from Dr. Jeroen Groot from Farming Systems Ecology group at Wageningen University. I would also like to thank Sam Mpiira from Bioversity International at Kampala, Uganda for taking care of me while I was in Uganda and for helping me with data collection along with Francis Kalyango and Henry Kabonge. Last but not least, I would like to express thanks to Piet van Asten, Bioversity colleagues, friends and family for helping, encouraging and making this project possible.

Songyos Kongkijthavorn

Summary

Production decline in banana cropping systems in the area surrounding the Lake Victoria in central Uganda has been a major concern for several decades. A traditional no-off farm input system does not replenish soil nutrients level enough to sustain banana production over the years. Bioversity International in collaboration with NARO and IITA and other organizations have come up with four alternative nutrient management strategies to provide a solution to the problem. Four alternatives are as follows: fertiliser addition, annual crop production with transfer of residue to banana production, poultry production with transfer of manure to banana production, and lastly goat with on-farm trees and shrubs for transfer of residue and goat manure to banana production. A further analysis of each system was performed in this study. Calculating nutrient balances was the main focus while the feasibility in terms of capital, labour, and land requirements and limitations of each alternative was also taken into account.

The study was carried out in three districts around Central Uganda: Nakaseke, Kiboga and Sembabule. A total of 60 farmers from three districts took part in the study with a part of their farms dedicated to the experiment. Nutrient parameters used in nutrient balance calculations were obtained from soil, manure, feed, and foliar samples. Additionally, farm surveys were done to obtain information on capital, labour and land availability.

Results from the study demonstrated that soils from Nakaseke were less fertile than those from Kiboga and Sembabule. For every 10 Mg of banana harvested about 26 kg of N, 1 kg of P and 90 kg of K are taken out of a system. In terms of nutrient balance, a traditional no off-farm input system with 10 Mg of banana harvested per year showed a negative balance of -34 to -38 kg N, -1 to 0 kg P, and -87 to -88 kg K. Harvested products and soil erosion were two major outflows, while atmospheric deposition was the only major inflow in a tradition no-off farm input system. In the same part of the farms in the three districts, another ongoing experiment also looked at the obtainable yield in four treatments, control, mulch, manure, and mulch and manure application on banana plots. A mixed model multiple regression result showed a yield response to N, P and K content of the soil. 63.2% of the variation could be explained by 43.4% treatment (control, mulch, manure, and mulch and manure application), and to a lesser degree by the interaction between nitrogen content and district, K content, and P content. A yield response equation was also derived with the same response of P and K in all three sites. Yield responses to nitrogen, on the other hand, were different, lowest in Kiboga and highest in Nakaseke. Mulch and manure fertilised plots also had higher y-intercepts in every site compared to the control plots. Nutrient balance calculation results showed that to offset 20 Mg ha^{-1} yr^{-1} banana yield approximately 70-85 kg of N, 2 kg of P, and 180 kg of K are needed for all three sites. In another perspective, 653-710 kg of N, 456-540 kg of K are needed in order to obtain 20 Mg ha^{-1} yr^{-1} based on a fertiliser response data from a past experiment. When calculated from the zero nutrient balance point of view, 1.5 ha of maize or 8.1 ha of bean or 2842 chickens or 52 goats or 0.2 to 1 ha of on-farm trees and shrubs biomass is required to produce enough residues or manure to sustain 1 ha of

banana production without an occurrence of nutrient mining. In terms of costs, the scenarios of fertiliser addition, maize production and goat + on-farm biomass production were comparable ranging from 10 million Uganda Shillings (USh) to 14 million USh. Poultry production, in contrast, required 168 million USh with 81% of the cost originated from chicken concentrates while bean production required 26 million USh. However, gross margin was also highest in poultry production at 250 million USh followed by bean production at 8 million USh, goat + on-farm biomass at 7 million USh and 6 million in both fertiliser addition and maize production. Bean production required the highest labour hours at 19000 hours followed by poultry production at 13000 hours, maize production at 9000 hours, goat + on-farm biomass at 7000 hours, and fertiliser addition at 6000 hours.

From the study, it was evident that an optimum ratio of N:K in organic materials for the mulching purpose was 1:2.1-2.5 as they provide just enough of both nutrients. Yield response data stressed the influence of nutrient availability and soil moisture content on banana yield. Other factors such as pest and diseases and a discrepancy in farmers' yield report may have contributed to the gap in the observed/predicted yield r^2. Strengths and weaknesses of each alternative were assessed. Fertiliser addition alternative weaknesses were high price, inconsistent supply and high transportation cost which limits the adoption to <150km. Maize + banana alternative showed a near optimum N:K ratio; however, nutrient release pattern needs to be studied. Bean + banana alternative required a large amount of land and labour. Poultry production required high capital and labour. Manure nutrient content and K concentration were low thus limiting the adoption of chicken or goat manure as the sole source of nutrient replenishment. However, an integration of goat and on-farm trees and shrubs was promising as shrubs such as Tithonia provide a lot of potassium and could be intercropped with banana trees. Sensitivity analysis showed the importance of parameters such as crop residue and manure K%, crop removal factor, and DM yield of trees and shrubs.

An adoption of a strategy must take into account labour, capital, land and resources limitations. It was shown from our study that maize + banana and goat + on-farm trees and shrubs + banana were relatively more efficient and feasible systems. A focus study on an alternative will be required to refine parameters used in this study.

Introduction

In the area surrounding the Lake Victoria in central Uganda, different types of banana trees are cultivated including cooking banana also known as ‘matooke’, beer banana locally known as ‘mbide’, roasting banana and dessert banana (Bagamba et al. 2010). In recent years, the production of these bananas has declined threatening the livelihood of the Ugandan communities, which consume bananas as their main crop. Several problems were accounted for the decline in production. These include reduction of farm size (Gold et al. 2000), drought (Okumu et al. 2011; van Asten et al. 2011), pest and diseases (Gold et al. 1999), soil degradation (Sanchez et al. 1989), and nutrient depletion (Wairegi et al. 2010).

Nutrient depletion is one of the major problems responsible for the reduction in yield of bananas (Van Asten et al. 2005; Okumu et al. 2011). Due to constraints such as poor supply and high cost of fertilizers (van Asten et al. 2010), fertilizers are not generally added to the system to replace nutrients lost from previous harvests and continuous losses through leaching, denitrification and soil erosion (Baijukya and de Steenhuijsen Piters 1998). Organic materials such as maize stover, bean trash and manure are sometimes used to improve the nutrient status of banana cropping systems (Bekunda and Woomer 1996). However, the amount of organic materials added to the systems is evidently not enough to replace losses (Bagamba et al. 2010; Zake et al. 2000). As a result, nutrient mining occurs over time which depletes soil fertility and subsequently causing a reduction in yield (Van Asten et al. 2005).

To solve the problem of nutrient depletion, four nutrient management strategies have been proposed by researchers from Bioversity International in collaboration with local organizations and universities in the project “Growing Bananas with trees and livestock.”

Four nutrient management strategies are to supply banana trees with nutrients from different sources (Appendix A):

1. Fertilizer addition.
2. Annual crop production.
3. Poultry production.
4. Goat production and on-farm trees and shrubs.

In the case of fertilizer addition alternative, only chemical fertilizers will be added to the system. In the second alternative with annual crop production, litters from annual crops will be transferred to the banana cropping system. In the poultry production system, chicken manure will be transferred to the banana cropping system. And lastly, in the last alternative, trees and shrubs biomass will be used as mulch in the banana cropping systems and as goat’s feed. Manure produced from goat will also be utilized as an organic fertilizer in this alternative.

The objective of this study was to investigate a traditional no off-farm input banana production system and alternative systems based on four strategies stated above to assess which strategies are practical and can be successfully adopted by farmers. In order to fulfil the objective, the following elements have to be identified and quantified:

1. Nutrient balance and nutrient flow of the traditional and alternative production systems
2. Labour and capital required for each alternative production systems

In order to understand nutrient flows at farm level, technical parameters in the nutrient management schemes must be investigated. Over the years, bits and pieces of information associated with nutrient flows in these systems have been collected. This includes parameters such as yield and nutrient concentrations in leaves and pseudostems (Nyombi et al. 2010). Other researches focused on other components in an agroforestry system such as livestock (Baijukya and de Steenhuijsen Piters 1998; Mubiru et al. 2011) and trees, shrubs and crop residues (Bekunda and Woomer 1996). As the relevant technical parameters are quantified, nutrient budgets and nutrient flow diagrams could be constructed for a better understanding of nutrient management.

In this study, nutrient management strategies were assessed using nutrient balance calculation. A target yield of 20 Mg ha^{-1} yr^{-1} was determined and used as the set point. Nutrient balance calculation was then used to determine how much input was needed to balance out the outflows so as to achieve zero balance thus prevent nutrient depletion. In the fertiliser addition strategy, the outcome of the scenario was the amount of fertiliser needed. For annual crop production strategy, the outcome of the scenario was the amount of land to grow either maize or bean for biomass transfer. Likewise, the outcome of poultry production strategy was the amount of chicken for producing manure. Lastly, the outcome of goat and on farm trees and shrubs was the amount of land required to grow biomass for mulching and feed.

Additionally, four nutrient management strategies were also assessed using the fertiliser response point of view. In this approach, the response of banana trees to nutrients, N, P and K, was used to calculate the outcome of each strategy. Likewise, 20 Mg ha^{-1} yr^{-1} was also used as the set point for this approach. By combining two methods, the weakness of zero balance approach of not taking into account the nutrient stock in the soil was covered by the fertiliser response approach.

In addition, social and economic aspects related to traditional no off-farm input system as well as alternative nutrient management strategies need to be determined. This includes cost of fertilizers, cost of labour, family size and income, and nutrient losses to the environment, for instance. Subsequently, social, economic, environmental and technical parameters can be entered into a simulation model for a purpose of finding the most suitable nutrient management strategy. Nutrient, economic and labour balances were investigated with a use of excel spreadsheets.

Material and methods

2.1 Sites characteristics

The study was performed in three districts around the Central Uganda surrounding Lake Victoria Basin: Nakaseke district, Kiboga district and Sembabule district. The locations are Nakaseke district (0°43´N, 32°24´E, 1210 m asl.) Kiboga district (0°55´N, 31°45´E, 1180 m asl.), and Sembabule district (0°06´S, 31°30´E, 1200 m asl.). This study was a sub-study, which focused on nutrient management of banana agroforestry system from an overarching project ”Growing Bananas with trees and livestock”. The study incorporated data from previous experiments from the sites during 2011-2014 growing seasons as well as data newly obtained. Data for nutrient balance, labour and economic calculations were the main components collected from 20 banana farmers in each district, 60 farmers in total. Soils in the areas are classified as Ferric Acrisols (FAO 1977). Bimodal rainfall pattern is present in the areas, starting from March to June and August to December. From January to December 2012, annual precipitation was 651 mm in Nakaseke, 1096 mm in Kiboga and 1043 mm in Sembabule. Mean temperature is similar for all the sites, 15°C minimum to 30°C maximum.

2.2 Initial experimental design

Data were collected from selected farmers from each site who had been closely monitoring their experiments designed by the banana agroforestry project. A part of each farmer's land has been dedicated to an experiment where four treatments have been tested: control, mulch, manure, and mulch and manure. Total area of the experiment in each farm is 372 m^2 with 40 banana trees per farm, 10 for each treatment, and plant spacing of 3 m by 3 m. Average farm size is 3.1 ha. The main crop grown in the experiment is banana. Coffee, beans, maize are also present, though not on the experimental plots. Shrubs such as Calliandra, Gliricidia, Leucaena and Sesbania were planted in between the rows for feeding goats as well as for mulching banana trees. Existing fruit trees including avocado, mango and jackfruit can also be found on the property, which are similarly used for mulching. Farmers were given an exotic goat for the experiment in the first year. In February 2014, the average number of goats per farm is 3.6, 3.6, 4.8 for Nakaseke, Kiboga, and Sembabule respectively. The density of goat per hectare is 1.5, 1.1 and 1.9 for Nakaseke, Kiboga, and Sembabule respectively.

2.3 Nutrient balance calculation

Several parameters are needed for the nutrient balance calculation, which can be obtained from a survey, soil sampling, feed, manure and annual crop residues samplings. An overview of the method can be found in the nutrient balance model (Table 1) adapted from the five inputs and five outputs model by Smaling and Fresco (1993).

Table 1. Nutrient balance model

Nutrients	Flow	Description	Method
Mineral fertilizer	IN1	type and amount	Survey
Organic fertilizer	IN2	type and amount and nutrient content	Survey
Concentrates for poultry	IN2a	amount and nutrient content	Survey and laboratory analysis
Manure	IN2b	amount and nutrient content	Field measurement and laboratory analysis
Annual crops residues	IN2c	type, amount and nutrient content	Survey and laboratory analysis
On-farm plants residues	IN2d	type, amount and nutrient content	Survey, laboratory analysis and literature
Deposition	IN3	rainfall record and nutrient content	Existing data and calculation with transfer function
Biological Nitrogen Fixation	IN4	type, yield, nutrient content	Survey, literature and calculation (assuming 50% of total N comes from N fixation)
Asymbiotic Nitrogen Fixation	IN5	amount	Calculation with transfer function
Sedimentation	IN6	omitted due to non-irrigated land	
Subsoil exploitation	IN7	omitted	
Harvested product	OUT1		
Bananas	OUT1a	yield and nutrient content	Survey and literature
Annual crops	OUT1b	yield and nutrient content	Survey, laboratory analysis and literature
Meat, milk and eggs	OUT1c	Not relevant for calculation	
Crop residues leaving the farm	OUT2	omitted	
Leaching	OUT3	amount	Calculation with transfer function
Gaseous losses	OUT4	amount	Calculation with transfer function
Erosion	OUT5	amount	literature

Descriptions of key components as well as methods of obtaining information are provided in Table 1. Graphical representation of Table 1 is shown in Fig 1.

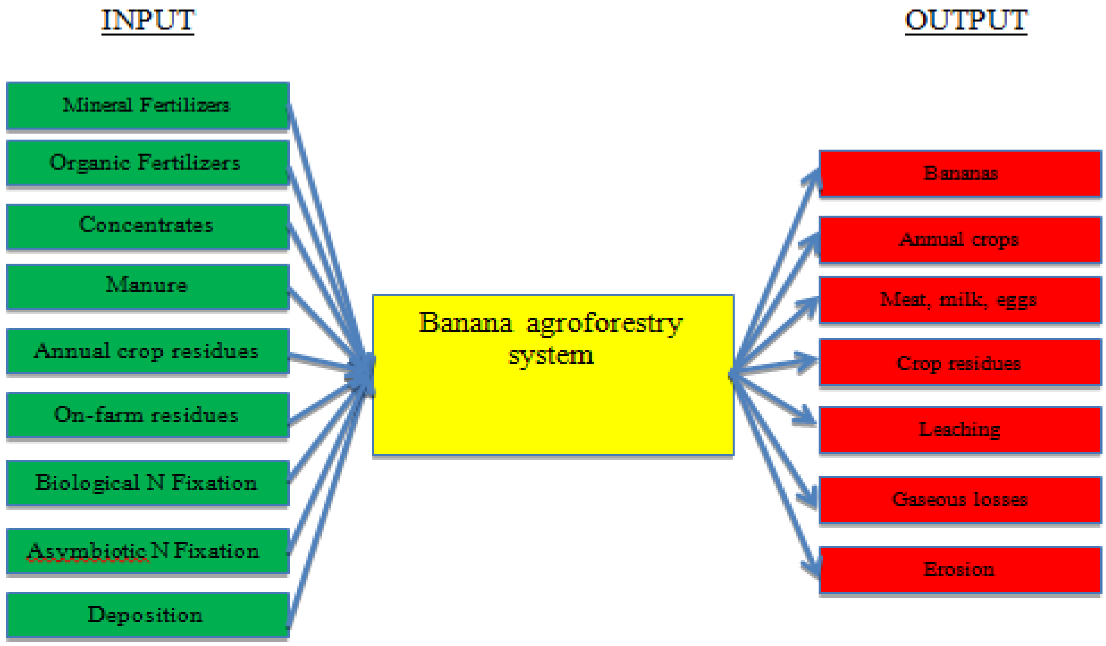


Fig. 1 Graphical overview of the nutrient balance model.

2.3.1 Nutrient contents of banana, crop residues, and on-farm trees and shrubs

Nutrient contents of banana used in this study were 0.26% FW N, 0.01% FW P, and 0.9% FW K (Wortmann and Kaizzi 1998; Baijukya and de Steenhuijsen Piters 1998). A 500 g sample of a maize stover was collected from a farmer's plot in Kiboga to determine nutrient contents, %N, %P, and %K in Kawanda laboratory. Nutrient contents of bean residue were 0.8% FW N, 0.12% FW P, and 0.8% FW K (Wortmann and Kaizzi 1998). On farm trees and shrubs samples consisting of leaves and twigs of approximately 200 g, one sample for each species, were also randomly collected from the three sites. These are *Vernonia*, *Ficus*, *Mulberry*, *Erythrina*, *Calliandra*, *Leucaena*, *Sesbania*, *Gliricidia*, *Mangifera*, *Persea*, *Artocarpus*. The samples were sent to Kawanda laboratory for analysis of the percentage of N, P, K, Ca and Mg in the dry matter.

2.3.2 Manure and feed analysis

Three 500 g chicken manure samples were collected from bags of chicken manure from different chicken farmers, which were then sent to Kawanda Laboratory for analysis of the percentage of organic matter, N, P, K, Ca and Mg in the fresh matter. Three 250 g chicken feed samples were also collected from the farmers for analysis of the percentage of organic matter, N, P, K, Ca and Na in the fresh matter. Three goat manure samples of 500 g from each site were collected from farmers' manure pits for organic matter content analysis of the percentage of organic matter N, P, K, Ca and Mg in the fresh matter. In addition to the laboratory analysis on goat manures and chicken manures, data from FAO (2004) will also be used for nutrient balance calculations. According to FAO, chicken manure based on fresh weight has 1.08% N, 0.39% P, and 0.35% K. Goat manure has 0.76% N, 0.15% P, and 0.67% K.

2.3.3 Atmospheric Deposition

Atmospheric deposition was determined by using transfer functions according to NUTMON by Smaling and Fresco (1993).

$N_{DEPOSITION} = 0.14 \times \sqrt{Precipitation}$
$P_{DEPOSITION} = 0.023 \times \sqrt{Precipitation}$
$K_{DEPOSITION} = 0.092 \times \sqrt{Precipitation}$

Where Precipitation = annual precipitation (mm/year)
$N_{DEPOSITION}$ = nitrogen input from deposition (kg ha^{-1} yr^{-1})
$P_{DEPOSITION}$ = phosphorus input from deposition (kg ha^{-1} yr^{-1})
$K_{DEPOSITION}$ = potassium input from deposition (kg ha^{-1} yr)

2.3.4 Biological Nitrogen Fixation

Biological nitrogen fixation came from on farm trees and shrubs such as bean, Calliandra, Leucaena and Sesbania. Percentages of N contributed by symbiotic N fixation were estimated as 50% of the total N content of above ground biomass production (Baijukya and de Steenhuijsen Piters 1998).
Asymbiotic N fixation by free-living microorganisms was determined using the mean annual precipitation. The following equation shows the relationship between asymbiotic N fixation and precipitation (Smaling and Fresco 1993).

$N_{ASYMBIOTIC} = 2 + (Precipitation - 1350) \times 0.005$

Where $N_{ASYMBIOTIC}$ = Total N fixed by free-living microbes (kg ha^{-1} yr^{-1}) ; Precipitation = precipitation (mm/year)

2.3.5 Leaching

Leaching was calculated based on NUTMON model with transfer functions (Smaling and Fresco 1993). Only N and K were taken into account.

N loss
$N_{LEACHING} = (N_s + N_f) \times (0.021 \times P - 3.9)/100$ If $C < 35\%$
$N_{LEACHING} = (N_s + N_f) \times (0.014 \times P + 0.71)/100$ If $35\% < C < 55\%$
$N_{LEACHING} = (N_s + N_f) \times (0.0071 \times P + 5.4)/100$ If $C > 55\%$

where:

N_s = amount of mineralized N in the upper 20 cm of the soil (kg ha^{-1} yr^{-1})
N_f = amount of N applied with mineral and organic fertilizers (kg ha^{-1} yr^{-1})
P = annual precipitation (mm/year)
C = clay content of the topsoil (percent)
$N_{LEACHING}$ = Total loss of nitrogen through leaching (kg ha^{-1} yr^{-1})

K loss

$K_{LEACHING} = (K_e + K_f) \times (0.00029 \times P + 0.41)/100$ If C < 35%

$K_{LEACHING} = (K_e + K_f) \times (0.00029 \times P + 0.26)/100$ If 35%< C < 55%

$K_{LEACHING} = (K_e + K_f) \times (0.00029 \times P + 0.11)/100$ If C > 55%

where:

K_e = exchangeable K (cmol/kg)
K_f = amount of K applied with mineral and organic fertilizers (kg ha^{-1} yr^{-1})
P = annual precipitation (mm/year)
C = clay content of the topsoil (percent)
$K_{LEACHING}$ = Total loss of potassium through leaching (kg ha^{-1} yr^{-1})

2.3.6 Denitrification

Denitrification (DN) was calculated as a percentage of mineralized and applied nitrogen by using a transfer function of Smaling and Fresco (1993) as follows:

DN (%) = -9.4 + 0.13 x clay content (%) + 0.01 x annual rainfall (mm yr^{-1})

Thus,

$N_{DENITRIF}$ = (N mineralization + N applied) x DN

2.3.7 Ammonia volatilization

Ammonia volatilization in East Africa is negligible due to highly weathered acidic soils.

2.3.8 Soil Erosion

Nutrients losses from soil erosion were based on an experiment conducted by Wortmann and Kaizzi (1998). They estimated the mean soil loss of four locations in eastern and central Uganda. In banana-based systems, on average 3.2 t ha^{-1} yr^{-1} is lost. Nutrient losses through soil erosion were calculated by multiplying nutrient concentration x amount of soil loss (kg ha^{-1}) x enrichment factor, representing the nutrients in finer soil particles which are easily removed earlier during erosion, 2.3 for N, 2.8 for P, and 3.2 for K (FAO 2004). Additionally, when soil is eroded, deeper root zone will be explored by roots of the plants; thereby decreasing a negative effect of nutrient lost through soil erosion. Thus, the result of nutrient losses was multiplied by 0.75 so as to take into account for the 25% increase in nutrient stock from root exploration (FAO 2004).

For example:

32000 kg soil eroded ha^{-1} yr^{-1} x 10 mg N kg^{-1} x 2.3 x 0.75 = 55.2 kg N ha^{-1} yr^{-1} loss through erosion.

In order to calculate P and K losses through soil erosion, exchangeable K and available P must be converted to total K and P in ppm (mg kg^{-1}). This can be achieved by multiplying exchangeable K with the atomic mass of K, 39.1 g mol^{-1}

K_{total} (mg kg^{-1}) = exchangeable K (cmol kg^{-1} of soil) x 39100 (mg of K mol^{-1}) x 0.01 (mol $cmol^{-1}$)

for P, the following equation was used (FAO, 2003):
P_{total} (mg kg^{-1}) = 13 x $P_{available}$ (mg $kg^{-1})^{1.5}$

2.4 Soil sampling

Two representative 250 g soil samples for a control plot and a mulch + manure plot per farm were collected from 20 farms adopting banana agroforestry system in each site. Samples were collected from 0-20 cm depth and 50 cm from tree trunks. In each treatment plot, 5 samples were collected in a zigzag pattern from the 10 trees. The samples were mixed together until it was uniform with no soil aggregates presented and 250 g of sample was then bagged. Soil samples were sent to Kawanda soil and plant analytical laboratory in Uganda. Samples were then oven-dried at 50°C for 2 consecutive days, then grounded to pass 2 mm sieve. Soil pH was determined using deionized water with a soil to water ratio of 1:2.5. Soil organic matter was determined using an oxidation procedure derived from the Walkley-Black method. Total N was determined by Kjeldahl oxidation and semi micro Kjehdahl distillation (Bremner 1960). Mehlich-3 method were performed to extract available P and exchangeable K (Mehlich 1984). Phosphorus was determined using colorimetric method. Potassium was determined using a flame photometer. Other bases will be determined by atomic absorption spectrometry (Okalebo et al. 2002).

2.5 Farm survey

Twenty households of participating farmers from each site in the banana agroforestry project were interviewed with a list of questions (Appendix B). The questionnaire consisted of farm and banana cultivation area, annual crop production, on-farm plants use, livestock and poultry number, banana yield, family size and composition, cost of cultivation, cost of animal production and labour requirement.

2.6 Yield response to soil parameters

Yields per hectare for the control treatments and mulch and manure treatments from each farmer from each site were calculated based on farmers' reports. Since, the yields reported were from 372 m^2 of the banana cropping system from 40 plants, the numbers were then multiplied by 26.9 to get yields per hectare. Yield data is shown in Appendix C. Yield data and soil parameters (N, P and K content), obtained from laboratory analysis were analysed by IBM SPSS Statistics 20 using a mixed model multiple regression analysis. The results were plotted on graphs and multiple regression analysis was conducted with its respective soil parameter versus yield.

2.7 Four alternative strategies calculation

Using the obtained data from laboratory analyses and rainfall records, nutrient balance calculations were performed on an excel spreadsheet. Each alternative strategy was explored by first calculating the nutrient outflow from the traditional system then create a zero-balance system by calculating backward the requirements needed for each strategy. An achievable banana yield of 20 Mg ha^{-1} yr^{-1} was used as a base line in the nutrient balance calculation. Nutrients management strategies are as followed: 1. Fertilizer addition, 2. Annual crop production, 3. Poultry production, 4. Goat production and on-farm trees and shrubs. Methods of calculation for each strategy is described below:

2.7.1 Fertilizer addition

Fresh matter yield was set to 20 Mg ha^{-1} yr^{-1} and N, P, K outflows from the yield were calculated. To achieve nutrient balance, inputs of "mineral fertiliser" were manually adjusted until positive balance closest to zero was achieved for each nutrient.

A fertiliser recommendation for achieving a yield of 20 Mg ha^{-1} yr^{-1} based on a fertilisers response was calculated using an equation from Nyombi et al. (2010) presented below.

$$Nutrient_{need} = \{1.16 \times (DM\ yield/CE) – NS\}/ARF$$

where:

$Nutrient_{need}$ = nutrient required to obtain a specific yield (kg ha^{-1} yr^{-1} N or P or K)
DM yield = Dry matter yield of banana (kg ha^{-1} yr^{-1})
CE = conversion efficiency of a specific nutrient (kg DM finger kg^{-1} N or P or K)
NS = Indigenous nutrient supply of a specific nutrient (kg ha^{-1} N or P or K)

ARF = Apparent recovery fraction of a specific nutrient (kg N or P or K uptake kg^{-1} N or P or K applied)

The equation utilized indigenous nutrient supply, dry matter yield of banana, fertiliser apparent recovery fraction (ARF), and conversion efficiency (CE) to calculate. Apparent recovery fraction is the ratio of nutrient uptake over nutrient supply of a specific nutrient. Conversion efficiency is the ratio of total banana finger yield over total plant uptake of a specific nutrient. Indigenous nutrient supply was calculated for each nutrient, N (INS), P (IPS) and K (IKS) using the following equations (Nyombi et al. 2010).

INS = 58.01 x Total N (%)
IPS = 2.73 x Available P (ppm)
IKS = 230.5 x Exchangeable K (cmol kg^{-1})

Dry matter yield of banana was determined by multiplying fresh yield of banana by fraction of fingers to bunch, 0.92, and dry matter percentage of fingers, 18%. ARF and CE were set differently for each nutrient. Nitrogen, phosphorus, potassium ARFs were 0.095, 0.049, and 0.49 (kg N or P or K uptake kg^{-1} N or P or K applied) respectively. CE for nitrogen, phosphorus and potassium were 48, 549.2, 12.1 (kg DM finger kg^{-1} N or P or K) respectively.

2.7.2 Annual crop production

In this scenario, a ratio of an amount of land required to grow either maize or bean, to produce enough litter for fertilizing a banana cropping system, to a hectare of banana was estimated. Calculations were based on either maize + banana or bean +banana systems. Methods of calculation for each annual crop are described below:

The amount of fertiliser required to achieve nutrient balance and fertiliser response from the first scenario were used as the baseline. Then the amount of maize and bean residues required to satisfy each nutrient requirement was calculated using the equation below.

$$Residue_{required} = Fertiliser_{required} / Residue_{nutrient\ conc.}$$

where:

$Residue_{required}$ = the amount of maize stover or bean trash required (Mg)
$Fertiliser_{required}$ = the amount of fertiliser required from scenario 1 (Mg)
$Residue_{nutrient\ conc.}$ = the residue nutrient concentration (%DM)

The most limiting nutrient would display the highest amount of maize stover or bean trash needed. This number was then used to calculate the amount of land needed for growing maize or bean to produce the required amount of maize stover or bean trash using the following equation.

$Land_{required} = Residue_{required} / (Yield / HI \times (1 - HI)) \times RF$ (%)

where:

$Land_{required}$ = the amount of land required to grow maize or bean (ha)
$Residue_{required}$ = the amount of maize stover or bean trash required (Mg yr^{-1})
Yield = the amount of maize or bean produced (Mg ha^{-1} yr^{-1})
HI = harvest index (%)
RF = removal factor (%)

Maize yield was set to 4 Mg FM ha^{-1} yr^{-1} (Wortmann and Kaizzi 1998). Removal factor and harvest index were 71% and 32% respectively (Kaizzi et al. 2012). Bean yield was set to 1.6 Mg FM ha^{-1} yr^{-1} (Wortmann and Kaizzi 1998). Similarly, 74% removal factor and 30% harvest index was used.

2.7.3 Poultry production

Similar to scenario 2, the amount of fertiliser required to achieve nutrient balance and fertiliser response from the first scenario were used as the baseline. In our analysis, K was the most limiting nutrient, thus equation below was based on K requirement.

$Chicks_{no.} = K_{req} / \{(1 - C_{MR}) \times C_{weight} \times M_{produced} \times M_{k\ content}\}$

where:

$Chicks_{no.}$ = Amount of chicks need to be bought
K_{req} = the amount of K required (kg K ha^{-1} yr^{-1})
C_{MR} = chicken mortality rate (no. dead chicken total no. of $chicken^{-1}$)
C_{weight} = average chicken weight over life time (kg chicken)
$M_{produced}$ = manure excreted per kg weight of chicken (kg manure kg^{-1}chicken yr^{-1})
$M_{k\ content}$ = K content in manure (kg K kg^{-1} manure)

Chicken mortality was set at 0.05. The average weight of a chicken over lifetime was set at 1.11 kg. Manure excreted per kg weight of chicken was calculated based on farmer's interview and was set at 17.2 kg yr^{-1}.

2.7.4 Goat production and on-farm trees and shrubs

In this scenario, the fertiliser requirement to achieve nutrient balance and fertiliser response from the first scenario were also used as the baseline for calculation. The scenario calculations were approached from three different ways: goats only, mulch only, and a combination of goats and mulch.

In the first approach, nutrient supply came solely from goat manure. The number of goats required was calculated using the following equation.

$$Goat_{no.} = Nutrient_{need} / (Basin_{produced}^{1} \times Basin_{weight} \times 52 \times M_{nutrient\ conc.})$$

where:

$Goat_{no.}$ = number of goats required
$Nutrient_{need}$ = nutrient required to obtain a specific yield (kg ha^{-1} yr^{-1} N or P or K)
$Basin_{produced}$ = no. of basin produced by one goat per week ($week^{-1}$)
$Basin_{weight}$ = weight of a basin (kg)
$M_{nutrient\ conc.}$ = nutrients concentration of manure (kg N or P or K kg^{-1} manure)

[1] basin is the container which farmers use to collect goat manure

Nutrients required were obtained from the result of the first scenario. Number of basin produced by one goat per week and weight of a basin were obtained from farmer's interview. Nutrients concentration of goat manure came from FAO (2004) and the laboratory analysis. Feed requirement for the number of goats were calculated by multiplying number of goats with average weight over lifetime and dry matter intake per body weight per day. The average weight over lifetime was assumed to be 40 kg and dry matter intake per body weight per day was 3%.

In the second approach, nutrients in mulches coming from on-farm trees and shrubs were responsible for fulfilling the banana cropping system nutrients requirement. The following equation was used:

$$Land_{biomass} = Nutrient_{need} / (B_{nutrient\ conc} \times Yield)$$

where:

$Land_{biomass}$ = Area needed for a species of tree or shrub (ha)
$Nutrient_{need}$ = nutrient required to obtain a specific yield (kg ha^{-1} yr^{-1} N or P or K)
$B_{nutrient\ conc.}$ = Nutrient concentration in biomass of the species of tree or shrub (kg N or P or K kg^{-1} DM yield ha^{-1} yr^{-1})
Yield = DM yield of the tree or shrub (kg DM yield ha^{-1} yr^{-1})

In the third approach, an average number of goats in a farm was used to calculate nutrients supply as goat manure (kg yr^{-1}). Then, the average number of trees in 1 ha was used to calculate the amount of nutrients in the form of mulch. On average, 1.5 *Ficus*, 1.2 *Mangifera*, 0.7 *Persea*, and 1.8 *Artocarpus* trees are present in 1 ha of farmland. The total nutrients required was then subtracted by nutrients supplied by manure and mulches from trees. The remaining nutrients was achieved by mulching with shrubs. Additionally, goats fed only on shrubs biomass. The following equations were used to calculate the amount of land required to grow shrubs for goat consumption and mulching.

$$Land_{goat} = Goat_{no} \times DMI \times G_{weight} \times 365 / Yield_{shrub}$$

where:

$Land_{goat}$ = Land required for growing shrubs for goat consumption (ha)
$Goat_{no}$ = average no. of goats
DMI = dry matter intake (kg DM biomass kg^{-1} goat day^{-1})
G_{weight} = average weight over lifetime (kg $goat^{-1}$)
$Yield_{shrub}$ = DM yield of a species of shrub (kg DM biomass ha^{-1} yr^{-1})

Landmulch= {Nutrientneedr. / Bnutrient conc. x Yieldshrub

where:

$Land_{mulch}$ = Land required for growing shrubs for mulching (ha)
$Nutrient_{needr.}$ = remaining nutrients requirement (kg N and P and K)
$B_{nutrient\ conc.}$ = Nutrient concentration in biomass of the species of tree or shrub (kg N or P or K kg^{-1} DM yield ha^{-1} yr^{-1})
$Yield_{shrub}$ = DM yield of a species of shrub (kg DM biomass ha^{-1} yr^{-1})

The total land required was then calculated by adding the amount of land required for growing shrubs for goat consumption and mulching together.

2.8 Labour and economic calculation

Labour and economic calculations were performed for the four alternative strategies. The calculations were based on the results from nutrient balance calculations. Since an establishment of banana trees does not occur every year the cost of establishment of banana was not taken into account for the total cost of production. However, a summary of the cost of establishment was computed and presented.

In labour and economic calculations, labour requirement and cost of banana production are shared components for all four strategies. Total cost was calculated based on two major components: cost of banana production and cost of applying a strategy. Cost of banana production included the following: weeding, harvesting, pesticide, and cultural practices. Weeding cost was estimated from the farmers' reported annual cost of weeding. A calculation of cost of harvesting was reported in hours of labour rather than an annual cost. For this, an assumption was made to help calculate the cost of harvesting. An average hourly wage of 1100 USh was assumed. By multiplying an hourly wage to hours of labour required for harvesting, the cost of harvesting was obtained. Cost of pesticide, similar to weeding cost, was obtained from the survey which already included cost of labour and cost of pesticides. Cost of cultural practices, like harvesting cost, was computed by multiplying labour hours with the hourly wage. Total labour requirement from banana production is a sum of labour required for weeding, harvesting, and cultural practices.

Gross revenue was calculated from banana bunches and other commodities. A banana yield of 20 Mg ha^{-1} yr^{-1} was used for calculations. As farmers reported the price of banana in price per bunch, bunches harvested need to be calculated. The number of bunches harvested (bunches ha^{-1} yr^{-1}) was then calculated by multiplying the average bunch harvested (bunches $tree^{-1}$ yr^{-1}) to numbers of trees (trees ha^{-1}). It was assumed that the average bunches harvested per year per tree was 2 bunches; 1000 banana trees per hectare; and bunch weight of 10 kg. Gross margin was then calculated by subtracting gross revenues from production costs.

In the following sections, detailed calculations for each strategy are outlined.

2.8.1 Fertilizer addition

Cost of applying this strategy was solely based on the cost of artificial fertilizers. A combination of fertilisers was determined to meet nutrients requirement while minimizing cost of fertilizers. Fertilizers used for this calculation were based on fertiliser formula available in retail shops in Kampala. Average prices of fertilisers were also acquired from the shops. In this calculation, DAP (18-46-0), urea (46-0-0) and potash (0-0-60) were used as the combination was the most cost-effective while fulfilling nutrients demand. Based on 50kg bag, DAP costs 140000 USh; Urea costs 100000 USh; and Potash costs 130000 USh. An amount of fertiliser required was calculated using the following formula:

$Fertilizer_{need} = Nutrient_{need} / Fertilizer_{nutrient\ conc.} \times CF$

where:

$Fertilizer_{need}$ = Amount of fertiliser (kg)
$Nutrient_{need}$ = Nutrient needed (kg N, P or K)
$Fertilizer_{nutrient\ conc.}$ = nutrient content (kg N or P_2O_5 or K_2O kg^{-1} fertilizer bag)
CF = conversion factor (kg N or P or K kg^{-1} N or P_2O_5 or K_2O respectively)

Site-specific nutrient requirements were obtained from the nutrient balance calculations. Fertiliser formula was 18%, 46%, and 0% for N, P_2O_5, and K_2O respectively for DAP. Urea chemical formula was 46% N. Lastly, potash chemical formula was 60% K_2O. Conversion factor took into account the amount of elemental P or K in the chemical formula P_2O_5 and K_2O respectively. Conversion factor was 0.44 for P/P_2O_5 and 0.83 for K/K_2O.

The cost of applying this strategy was then calculated by multiplying the calculated amount of each fertiliser formulae to its cost and then summed the costs altogether.

2.8.2 Annual crop production

Labour cost and production cost calculations for this strategy were calculated separately for maize and bean. Components of labour cost and production cost for both maize and bean were alike: establishment, weeding, harvesting, pesticide, and fertilization.

Establishment and pesticide costs were obtained from the farmers' reports, which already incorporated both labour cost and material cost. Weeding and harvesting cost were based on the reported labour requirement multiplied by the average hourly wage. Fertilization cost included two components: material cost from the report and calculated labour cost.

Labour cost was also calculated from the results of nutrient balance calculations, which were expressed as the ratio of the area under annual crop production needed to 1 ha of banana production. Therefore, labour requirements from this calculation took into account the area of annual crop production from the ratio as well as the 1 ha of banana production. Likewise, gross revenue from maize or bean was also calculated based on the area of annual crop production from the ratio. Prices of maize and bean were obtained from farmer interviews.

2.8.3 Poultry production

Cost of applying this strategy included acquisition of chicks, manure collection, imports, pesticide and vaccination, labour for feeding, concentrates, barn clearing and watering. A number of chicks bought was obtained from the nutrient balance calculation. Price of a chick was obtained from farmer interviews. Cost of manure collection was calculated from cost of management and labour cost per chicken obtained from farmer interviews multiplied by total number of chickens. Similarly, imports, pesticides, vaccination, watering, and barn clearing were calculated based on the cost per chicken basis. Labour for feeding was acquired from the interviews which was then multiplied by the average hourly wage to obtain cost of labour for feeding. The amount of concentrates was also calculated in kg feed yr^{-1} $chicken^{-1}$ based on data obtained from farmer interviews, then multiply by total numbers of chicken and cost of concentrate per kg to get the total cost of concentrate.

Apart from bananas, gross revenues also came from chicken and eggs. The quantity of chicken sold was calculated from the number of chickens survived. Egg production per year, price of egg, and price of chicken were acquired from farmer interviews.

2.8.4 Goat production with on-farm trees and shrubs

Cost of applying this strategy came from acquisition of goats, manure collection, and feeding. Cost of a goat was obtained from farmer interviews and the number of goats came from nutrient balance calculation. Manure collection and feeding was obtained from labour cost of manure collection and feeding from the interviews. Total labour hours, apart from banana production system, originated from manure collection and feeding.

Gross revenue was calculated from banana and goat. It was assumed that goats were raised for one and a half year before selling, thus for each year, the revenue gain from selling goats can be obtained by dividing the result by 1.5.

2.9 Sensitivity Analysis

Sensitivity analysis was performed to determine sensitivity of factors used in the nutrient balance calculation for the four scenarios. Input factors for each scenario were increased by 50% and decreased by 50% to see the degree of influence they have on the output factor in their respective scenarios. In the fertilizer addition scenario, an analysis was performed with nutrient balance as the output. Input factors were soil erosion, banana nutrient concentration, clay percentage and the amount of rainfall. In annual crop production scenario, area required for cultivating maize was taken as the output while crop residue K%, harvest index, removal factor, and yield were considered input factors. In the case of poultry production, average weight of chicken, chick mortality, manure K% and the amount of manure production by chicken were tested as inputs against no. of chicken required as the output. Sensitivity analysis was also performed for goat and on-farm biomass scenario, *Calliandra* was used as the choice of shrub. Input factors include DM yield of shrub, K% of shrub, number of goats, dry matter intake percentage, average weight of goat during a lifetime, goat manure production, and manure N and P concentration. The output used was area required for growing *Calliandra* to meet the amount of feed and mulch requirements.

3. Results

3.1 Technical parameters

Between 34 and 36 samples were analysed for each site. Several plots from farmer's experiments were omitted from this study due to inconsistencies in nutrient management routines (Table 2). It was evident that soils from Kiboga and Sembabule had relatively higher nutrient and organic matter contents than those from Nakaseke. However, Nakaseke soils had the second highest level of potassium. According to FAO (2004), Ferric Acrisol soil which is prevalent in Central Uganda has approximately 30% clay.

Table 2. Soil chemical properties from central Uganda.

Property	Nakaseke	Kiboga	Sembabule
No of samples	36	34	34
pH	6.1 (0.4)	6.4 (0.4)	6.6 (0.6)
OM (%)	4.6 (0.7)	7.1 (1.5)	5.5 (1.2)
N (%)	0.22 (0.03)	0.32 (0.06)	0.26 (0.05)
P (ppm)	17.9 (14.7)	27.8 (33.7)	42.7 (60.4)
K (ppm)	103.8 (62.0)	159.2 (94.9)	90.1 (64.1)
Ca (ppm)	2205 (620)	3069 (1075)	3165 (1639)
Mg (ppm)	715 (162)	1092 (253)	989 (289)

Figures in parentheses are Standard Deviation

Data on chicken manures and goat manures were obtained from both laboratory analyses and FAO (2004) for comparison (Table 3). Nutrient concentrations of manures from laboratory analyses were lower than the data from FAO, 2004; except the percentage of nitrogen in goat manures which was almost twice in comparison, 1.36% and 0.76% for laboratory analysis and FAO, 2004 respectively. Nitrogen was at 1.08% for chicken manure from FAO and 1.02% from laboratory analysis. A vast difference of percentage of phosphorus was evident in different data sources of chicken manures. 0.39% P was obtained from FAO and 0.07% from lab analysis. Similarly, the difference between potassium data was approximately seven-fold with 0.35% K for FAO and 0.05% K for lab analysis.

Table 3. Animal manures and chicken feed nutrient contents

Type	Quantity (kg head^{-1} yr^{-1})	Nutrient concentration (%)			Source
		N	P	K	
Chicken manure	19.0*	1.08	0.39	0.35	FAO, 2004
		1.02	0.07	0.05	Lab analysis
Goat manure	520.0*	0.76	0.15	0.67	FAO, 2004
		1.36	0.06	0.06	Lab analysis
Chicken feed	40.4*	2.38	0.76	1.33	Lab analysis

* Data derived from farm interviews.

Approximately 19.04 kg of chicken manure is produced per chicken per year. The amount was calculated based on a farmers' survey on manure production, 17.2 kg of manure kg weight^{-1} yr^{-1}, and the assumptions that an average weight of chicken throughout a growing cycle is 1110 kg and chickens are sold after one year of growth.

The data from FAO showed higher potassium and phosphorus contents compared to the lab analysis; P at 0.15% and 0.06% respectively; K at 0.67% and 0.06% respectively. Farmers reported that a goat produced approximately 1 basin of manure each week; a basin weighs 10 kg on average. Total manure production of a goat was estimated at 520.00 kg per year. Average weight of goat during a growing cycle was estimated at 40 kg; and dry matter intake per body weight basis is 3% per day.

Approximately, 40.4 kg feed is required for one chicken each year. The data was based from 0.11 kg of feed kg weight^{-1} yr^{-1} and the average weight of a chicken during a growing cycle. Chicken feed, on average, had 2.38% N, 0.76% P and 1.33% K.

Table 4. Nutrient concentration and amount produced by on-farm trees and shrubs.

Species	DM yield (Mg ha^{-1} yr^{-1})*	Nutrient concentration (% DW)			Plant spacing (m^2)
		N	P	K	
Tithonia	3	4.38	0.16	11.95	1
Sesbania	8	4.97	0.12	3.54	1
Calliandra	8.5	5.13	0.15	6.48	1
Leucaena	6.5	2.87	0.09	0.24	1
Erythrina	15	4.12	0.15	1.34	4
Gliricidia	10.5	3.21	0.11	8.57	1
Morus	23	4.03	0.15	5.57	1
Ficus	8.8	1.44	0.07	3.39	25
Mangifera	44.4	0.99	0.08	n/a	36
Persea	44.4	4.08	0.15	5.51	36
Artocarpus	41.7	3.91	0.13	7.08	36

* Production of leaves and twigs based on the number of full-grown plants in a hectare calculated using above plant spacing.

Nutrient concentration, dry matter yield (DM), and plant spacing were analysed and collected for each species of trees and shrubs presented on the farms (Table 4). Most of trees and shrubs' nitrogen concentration falls within a range of 3-4% except *Calliandra*, *Leucaena*, *Mangifera* and *Ficus*. Highest nitrogen concentration was presented in *Calliandra* and lowest in *Mangifera*. Phosphorus concentration ranges from 0.08% in *Mangifera* to 0.16% in *Tithonia*. Tithonia also showed the highest concentration of potassium at 11.95 % dry weight (DW); while *Leucaena* showed the lowest at 0.24% DW. In term of dry matter yield, fruit trees: *Mangifera, Persea*, *Artocarpus*, showed the highest production at 41.7 - 44.4 Mg per hectare. *Ficus* which were presented on farms both as shrubs and trees produced approximately 8.8 Mg per hectare. Other species were present primarily as shrubs and their yield ranges from 3 to 23 Mg per hectare.

3.2 Yield response to soil parameters

A mixed model multiple regression analysis showed 63.2% correlation between the fitted line to the observed data points on yield (Table 5). A full analysis is available in Appendix D. The mulch and manure treatment resulted in a significantly higher yield and explained that largest proportion of variance (43.4%; $p < 0.001$). Other factors, N content, P content, K content, district, and interaction between N content and district, had comparable effects ranging from 2.5% to 4.9%

Table 5 Explanation of yield to nutrient concentration model's R^2

Soil N content	4.7%
Soil P content	2.5%
Soil K content	3.7%
District	3.9%
Treatment	43.4%
Ncontent:District	4.9%
Residual	
Total	63.2%

Yield response to N content, K content, and the interaction between N content and district were significant at $p < 0.005$. P content and district effects on yield were also significant at $p < 0.05$. The effect of N content of the soil was strongest in Nakaseke, followed by Sembabule and was negative in Kiboga. Figure 2 shows the graphical representation of yield response to N, P and K. As a whole, mulch and manure treatments resulted in higher yields with every nutrient parameter. From the analysis, the following yield response equations were established (Table 6).

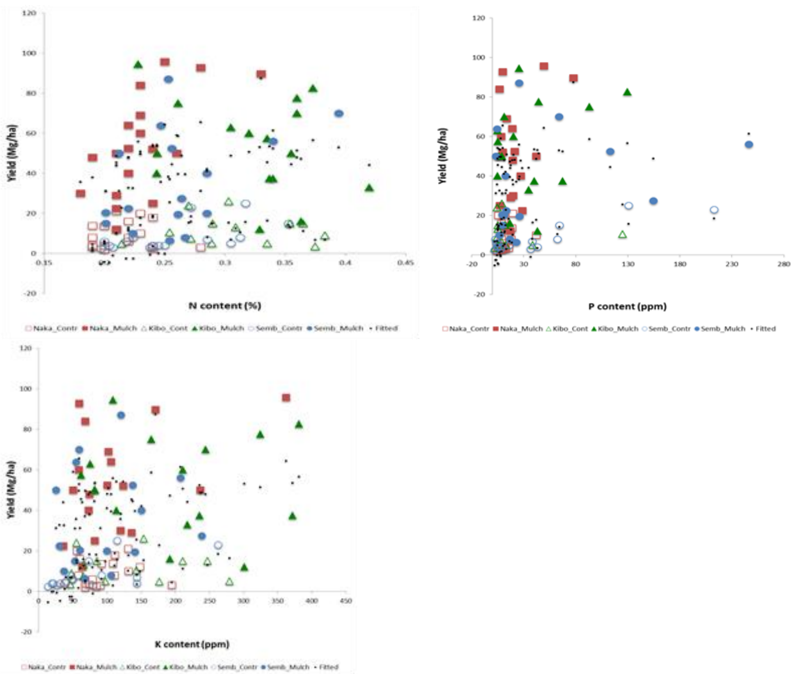


Fig. 2 Yield response to soil nutrient parameters N, P and K. Rectangles represent Nakaseke soil; Triangles represent Kiboga soils; and circles represent Sembabule soils. Filled symbols represent mulch and manure treatments and opened symbols show control treatments. Black dots are the fitted values.

Table 6. Yield response equations

	With manure and mulch	Without manure and mulch
Kiboga	Y=69.8–76.1*N+0.057*P+0.020*K	Y=34.6–76.1*N+0.057*P+0.020*K
Nakaseke	Y=-24.9+317*N+0.057*P+0.020*K	Y=-60.1+317*N+0.057*P+0.020*K
Sembabule	Y=9.87+98.3*N+0.057*P+0.020*K	Y=-25.3+98.3*N+0.057*P+0.020*K

Phosphorus and potassium generated the same yield response for all three sites, 0.057 Mg ha^{-1} yr^{-1} ppm^{-1} and 0.020 Mg ha^{-1} yr^{-1} ppm^{-1} respectively. Yield response to nitrogen was negative in Kiboga at -76.1 Mg ha^{-1} yr^{-1} per g N g^{-1} soil and positive for Nakaseke and Sembabule at 317 Mg ha^{-1} yr^{-1} per g N g^{-1} soil and 98.3 Mg ha^{-1} yr^{-1} per g N g^{-1} soil respectively. Y-intercepts were negative in Sembabule in without manure and mulch treatment and in Nakaseke in both with and without mulch and manure treatments. Kiboga had the highest Y-intercepts in both with and without manure and mulch treatments, 69.8 and 34.6 respectively; while Nakaseke had the lowest intercepts in with and without manure and mulch treatments, -24.9 and -60.1 respectively. In Sembabule, intercept was negative in with mulch and manure treatment at -25.3 and positive in without mulch and manure treatment at 9.87.

3.3 Nutrient balance calculation of no off-farm input system

Nutrient balance of no off-farm input system was calculated based on the attained yield derived from the control plot treatment, approximately 10 Mg ha^{-1}. Table 7 shows the nutrient balance calculation in detail.

Table 7 Nutrient balance of no-off farm input system in three sites across central Uganda

Location	Nutrient	Input			Output					Balance
		ANF	BNF	DEP	FER	HAR	LEA	DEN	ERO	
Nakaseke	N	0	0	3.6	0	26	0	0	12	-34.4
	P	0	0	0.6	0	1	0	0	0.1	-0.5
	K	0	0	2.3	0	90	0	0	0.7	-88.4
Kiboga	N	0.7	0	4.6	0	26	0.1	0	17.1	-37.9
	P	0	0	0.8	0	1	0	0	0.2	-0.4
	K	0	0	3.0	0	90	0	0	1.2	-88.2
Sembabule	N	0.5	0	4.5	0	26	0.1	0	14.4	-35.5
	P	0	0	0.7	0	1	0	0	0.3	-0.5
	K	0	0	3.0	0	90	0	0	0.7	-87.7

ANF, BNF, DEP, FER, HAR, LEA, DEN and ERO represent nutrient flows from asymbiotic nitrogen fixation, biological nitrogen fixation, deposition, fertilizer, harvested product, leaching, denitrification and erosion respectively.

The result showed that nitrogen is depleted by 34.4-37.9 kg ha^{-1} yr^{-1}; phosphorus is depleted by 0.4-0.5 kg ha^{-1} yr^{-1}; and lastly potassium 87.7-88.4 kg ha^{-1} yr^{-1} in a no off-farm input system. Two major outflows of nutrients are harvested products and erosion. 26 kg of nitrogen, 1 kg of phosphorus and 90 kg of potassium are taken away in the form of harvested banana bunches. Erosion also showed a relatively big loss of nutrient with nitrogen loss ranging from 12-17.1 kg ha^{-1} yr^{-1}; phosphorus loss from 0.1-0.3 kg ha^{-1} yr^{-1} and potassium loss at 0.7-1.2 kg ha^{-1} yr^{-1}. Deposition is the only major inflow of nutrient in the no off-farm input system with N added ranging from 3.6-4.5 kg ha^{-1} yr^{-1}; P added ranging from 0.6-0.7 kg ha^{-1} yr^{-1}; K added ranging from 2.3-3.0 kg ha^{-1} yr^{-1}.

3.4 Four alternative strategies

3.4.1 Fertiliser addition

In scenario 1, mineral fertiliser requirements are shown in Table 8. To achieve nutrient balance, 2 kg of P and 180 kg of K are needed for all three sites. Amounts of nitrogen required for each site are slightly different, ranging from 70 kg in Nakaseke, 80 kg in Sembabule and 85 kg in Kiboga. To achieve a yield of 20 Mg ha^{-1} based on fertiliser response by Nyombi et al. (2010), much higher nutrients concentration, N and K, are required. Phosphorus additions are not needed to achieve 20 Mg ha^{-1}.

Table 8. Mineral fertilizer requirements to achieve fertiliser response or nutrient balance based on scenario 1.

	Fertiliser response			Nutrient balance		
	N (kg)	P (kg)	K (kg)	N (kg)	P (kg)	K (kg)
Nakaseke	710	0	533	70	2	180
Kiboga	653	0	456	85	2	180
Sembabule	654	0	540	80	2	180

3.4.2 Annual crop production

In the case of scenario 2, results are expressed in an amount of land needed for maize or bean cultivation to fulfil nutrient requirement for 1 hectare of banana with a yield of 20 Mg ha^{-1}. The outcome is presented in Table 9.

Table 9. Ratio of land needed of banana trees to annual crops production to satisfy nutrient requirement based on the fertiliser response or nutrient balance based on scenario 2.

		Maize	Bean
Nakaseke	Fertiliser response	1:10	1:32
	Nutrient balance	1:1.5	1:8.1
Kiboga	Fertiliser response	1:8.9	1:30
	Nutrient balance	1:1.5	1:8.1
Sembabule	Fertiliser response	1:9.4	1:30
	Nutrient balance	1:1.5	1:8.1

In all three sites, maize production requires less land compared to bean production. Only 1.5 ha is needed to produce sufficient maize stover to balance out nutrient outflows from banana production, whereas 8.1 ha is required for bean. Similarly, to achieve fertiliser response, 8.9 ha to 10 ha of maize production is needed; while 30 ha to 32 ha of bean is needed. The calculation was based on the land required to satisfy the most limiting nutrient in banana farming system and in this case it is potassium. Thus, maize stover having relatively high potassium compared to bean trash required less amount of lands (Table 10). In the case of achieving nutrient balance using bean trash, approximately 110 kg of N excess is shown.

Table 10. Nutrient concentration of maize stover and bean trash.

	Nutrient Concentration (%)		
	N	P	K
Maize stover	1.21	0.07	2.02
Bean trash	0.8	0.12	0.8

3.4.3 Poultry production

The third scenario with poultry production showed that a considerable amount of chickens are essential to produce enough manure for a banana cropping system. From a calculation, in order to account for the losses of nutrient from banana cropping systems, 2842 chickens need to be bought and approximately 341 kg of feed is required each day. The same amount of chickens and feeds are required for all three sites since potassium deficit, being the most limiting nutrient, is the same for every site. To achieve the fertiliser response, on the other hand, required different amount of chickens and subsequently feed (Table 11).

Table 11 Chicken and feed required to achieve fertiliser response for each site.

Site	No. of chickens	Feed (kg day^{-1})
Nakaseke	8591	1031
Kiboga	7202	864
Sembabule	8528	1023

3.4.4 Goat production and on-farm trees and shrubs

In this scenario, calculations were based on 3 points of views: goats only, biomass for mulch only, and combination of goats and mulch. Laboratory results for nutrient parameters used in this calculation are presented in Table 3 and 4.

In the first case, goats being the primary nutrient supplier, when calculated based on FAO's goat manure nutrient concentration, 52 goats are needed to offset nutrient output for each and every sites (Table 12). In contrast, 541 goats are required when calculated from our goat manure laboratory result. Numbers of goats needed to satisfy N and P requirements are lower than to satisfy K. Using FAO's data, to balance out nitrogen outflow, 18-22 heads is required. P, on the other hand, only required 3 heads. Similarly, with the use of our own manure concentration, N requirement is satisfied with 10-12 heads and P with 7 heads.

Table 12. Number of goats required when goats being the only nutrient supplier.

To fulfil nutrient req.	Nakaseke		Kiboga		Sembabule	
	Experiment	FAO	Experiment	FAO	Experiment	FAO
N	10	18	12	22	11	20
P	7	3	7	3	7	3
K	541	52	541	52	541	52

In the second case, mulch being used as the primary nutrient supplier, land requirements were calculated based on the amount biomass production from trees and shrubs, which coincided with N, P and K requirements. The result showed that *Morus spp*. required the least amount of land compared to other trees and shrubs. To balance out nutrient outflow, 3.2 Mg of dry matter production is required for each and every sites. This amount of biomass can be produced from 0.14 ha of *Morus spp*. The amount of biomass needs varies from 1.6 Mg, with the use of *Tithonia* in Nakaseke to 73.7 Mg with *Leucaena* in Nakaseke, Kiboga and Sembabule (Table 13).

Table 13. Mulch and land requirements as the sole nutrient supplier

	Site	Biomass requirement based on nutrient prerequisite (Mg)			Area required (ha)
		N	P	K	
Tithonia	Nakaseke	**1.59**	1.22	1.50	0.53
	Kiboga	**1.94**	1.22	1.50	0.64
	Sembabule	**1.82**	1.22	1.50	0.60
Sesbania	Nakaseke	1.40	1.60	**5.07**	0.63
	Kiboga	1.71	1.60	**5.07**	0.63
	Sembabule	1.60	1.60	**5.07**	0.63
Calliandra	Nakaseke	1.36	1.29	**2.77**	0.32
	Kiboga	1.65	1.29	**2.77**	0.32
	Sembabule	1.56	1.29	**2.77**	0.32
Leucaena	Nakaseke	2.43	2.31	**73.74**	11.34
	Kiboga	2.95	2.31	**73.74**	11.34
	Sembabule	2.78	2.31	**73.74**	11.34
Ficus	Nakaseke	4.84	2.82	**5.30**	0.60
	Kiboga	**5.88**	2.82	5.30	0.60
	Sembabule	**5.53**	2.82	5.30	0.60
Morus	Nakaseke	1.73	1.34	**3.23**	0.14
	Kiboga	2.10	1.34	**3.23**	0.14
	Sembabule	1.98	1.34	**3.23**	0.14
Erythrina	Nakaseke	1.69	1.36	**13.39**	0.89
	Kiboga	2.06	1.36	**13.39**	0.89
	Sembabule	1.94	1.36	**13.39**	0.89
Gliricidia	Nakaseke	**2.18**	1.77	2.10	0.20
	Kiboga	**2.64**	1.77	2.10	0.25
	Sembabule	**2.49**	1.77	2.10	0.23

In the last case, the average number of goats and on-farm fruit trees are taken into account before calculating the amount of mulching need from on-farm trees and shrubs. On average, there are 4 goats per farm, which consume 1752 kg of feed. These goats produce approximately 2080 kg manure. This amount is larger than the amount of feed because manure collected is usually contaminated with soil particles and left over feed. This amount of manure gives off 28.3 kg N, 1.2 kg P, 1.3 kg K based on our lab samples;

15.8 kg N, 3.1 kg P, 13.9 kg K based on FAO's data. In term of fruit trees, on average, there are 1.5 ficus trees, 1.2 mango trees, 0.7 avocado trees and 1.8 jackfruit trees in one hectare. The sum of biomass produced by all of these trees is 616.7 kg yr^{-1} which equals 17.8 kg N, 0.7 kg P and 26.9 kg K. Approximately 173.5 m^2 is occupied by these trees in one hectare of farm land. In this scenario, we assume that biomass produced from fruit trees is only used for mulching for simplification. The amount of feed required for 4 goats, 1752 kg, can be achieved by having either 0.584 kg of *Tithonia*, 0.219 ha of *Sesbania*, 0.206 ha of *Calliandra*, 0.270 ha of *Leucaena*, 0.199 ha of *Ficus*, 0.076 of *Morus*, 0.117 ha of *Erythrina*, or 0.167 ha of *Gliricidia*. When the amount of nutrient obtained from mulching and goat manure is subtracted from the nutrient required for offsetting nutrient outflow, we can calculate an amount of land dedicated for growing on-farm trees and shrubs for a mulching purpose. The result is displayed in Table 14.

Table 14. Land needed for growing trees and shrubs for mulching (ha)

	Lab result	FAO
Tithonia	0.42	0.38
Sesbania	0.53	0.49
Calliandra	0.27	0.25
Leucaena	9.56	8.77
Ficus	0.50	0.46
Morus	0.11	0.10
Erythrina	0.75	0.69
Gliricidia	0.16	0.15

After the amount of land needed for growing shrubs for mulching is determined, the total area dedicated to growing trees and shrubs can be calculated by adding land needed for mulching to land needed for goat consumption. The result is presented in Table 15.

Table 15. Total land required for growing trees and shrubs (ha)

	Lab result	FAO
Tithonia	1.00	0.97
Sesbania	0.75	0.71
Calliandra	0.48	0.45
Leucaena	9.83	9.04
Ficus	0.70	0.66
Morus	0.19	0.18
Erythrina	0.86	0.80
Gliricidia	0.33	0.32

3.5 Labour and economic comparison between the proposed alternatives

Farmers reported that on average a banana sucker costs 1500 USh. Cost of labour for digging a hole during an establishment phase is 500 USh. Labour cost for other activities during the establishment phase except hole digging is 1614585 USh ha^{-1}. This results in the total of 3614585 USh for establishment of banana trees in 1 ha with 1000 trees.

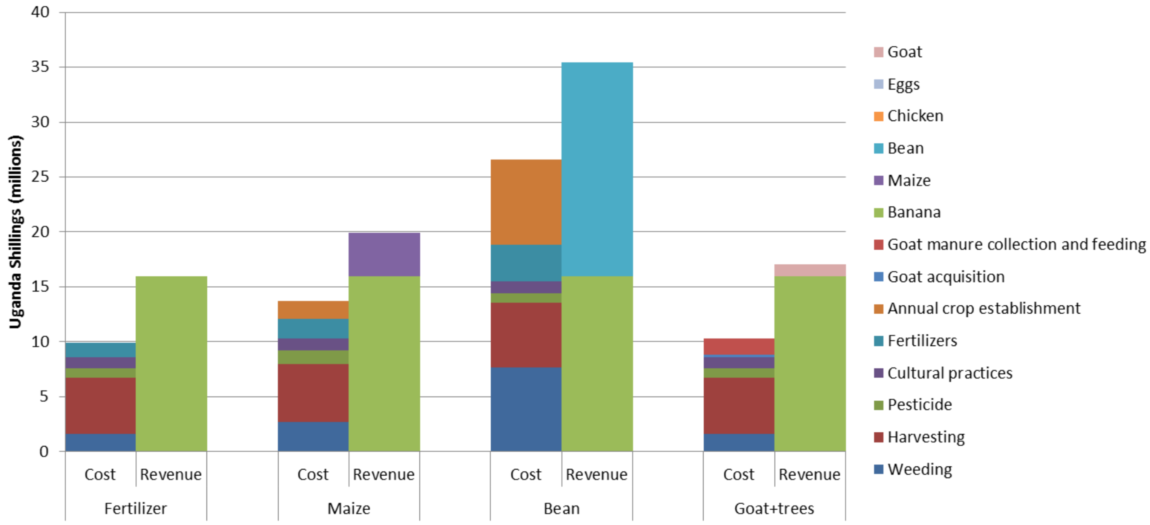


Fig. 3 Revenues and cost for each alternatives based on nutrient balance; poultry production not included due to off-scaled chart.

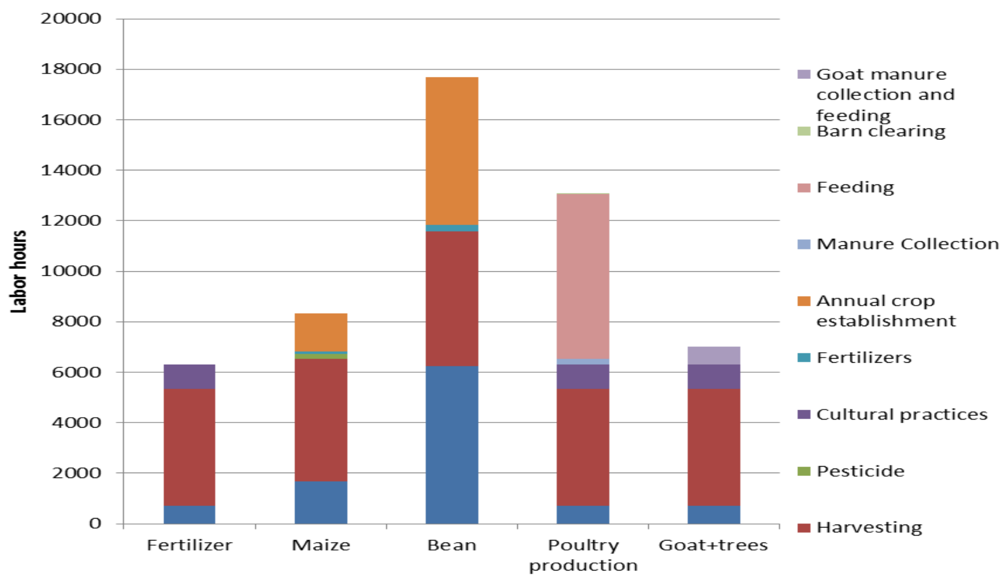


Fig. 4 Labour requirements for each alternatives based on nutrient balance.

Weeding costs 1625349 USh ha^{-1} yr^{-1} and requires 726.6 hours of labour yr^{-1}. Harvesting demands 4614.4 hr ha^{-1} yr^{-1} which sums up to 5078004 USh yr^{-1}. Pesticide application was highly inconsistent from farm to farm. An average of 863803 USh yr^{-1} was estimated. Practices such as de-suckering, pruning, moving residues, deflowering, removing female hands, propping and staking are taken into account as cultural practices. It was estimated that 968.8 hours of labour is needed for cultural practices which results in 1065626 USh yr^{-1}. The price of a banana bunch is 8000 USh on average. A gross revenue from selling 20 Mg of banana is then calculated to be 16000000 USh. The following sections present the summary of costs, revenues, margins, and labour requirements for each scenario. Fig. 3 illustrates the overview of costs and revenues for each scenario excluding poultry production. Fig 4. Shows the amount of labour required to carry out each scenario.

3.5.1 Fertiliser addition

A fertiliser addition was calculated based on nutrients needed to balance out the nutrient outflows from each site. In Nakaseke, 70 kg N, 2 kg P and 180 kg K are needed to balance out nutrient out flows each year. This translates to 9.9 kg DAP, 148.3 kg Urea and 361.4 k Potash. The total cost of production is 9896823.91 USh. Similarly, in Kiboga with 85 kg N, 2 kg P and 180 kg K requirements, 9.9 kg DAP, 180.9 kg Urea and 361.4 k Potash are required which costs 9962041.30 USh in total. Fertiliser requirements in Sembabule are 80 kg N, 2 kg P, and 180 kg K which needs 9.9 kg DAP, 170.0 kg Urea and 361.4 kg potash. The total cost for production in Sembabule is 9940302.02 USh. The fertilizers cost represents 13% of the total cost for all three sites. 51% of the total cost comes from harvesting and 16% from weeding, 10% from cultural practices and 9% from pesticide application.

For this scenario, a gross margin of 6103176.09, 6037958.70, and 6059697.83 USh per year can be obtained in Nakaseke, Kiboga and Sembabule respectively. The total hour of labour required is 6311.7 hours: 73% from harvesting bananas, 15% from cultural practices, and 12% from weeding.

3.5.2 Annual crop production

In an annual crop production integrated with a banana cropping system, either maize or bean is chosen as the annual crop. The following labour and economic analysis examines each system separately.

For maize crops, the total cost of production system is 13729449 USh yr^{-1}: 37% comes from banana harvesting, 13% from fertilization of maize crops, 12% each from weeding in the banana system and establishment of maize field, 8% each from weeding in the maize system and cultural practices in the banana cropping system, and lastly 6% from pesticide application in the banana cropping system. Total revenue gained from this system is 19900000: 80% from banana and 20% from maize. This results in a gross margin of 6170551 USh yr^{-1}. The total labour required is 9290.5 hours: 50% from harvesting bananas, 16% from the establishment of maize, 10% each for cultural practices of the banana system and weeding in maize, and 8% from weeding in the banana cropping system. In this scenario, the total of 2.5 ha of land is expected: 1 ha of banana and 1.5 ha of maize.

On the other hand, approximately 26566179 USh yr^{-1} is estimated for the total production cost of bean: 29% from the establishment of bean, 23% from weeding in the bean system, 19% from harvesting bananas, 13% from fertilization of bean, and 6% from weeding in the banana system. The total labour requirement is 18656 hours, 31% of which comes from bean establishment, 30% from weeding in bean, 24% from harvesting bananas. Gross revenue obtained from this scenario is 35440000 USh yr^{-1} : 55% from bean and 45% from banana. Gross margin is 8873821 USh yr^{-1}. The total land required is 9.1 ha: 1ha of banana and 8.1 ha of bean.

3.5.3 Poultry production

The total cost of a banana and poultry production system is 168466717 USh yr^{-1}. 81% of the total cost originates from chicken concentrates for feeding, 4% each for chicken acquisition and labour for feeding, and 3% each for harvesting banana and labour for collecting water for poultry. Gross revenue obtained from this scenario is 418570000 USh: 80% from eggs, 16% chicken, and 4% banana. The scenario results in 250103283 USh yr^{-1}. The total labour hours required is 13091 hours: 50% from feeding and 35% from harvesting bananas.

3.5.4 Goat production and on-farm trees and shrubs

The total cost of a goat and on-farm trees and shrubs system is 10113226 USh yr^{-1}. 15% of the total cost comes from the goat production, manure collection and feeding. 85% of the total cost arises from the banana cropping system: 50% from harvesting, 16% weeding, 10% cultural practices and 9% pesticide application. Gross revenue obtained from this scenario is 17066667 USh yr^{-1}: 94% from bananas and 6 % from goats. Gross margin is 6953440 USh yr^{-1}. The total labour needed is 7022.7 hours: 66% from harvesting bananas, 14% from cultural practices, 10% from weeding, and 10% from manure collecting and feeding.

3.6 Sensitivity Analysis

Sensitivity analysis results demonstrated that several factors had more impact on the outcome than the others (Appendix E). In the fertilizer addition scenario (Appendix E(a)), nutrient concentration of banana had an enormous impact on the nutrient balance especially with N and K compared to other factors. Clay percentage and rainfall did not have substantial impacts on nutrient balance in this study. Soil erosion had a greater influence than clay and rainfall; however, it was relatively insignificant compared to nutrient concentration of banana. In the case of the sensitivity analysis for annual crop production scenario (Appendix E(b)), all factors except harvest index showed that the effect they had on the output were the same. If they were reduced by half, the amount of land required for annual crop production will increase about twice. Harvest index had a relatively greater impact when it was decreased by 50% while it had a lesser impact when it was increased by 50%. For poultry production (Appendix E(c)), average weight of chicken, manure K% and manure production had a considerable impact on no. of chicken required in the same magnitude: twice of the amount of chicken required when these factors were reduced by half. Chicken mortality, on the other hand, did not have a great impact on the outcome. In the case of goat and on-farm biomass scenario (Appendix E(d)), land required was most sensitive to DM yield of *Calliandra*. This is followed by K% of *Calliandra*. Land requirement was not strongly responsive to the change in the number of goats, dry matter intake and average weight of goats. Goat manure production and nutrient concentration had almost insignificant impact on the outcome.

Discussion

4.1 The nutrient balance calculation

Nutrient balance, economic and labour calculations enabled us to gauge the possibility of adopting alternative nutrient management strategies by estimating nutrient, economic and labour parameters in an integrated banana production system. Several technical, economic, and labour parameters which were not available elsewhere were successfully identified and quantified. Our data revealed that some parameters played more significant roles in determining the practicality and adoptability of a strategy. Our findings demonstrated that specific alternatives were more practical than the others in terms of nutrient availability and balanced nutrient supplement as well as the labour and capital requirements.

In a typical no off-farm input system, the nutrient balance calculation showed that two highest nutrient exports came from harvested products and soil erosion. This result is consistent with the result obtained by in nutrient balance calculation by Wortmann and Kaizzi (1998). On the other hand, Baijukya and de Steenhuijsen Piters (1998) reported that denitrification and leaching were also major sources of nutrient loss in an annual cropping system in Tanzania. However, in the banana cropping system, soils were seldom tilled and nutrients were rarely added to the system, these losses possibly played a less significant role in nutrient exports. Without mineral fertilizers or organic amendments, atmospheric deposition was exclusively responsible for nutrient addition to the system which also agreed with findings from Wortmann and Kaizzi (1998). It is important to note that farmers applied banana stalks and leaves to the banana mats; however, these residues only helped preserve nutrients within the system but they do not contribute to an improvement of soil nutrient stock nor soil water conservation (Stover and Simmonds 1987).

Banana fertiliser response used in this study displayed a very high nutrients demand in order to reach a specific yield. This is a result of low fertiliser recovery rate which could possibly be attributed to a lack of water to facilitate transport of nutrients (Radersma et al. 2005) or a physiological problem in banana roots such as a damage caused by nematodes (Speijer and Kajumba 2000). As a comparison, nitrogen recovery rate from inorganic fertilizers is approximately 30-50% in tropical cropping systems (Baligar and Bennet 1986; Prasad and de Datta 1979). In our experiment, the nitrogen recovery rate used was 9.5%.

Two major nutrients, N and K are exported in large amount through harvested products. 26 kg N and 90 kg K are depleted from the soil with every 10 Mg ha^{-1} yield of banana. This export of products is the major factor influencing nutrient requirements. According to nutrient balance calculation, a ratio of 1 N: 2.1-2.5 K is the most desirable ratio in fertilizers for offsetting nutrients losses. Likewise, a ratio of 1.2-1.4 N: 1 K is the most suitable for achieving the fertiliser response. In order to reduce excess nutrients losses from decomposition of organic materials, it is crucial to supply nutrients in the form of organic amendments, which have the desired nutrient ratio.

4.2 Yield response to soil nutrient parameters

Multiple regression analysis enabled us to examine to what extent soil and treatment factors influenced yield. Treatment explained the largest proportion of variance with mulch and manure treatment having higher yield than control treatment. The underlying factors which caused a yield improvement in the mulch and manure treatments could perhaps be the improvement in nutrient status of the soil as a result of nutrient release from mulches. An increase in macro fauna activities could improve soil physical and chemical properties and subsequently, caused root proliferation which strengthened the growth and development of banana trees (Okwakol and Kagole 1993) (Swennen 1990). An increase in soil moisture and a greater water use efficiency in the upper 0 - 0.3 m where banana roots inhibited could also contributed to higher yield as mulches increased water infiltration and reduce evaporation and run-off (McIntyre et al. 2000; Ssali et al. 2003). Additionally, mulches are also expected to reduce soil erosion, to decrease weed proliferation, and to increase soil organic matter content (Mitchell 1988). These factors contributed to higher yields; however, it was not possible to pinpoint exactly how much each factor contributed in this experiment.

Several researchers have found that the two most important factors affecting yield were low soil fertility (Okumu et al. 2011; Wairegi and van Asten 2010) and drought stress (van Asten et al. 2011). It could possibly be inferred from our yield response regression that nutrient availability was the major limiting factor as the majority of the variance could be explained from nutrients levels, nutrient-site interaction and treatment effect. However, it was striking that site effect only explained 3.9% of the variance. Site factors possibly included soil texture, topography, land use history, temperature and rainfall. Rainfall being the most variable among the three sites, 651 mm in Nakaseke and 1043 mm, and 1096 mm for Sembabule and Kiboga respectively, it was expected that site effect would be relatively high. In contrast, in another experiment, it was found that when annual rainfall is below 1100 mm, 20-65% yield losses can be expected (van Asten et al. 2011). It could be possible that other factors such as soil texture or mycorrhizal association may have lessened the negative impact of low water availability.

The gap of r^2 value for the observed and expected yield relationship showed that there are some other factors that we have not yet taken into account. It was observed that the reported number of bunches harvested and bunch weights were highly variable. Many studies have noted problems associating with farmer estimates (Bekunda and Woomer 1996; Bagamba 2007). Moreover, factors such as pest and diseases could also contributed to the missing r^2 value as pest and diseases are also considered major yield-limiting factors in Central Uganda (Wairegi et al. 2010).

Yield response equation displayed significant correlations between soil nutrients and yield. Soil samples can be analysed in a laboratory and nutrient parameters can then be substituted into the equation to get the expected yield. However, it is vital to determine whether yield estimates are within the acceptable range. Several farmers in the experiment reported yield as high as 95.7 Mg ha^{-1} in mulch and manure treatment which was exceedingly high compared to the potential yield reported by (Van Asten et al. 2005) at 70 Mg ha^{-1}. However, (Nyombi et al. 2010) reported the simulated potential yields of 100 Mg ha^{-1} for Uganda. A major limitation for this equation also lies in the fact that for a specific yield, it is possible to have one nutrient less or more as long as the other nutrients compensate for the loss or gain. Therefore, a judicious use of the equation is imperative.

4.3 Four nutrient management alternatives

Inorganic fertilizer addition alternative displayed the least labour requirement and also the smallest margin compared to the other scenarios. van Asten et al. (2010) reported similar findings with fertilizer application required less labour than other soil fertility practices such as organic material corporation. The advantage of the use of fertilizer is that the exact amount can be applied in a given time thus synchronizing nutrient supply to nutrient demand by banana trees. Despite myriad benefits of fertilizer application, several factors limited the adoption of fertilizers in Uganda such as high prices (Omamo 2002) inadequate and irregular supply of fertilizers, perceived high labour requirement, perceived negative effects from fertilizer use (van Asten et al. 2010) and high variability in site-specific nutrient requirements (Wairegi and van Asten 2010). With fertilizer's high price, it is important to adjust fertilizer recommendation based on nutrient deficiencies in order to get investment return (Wairegi and van Asten 2010). The amount of fertilizer recommended to offset nutrient losses annually in this study is different compared with a blanket recommendation of 132 kg N ha, 12 kg P ha, 60 kg K ha in banana cropping systems as suggested by a USAID-funded agricultural productivity enhancement program (APEP). In our study, half amount of N and triple amount of K compared to the recommendation were required for banana cropping systems producing 20 Mg ha^{-1} yr^{-1}. In term of practicality, fertilizer adoption is recommended for farmers who have a labour constraint and live close (<150 km) to large urban markets (van Asten et al. 2010) which in our study are those who live in Nakaseke and Kiboga.

Application of annual crop residues as mulches on banana plots has been proven to be very profitable especially with maize stover (Bananuka et al. 2000; Zake et al. 2000). Application of mulch tackles the root causes of yield decline which are nutrients (Wairegi and van Asten 2010) and water availability (McIntyre et al. 2000). However, the downfall of this strategy is that a significant amount of land is required: with bean requiring about six times more land than maize due to the lower biomass (residue) production. Another problem is that labour requirements also follows amount of land cultivated: with more land, more labour is needed. Our finding showed that in bean + banana system, about twice the amount of labour is required compared to maize + banana system. From our study, maize stover is considered to be a good source of mulches for banana due to its high potassium to nitrogen ratio at 1.67:1 . On the other hand, bean residues had the same amount of N and K with a ratio of 1:1. In term of water conservation, it was found that bean residues decompose readily leaving only stems on the plots which noticeably did not help conserve soil moisture (Bananuka et al. 2000). Application of mulches come with many benefits; however, it is important to be cautious of nitrogen immobilization by microbes as a result of a high C:N ratio of organic material as it was found in an experiment that treatments receiving organic materials had low foliar N (Ssali et al. 2003). Trade-offs exist between choosing bean or maize as an annual crop residues. Land and labour requirements as well as nutrient contents and nutrient release pattern are some of the factors need to be considered. It was expected that beans would be a better option owing to its ability to fix nitrogen; however, due to its unbalanced nutrient contents and sub-optimal nutrient release pattern, bean residues are considered to be inferior as a mulch for banana compared to maize stover (Zake et al. 2000).

It was found in our study that poultry production as a nutrient management alternative has a very high capital and labour demand. Due to its low level of nutrients availability, manure is generally considered insufficient as a single source of nutrient supply (Wortmann and Kaizzi 1998). In addition, chicken manure showed a relatively low potassium to nitrogen ratio at 0.05-0.32 K : 1 N (Palm et al. 1997). As a result of these two limitations, a substantial amount of chickens was needed to produce enough manure to fulfil nutrient requirements for banana cropping system. This led to a shift from banana production system to a more animal production system with only 4% of the total revenue coming from the sale of bananas. Additionally, it was apparent from our survey with farmers that chicken feed quality was not consistent throughout the years. This change in feed quality negatively affected the consistency of nutrients content in chicken manure, which subsequently could result in oversupply or undersupply of nutrients to the banana cropping system. Another critical factor that possibly weighs in the practicality of this scenario is the changing amount of manure production throughout the growing cycle of chicken, whether manure production of the current stage of growth of the chickens is enough to meet banana’s nutrient demand.

Similarly, nutrient replenishment by goat manures required a large number of goats. The reason was that goat manure had low nutrient concentration and comparably low potassium to nitrogen ratio at 0.04-0.88 K: 1 N. However, in combination with mulches from on-farm trees and shrubs, this alternative presents a viable solution with moderate labour demand and relatively high profit. Trees and shrubs species used in this experiment have deep root system which could exploit nutrient reserve in deeper layers (Mekkonen 1995). This prevents losses of nutrient from the system; however, the method is only a way to spatially relocate nutrient within the farm; not adding nutrients into the farm. Therefore, nutrients must come from other sources to replenish the farm nutrient stock. One way is to select for nitrogen fixing species. Yet, they are only effective in introducing nitrogen while P and K could be limiting. In addition, it was found that without P addition, nitrogen fixing capability is reduced substantially (Nandwa and Bekunda 1998). Potassium, being the most limiting nutrients, needs to be added into the system either in the form of inorganic fertilizer or off-farm organic materials. Interestingly, a research had shown that plant spacing of 3 m x 3 m currently used was not optimal for banana production (Ndabamenye et al. 2012). Thus, there is a possibility of designing a farm configuration, which incorporates leguminous trees into the system as hedges or contour cropping. Numerous trees and shrubs could be considered viable as green manure for banana cropping system. (Vanlauwe et al. 2014) mentioned an installation of *Calliandra* hedges as a mean for feeding animals and decrease soil erosion. *Tithonia diversifolia* was also proven to be an excellent source of green manure with its high nitrogen and potassium content (Jama et al. 2000). *Morus sp*. also presents itself as an excellent source of green manure with its high biomass production and high nutrient concentration. The lack of research in the interactions between on-farm trees and shrubs with banana in a cropping system as well as trees and shrubs management practices may limit the adoptability of this alternative.

4.4 Qualitative comparison of the type of households

Four alternative strategies for improving banana yields in this study can be adopted by farmers based on their objectives and limitations. Limitations such as labour availability, capital, land, natural resources are taken into account in this study. It was found that relying solely on animal manures for nutrient replenishment may not be practical due to its low nutrients content (Wortmann and Kaizzi 1998) and its inability to help with soil moisture conservation due to relatively low soil coverage. In the case of having low labour availability, the most viable strategy was to rely on inorganic fertilizer since the labour required for application is minimal compared to the management required for other strategies (van Asten et al. 2010). Maize + banana and goat + on-farm trees and shrubs also required relatively moderate amount of labour. The two most labour-demanding systems were the banana with beans and banana with poultry production. Regarding capital required, poultry production demanded the highest capital while goat and on-farms trees and shrubs required the least amount of capital. Poultry housing, equipment and feeds represented the majority of the investment needed for the alternative. In the case of on-farm trees and shrubs, the cost of establishing and maintaining planted shrubs were not estimated in this study. Land requirements were similar for fertiliser addition and poultry production. On-farm trees and shrubs could perhaps be intercropped with banana trees (Sinclair and Sanchez 1995), thus requires approximately the same amount of land as fertiliser addition and poultry production alternatives. Annual crop production required the biggest amount of land, particularly bean production. Natural resources availability could play a big part in the decision. From our study, a severe lack of rainfall in Nakaseke means that a strategy involves effective use of water combined with soil moisture conservation should be employed. This rendered alternatives that did not make use of mulch cover for reducing soil moisture loss such as fertiliser addition and chicken manure alternatives impractical. Our study showed that the poultry production alternative, even though feasible, was not practical if the farmers would like to focus on banana production since most labour and capital would be concentrated on poultry production. Fertiliser addition has its drawback in the lack of soil moisture conservation aspect. With rain-fed cropping systems in Uganda, this alternative may be sub-optimal in a certain part of the country where low rainfall limits water availability. Additionally, fertilizer adoption is only feasible up to 150 km away from big cities (van Asten et al. 2010). The bean + banana cropping system also required unrealistic proportion of land for producing enough bean residue for banana plots. The maize + banana and goats + on-farm trees and shrubs were shown in our study to be the most promising alternatives taking into account farmers' objectives and limitations. Our study has shown that an integration of farm resources and off-farm inputs is a must in order to develop a feasible and productive system which agrees with the previous study done by Bekunda and Woomer (1996).

4.5 Data quality, gaps, and sensitivity analysis

In term of data availability, several gaps were present which assumptions or approximation had to be made. This is especially true with nutrient balance calculations for poultry production and goat and on-farm biomass alternatives. Average weight of chicken in a year was approximated in order to be able to calculate chicken manure production. Data on chicken manure nutrient concentration was also inconsistent with FAO's compiled data (FAO 2004). In the goat and on-farm biomass scenario, many variables did not have references from literature. This included dry matter yield (twigs and leaves) of several species of trees and shrubs, nutrient concentrations, average weight in the lifetime of goat, amount of manure produced by goat. Nutrient concentration of goat manure also substantially diverged from the compiled data (FAO 2004). Manure production and nutrient concentration were highly variable from farm to farm in this study due to the composition of manure basins (manure + soil + feed left overs), the storage condition, and the length of storage. A few nutrient flows were also not taken into account in this study including fibres exported in the form of banana leaves, suckers removal for sale or offering to neighbours, banana peelings being recycled back to the system. The data for these flows were inconsistent and not quantifiable.

As presented in the result section, sensitivity analysis displayed the influence of several factors used in the nutrient balance calculation. The results of many factors were as anticipated; for example, nutrient requirement was very sensitive to nutrient concentration of banana which was predictable since it was shown from the nutrient balance calculation that the number one outflow in banana cropping system was the banana itself. However, some factors had unexpected outcomes. Goat manure, for instance, did not have a big effect on the amount of mulch needed in goat and on-farm biomass scenario. This was due to the low potassium concentration in goat manure, 0.064% DM; increasing or decreasing the potassium content of goat manure by 50% did not significantly changed the amount of mulch needed to cover the rest of the nutrient requirement in the banana cropping system. The implication of this analysis is to show which factors have more influence in the nutrient balance calculation which dictated the need to precisely quantify them.

4.6 Targeted study to improve existing parameters used in the calculation

In our study, maize + banana and goat and on-farm trees and shrubs alternatives were more practical than other options, thus the targeted study should be focusing on these alternatives. Fertilizer addition alternatives, though feasible in some cases, had a large amount of data available and further study may not yield useful improvement. In the case of maize + banana cropping system, fine-tuning of nutrient concentration of maize stover may be necessary. Maize stover collected in our experiment may not be representative since a small sample size was collected as well as the length and condition of storage of these samples may have altered their nutrient concentration. Removal fraction of maize stover could also be further investigated as the factor greatly impact the outcome of the alternative.

Major improvements of nutrient balance calculation could be achieved in the goat and on-farm trees and shrubs scenario. Various data regarding on-farm trees and shrubs are still lacking. An experiment focusing on an attainable shrubs biomass production for feed and mulch in banana and shrubs intercropping system based on optimum planting density could be investigated. In our experiment, the annual yield data of on-farm trees and shrubs may not be representative due to the possibility of different developmental stages which trees and shrubs could be harvested. Nutrient concentration of several potential trees and shrubs can also be explored. Goat manure production and average lifetime weight could be improved even though based on the sensitivity analysis, the improvement may not produce a significant difference since the outcome was not very sensitive to these factors. Goat manure nutrient concentrations in this study were also unusually low. Several reasons could contribute to the low concentration, for example, quality of feed, storage condition and manure collection method.

Another way to approach our problem of determining which alternative represents the most practical and profitable outcome is to use fertiliser response. Shepherd and Soule (1998) pointed out that nutrient balance is a useful tool for developing a sustainable system; however, some important information is overlooked. Nutrient deficiency in soil nutrient stock, for example, is very crucial for developing an efficient system and it was not taken into account in our nutrient balance calculation. This depletion of soil nutrient stock happens continuously as a result of anthropological interference or natural processes (Nandwa and Bekunda 1998). Evidently, a site-specific fertiliser recommendation based on fertiliser response data needs to be made to address existing nutrient deficiencies. Fertiliser response parameters used in our experiment, fertiliser recovery rate in particular, were quite low which as a result may or may not be applicable for our three experimental sites (Nyombi et al. 2010). Therefore, the parameters may need to be calibrated for the sites. From then on, four alternatives could be assessed from both nutrient balance and fertiliser response point of view, which together is necessary for developing an efficient and sustainable system.

Lastly, labour and economic balance could be improved. Minor labour and economic flows were not identified and quantified. Flows such as labour requirement for fertiliser application and transfer of crop residues, adjusted weeding cost and labour for each scenario, and transportation cost of fertiliser and chicken are some of the flows, which were not taken in to account. These flows altogether may produce a different result, thus there is a need to look into the details in each scenario.

Conclusion

Our findings demonstrated the possibility of adopting four alternative nutrient management strategies taking into account technical, economical, and labour aspects. Two alternatives, maize and banana and goats, banana, and on-farm trees and shrubs integration, exhibited better outcomes in term of nutrient balance, profits and labour balance than the other two alternatives. Fertilizer addition alternative may not prove to be the feasible alternative due to its lack of soil moisture conservation aspect as well as high transportation cost and unpredictable supply of fertilizer. Poultry production alternative, on the other hand, demonstrated a shift from banana production towards a more animal production due to the large amount of chicken required to produce enough manure to offset nutrient outflow. In this study, technical parameters regarding nutrient flows were successfully quantified. However, if a nutrient management alternative strategy was to be adopted, fine-tuning of these parameters as well as further study on the integration of animals, annual crops and banana may be necessary in order to develop an efficient and feasible system.

References

Bagamba, F. 2007. Market Access and Agricultural Production: The Case of Banana Production in Uganda. *Ph.D. Thesis, Wageningen University*.

Bagamba, F., K. Burger, and W. Tushemereirwe. 2010. Banana (Musa spp.) production characteristics and performance in Uganda. *Acta Horticulturae* 879: 187-194.

Baijukya, F. P., and B. de Steenhuijsen Piters. 1998. Nutrient balances and their consequences in the banana-based land use systems of Bukoba district, northwest Tanzania. *Agriculture, Ecosystems & Environment* 71 (1–3): 147-158. http://dx.doi.org/http://dx.doi.org/10.1016/S0167-8809(98)00137-6.

Baligar, V. C., and O. L. Bennet. 1986. Outlook on fertilizer use efficiency in the tropics. *Fert. Res.* 10: 83-86.

Bananuka, J. A., P. R. Rubaihayo, and Y. K. Zake. 2000. Effect of Organic Mulches on Growth, Yield Components and Yield of East African Highland Bananas. *Acta Horticulturae* 540: 293-300.

Bekunda, M. A., and P. L. Woomer. 1996. Organic resource management in banana-based cropping systems of the Lake Victoria Basin, Uganda. *Agriculture, Ecosystems & Environment* 59 (3): 171-180. http://dx.doi.org/http://dx.doi.org/10.1016/0167-8809(96)01057-2.

Bremner, J. M. 1960. Determination of nitrogen in soil by the Kjeldahl method. *The Journal of Agricultural Science* 55 (01): 11-33. http://dx.doi.org/doi:10.1017/S0021859600021572.

FAO. 1977. Soil map of the world: Africa. *UNESCO* 6.

———. 2004. Scaling soil nutrient balances: Enabling mesolevel applications for African realities. *FAO fertilizer and plant nutrition bulletin* 15.

Gold, C. S., F. Bagamba, M. Wejuli, D. Karamura, and R. Kalyebara. 2000. Geographic shifts in highland banana production in Uganda. *Acta Horticulturae* 540: 55-62.

Gold, C. S., E. B. Karamura, A. Kiggundu, F. Bagamba, and A. M. K. Abera. 1999. Geographic shifts in the highland cooking banana (Musa spp., group AAA-EA) production in Uganda. *International Journal of Sustainable Development & World Ecology* 6 (1): 45-59. http://dx.doi.org/10.1080/13504509.1999.9728471.

Jama, B., C. A. Palm, R. J. Buresh, A. Niang, C. Gachengo, G. Nziguheba, and B. Amadalo. 2000. Tithonia diversifolia as a green manure for soil fertility improvement in western Kenya: A review. 49 (2): 201-221. http://dx.doi.org/10.1023/a:1006339025728.

Kaizzi, K. C., J. Byalebeka, O. Semalulu, I. Alou, W. Zimwanguyizza, A. Nansamba, P. Musinguzi, et al. 2012. Maize Response to Fertilizer and Nitrogen Use Efficiency in Uganda. *Agron. J.* 104 (1): 73-82. http://dx.doi.org/10.2134/agronj2011.0181.

McIntyre, B. D., P. R. Speijer, S. J. Riha, and F. Kizito. 2000. Effects of Mulching on Biomass, Nutrients, and Soil Water in Banana Inoculated with Nematodes 1 Mention of a specific trade or product name does not necessarily mean the endorsement or exclusion of other products by Cornell University. *Agron. J.* 92 (6): 1081-1085. http://dx.doi.org/10.2134/agronj2000.9261081x.

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. *Communications in Soil Science and Plant Analysis* 15 (12): 1409-1416. http://dx.doi.org/10.1080/00103628409367568.

Mekkonen, K. 1995. Rooting characteristics and inorganic nitrogen distribution in three land-use systems in an Oxisol in Western Kenya. *MSc Thesis, Moi University, Eldoret, Kenya*.

Mitchell, H. W. 1988. Cultivation and harvesting of the Arabica coffee tree. *Elsevier Applied Science* 4: 43-90.

Mubiru, L. S., D. Romney, N. Halberg, and J. S. Tenywa. 2011. Development of nutrient management strategies based on mapping of nitrogen flows and balances in dairy production systems in Uganda. *Livestock Science* 137 (1–3): 116-123. http://dx.doi.org/http://dx.doi.org/10.1016/j.livsci.2010.10.009.

Nandwa, S. M., and M. A. Bekunda. 1998. Research on nutrient flows and balances in East and Southern Africa: state-of-the-art. *Agriculture, Ecosystems & Environment* 71 (1–3): 5-18. http://dx.doi.org/http://dx.doi.org/10.1016/S0167-8809(98)00128-5.

Ndabamenye, T., P. J. A. Van Asten, N. Vanhoudt, G. Blomme, R. Swennen, J. G. Annandale, and R. O. Barnard. 2012. Ecological characteristics influence farmer selection of on-farm plant density and bunch mass of low input East African highland banana (Musa spp.) cropping systems. *Field Crops Research* 135 (0): 126-136. http://dx.doi.org/http://dx.doi.org/10.1016/j.fcr.2012.06.018.

Nyombi, K., P. J. A. van Asten, M. Corbeels, G. Taulya, P. A. Leffelaar, and K. E. Giller. 2010. Mineral fertilizer response and nutrient use efficiencies of East African highland banana (Musa spp., AAA-EAHB, cv. Kisansa). *Field Crops Research* 117 (1): 38-50. http://dx.doi.org/http://dx.doi.org/10.1016/j.fcr.2010.01.011.

Okalebo, J. K., G. K. W., and P. L. Woomer. 2002. Laboratory methods of soil and plant analysis: A working manual. *SACRED-Africa*.

Okumu, M. O., P. J. A. van Asten, E. Kahangi, S. H. Okech, J. Jefwa, and B. Vanlauwe. 2011. Production gradients in smallholder banana (cv. Giant Cavendish) farms in Central Kenya. *Scientia Horticulturae* 127 (4): 475-481. http://dx.doi.org/http://dx.doi.org/10.1016/j.scienta.2010.11.005.

Okwakol, M. J. N., and H. N. Kagole. 1993. Interactive effects of mulches and soil macrofauna on banana production at Kabanyolo, Uganda. *Mimeo*: 67.

Omamo, W. 2002. Fertilizer trade and pricing in Uganda. *Proc. Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) Workshop on the Assessment of the Fertilizer Sub-Sector in East Africa.*: 101-111.

Palm, C. A., R. J. K. Myers, and S. M. Nandwa. 1997. Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. *in press*.

Prasad, R., and S. K. de Datta. 1979. Increasing fertilizer nitrogen efficiency in wetland rice. *IRRI, Nitrogen and Rice, Los Banios, Phillipines*: 465-483.

Radersma, S., B. Lusiana, and M. v. Noordwijk. 2005. Simulation of soil drying induced phosphorus deficiency and phosphorus mobilization as determinants of maize growth near tree lines on a Ferralsol. *Field Crops Research* 91 (2–3): 171-184. http://dx.doi.org/http://dx.doi.org/10.1016/j.fcr.2004.06.005.

Sanchez, P. A., C. A. Palm, L. T. Szott, E. Cuevas, and R. Lal. 1989. Organic input management in tropical agroecosystems. *Dynamics of Soil Organic Matter in Tropical Ecosystems*: 125-152.

Shepherd, K. D., and M. J. Soule. 1998. Soil fertility management in West Kenya: dynamic simulation of productivity, profitability and sustainability at different resource endowment levels. *Agric. Ecosyst. Environ.* 71: 133-147.

Sinclair, F., and P. A. Sanchez. 1995. "Science in agroforestry." In *Agroforestry: Science, Policy and Practice*, 5-55. Springer Netherlands.

Smaling, E. M. A., and L. O. Fresco. 1993. A decision support model for monitoring nutrient balances under agricultural land use (NUTMON). *Geoderma* 60: 235-256.

Speijer, P. R., and C. Kajumba. 2000. Yield Loss from Plant Parasitic Nematodes in East African Highland Banana (*Musa* spp. AAA) *Acta Horticulturae* 540: 453-459.

Ssali, H., B. D. McIntyre, C. S. Gold, I. N. Kashaija, and F. Kizito. 2003. Effects of mulch and mineral fertilizer on crop, weevil and soil quality parameters in highland banana. 65 (2): 141-150. http://dx.doi.org/10.1023/a:1022184927506.

Stover, R. H., and N. W. Simmonds. 1987. Bananas. *Tropical Agriculture Series*: 468.

Swennen, R. 1990. Plantain cultivation under West African conditions. *A reference Manual. IITA, Ibadan, Nigeria*: 22.

Van Asten, P., C. S. Gold, J. Wendt, D. de Waele, S. H. Okech, H. Ssali, and W. K. Tushemereirwe. 2005. The contribution of soil quality to yield and its relation with other banana yield loss factors in Uganda. *Proceedings of a Workshop held on Farmer Participatory Testing of IPM Options for Sustainable Banana Production in Eastern Africa, Seeta, Uganda, International Plant Genetic Resources Institute, Montpellier, France*: 110-115.

van Asten, P. J. A., A. M. Fermont, and G. Taulya. 2011. Drought is a major yield loss factor for rainfed East African highland banana. *Agricultural Water Management* 98 (4): 541-552. http://dx.doi.org/http://dx.doi.org/10.1016/j.agwat.2010.10.005.

van Asten, P. J. A., L. W. I. Wairegi, F. Bagamba, and C. Drew. 2010. Factors Driving Fertilizer Adoption in Banana (Musa spp.) Systems in Uganda. *Acta Horticulturae* 879: 465-477.

Vanlauwe, B., D. Coyne, J. Gockowski, S. Hauser, J. Huising, C. Masso, G. Nziguheba, M. Schut, and P. Van Asten. 2014. Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability* 8 (0): 15-22. http://dx.doi.org/http://dx.doi.org/10.1016/j.cosust.2014.06.001.

Wairegi, L. W. I., and P. J. A. van Asten. 2010. The agronomic and economic benefits of fertilizer and mulch use in highland banana systems in Uganda. *Agricultural Systems* 103 (8): 543-550. http://dx.doi.org/http://dx.doi.org/10.1016/j.agsy.2010.06.002.

Wairegi, L. W. I., P. J. A. van Asten, M. M. Tenywa, and M. A. Bekunda. 2010. Abiotic constraints override biotic constraints in East African highland banana systems. *Field Crops Research* 117 (1): 146-153.

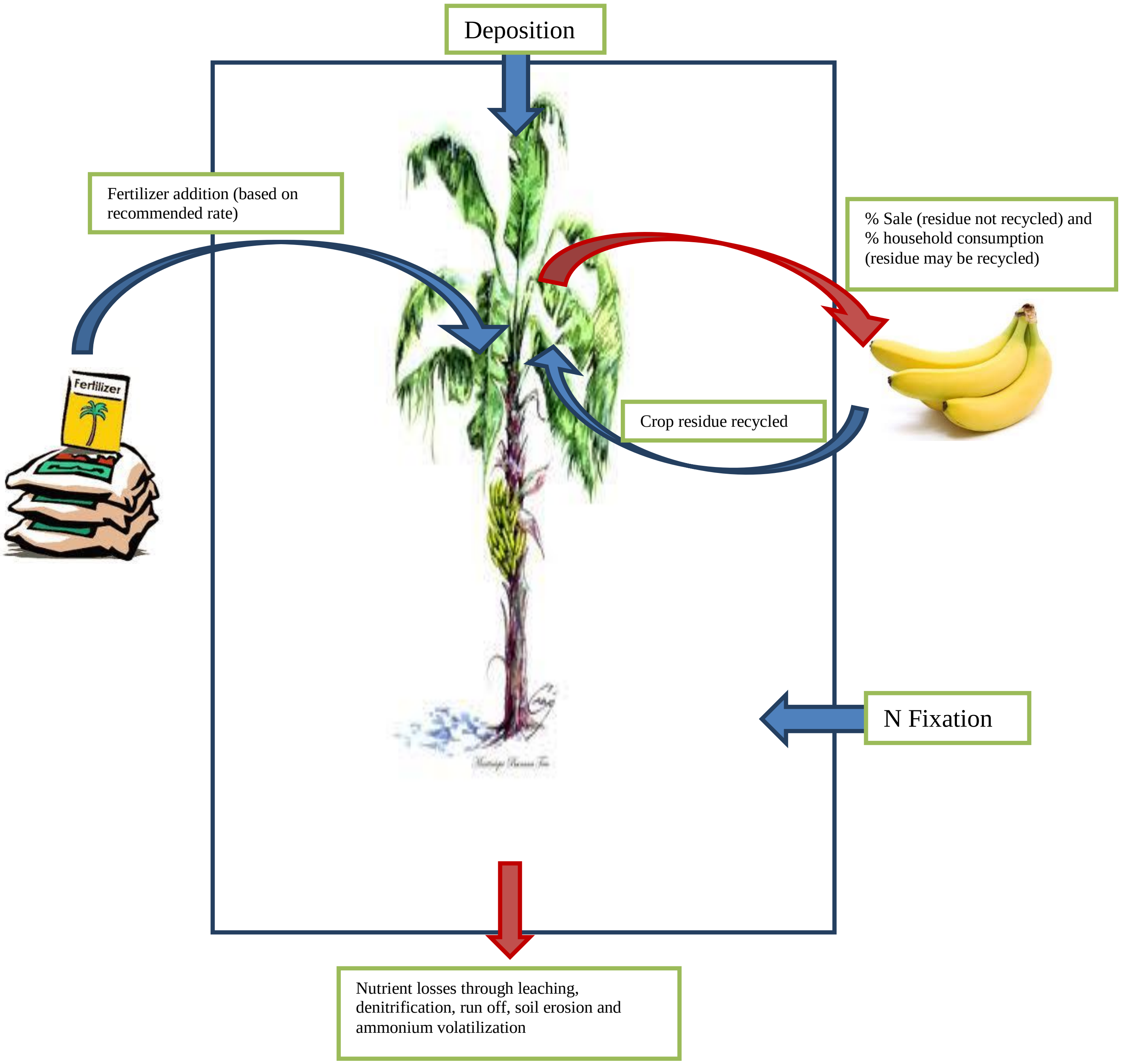
Wortmann, C. S., and C. K. Kaizzi. 1998. Nutrient balances and expected effects of alternative practices in farming systems of Uganda. *Agriculture, Ecosystems & Environment* 71 (1–3): 115-129. http://dx.doi.org/http://dx.doi.org/10.1016/S0167-8809(98)00135-2.

Zake, Y. K., D. P. Bwamiki, and C. Nkwiine. 2000. Soil Management Requirements for Banana Production on the Heavy Soils around Lake Victoria in Uganda. *Acta Horticulturae* 540: 285-292.

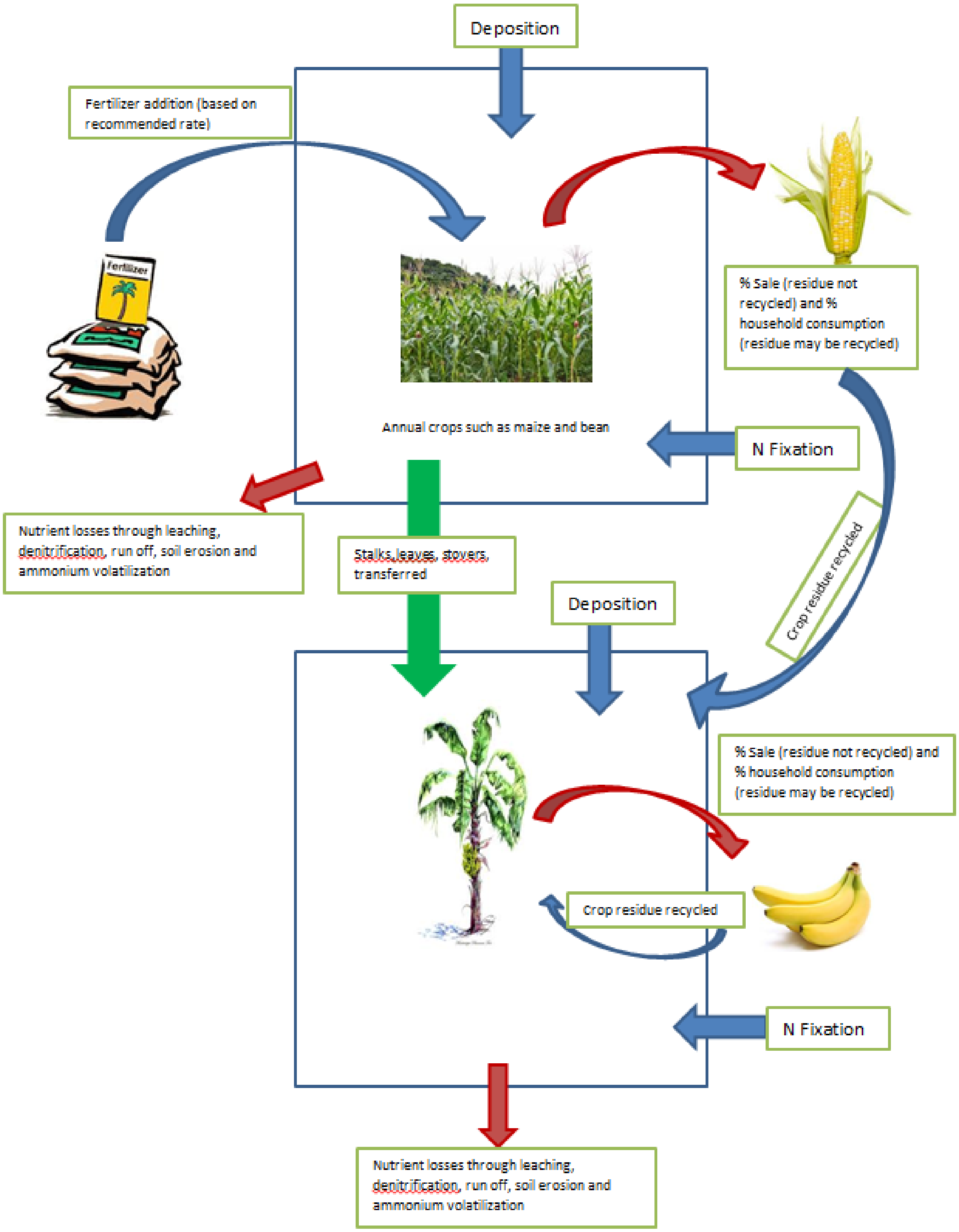
Appendices

Appendix A. Four strategies

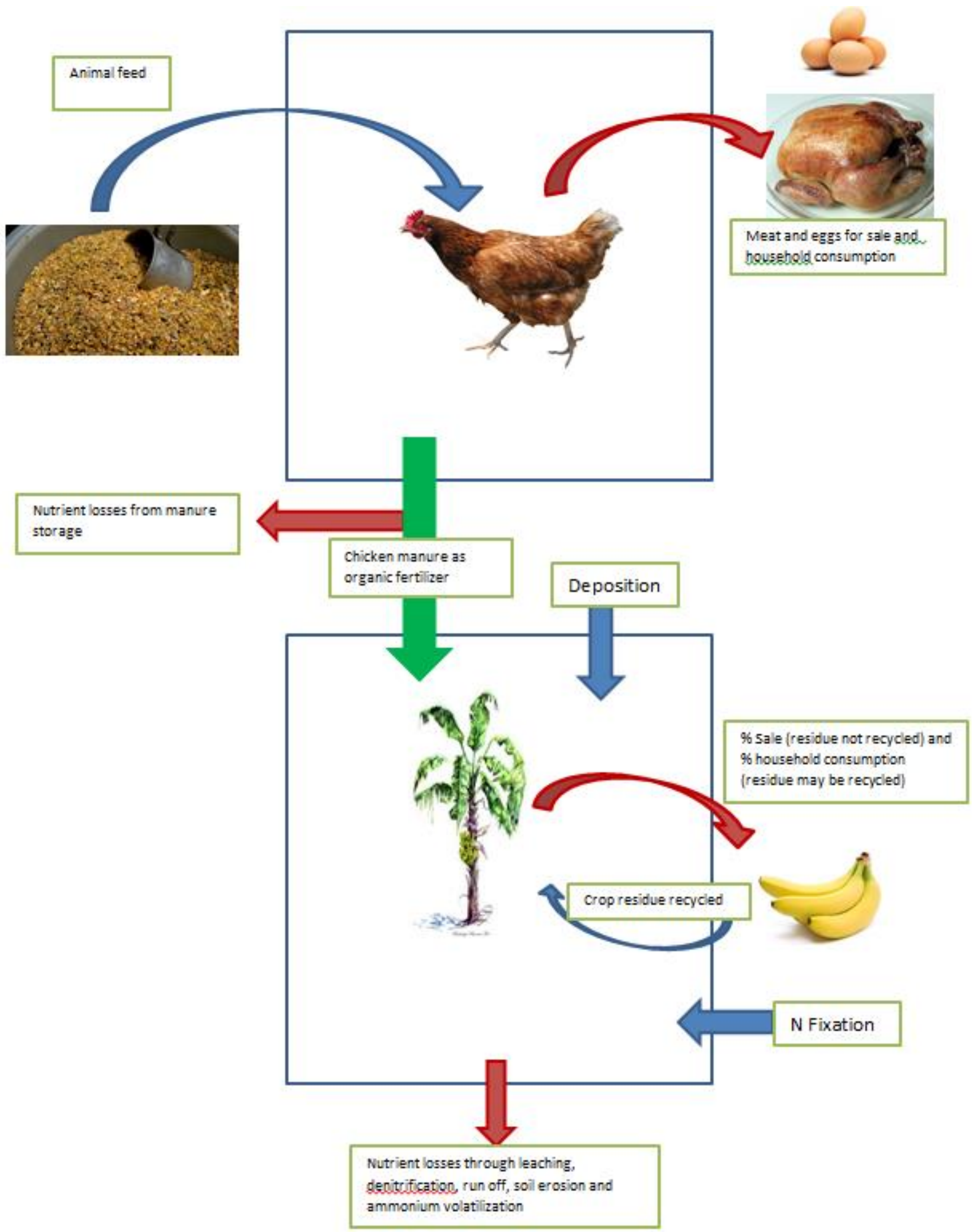
Scenario 1: Fertilizer



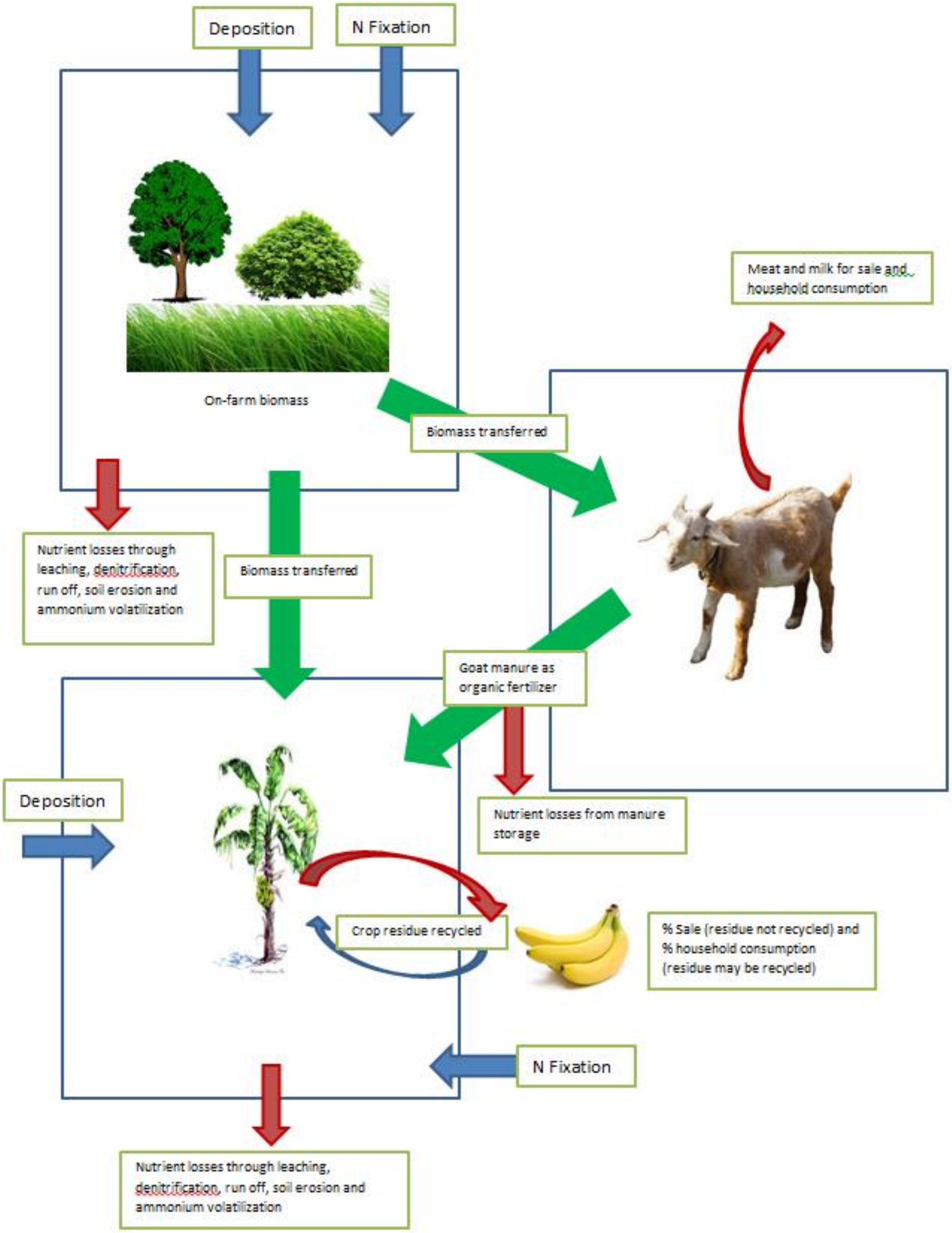
Scenario 2: Application of chemical fertilizer on annuals and transfer crop residue



Scenario 3 – animal feeds purchased to increase on-farm manure



Scenario 4 - on-farm biomass for mulch and feed



Appendix B. Farm interview questions

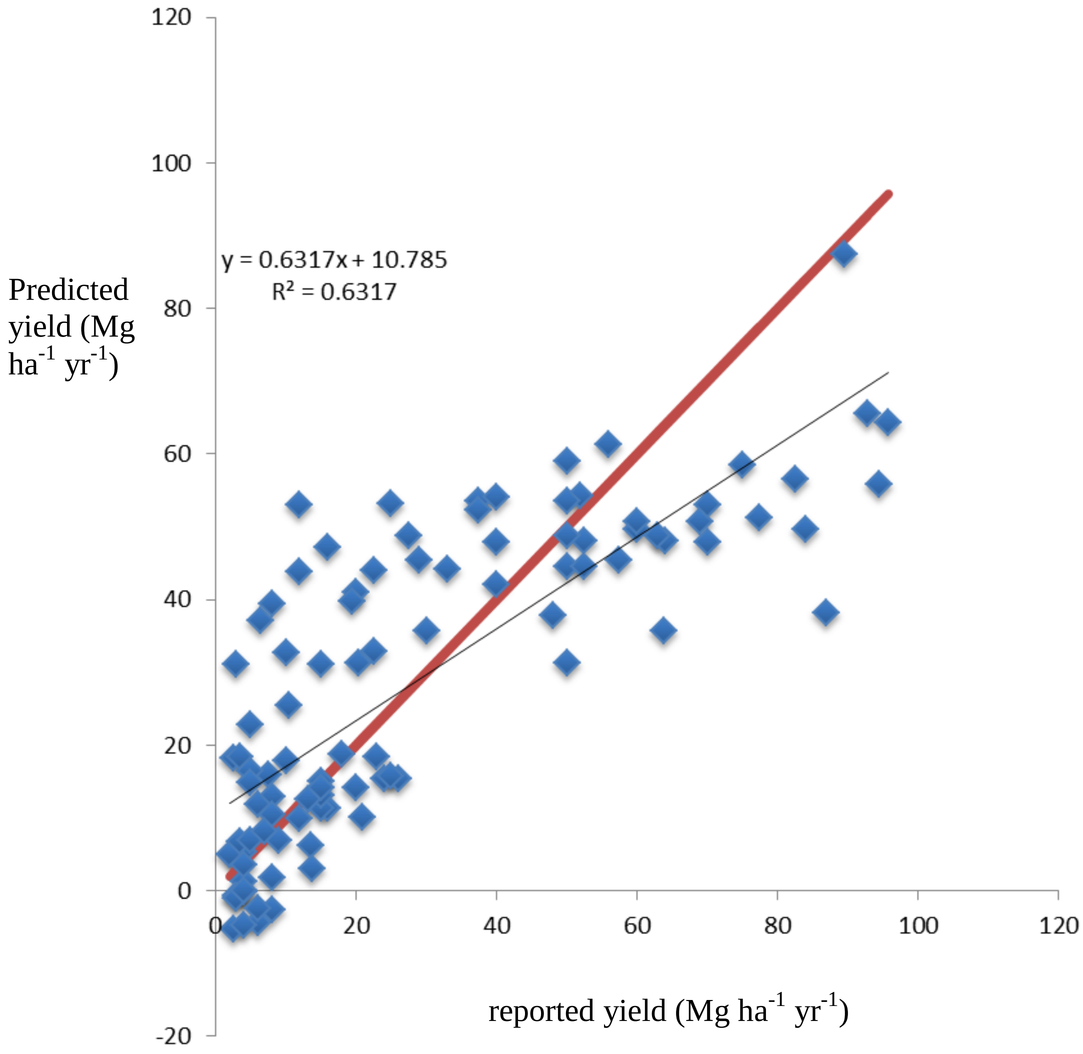
1. Farm and banana cultivation area
2. Banana residue use e.g. for feed or mulch
3. Annual crops production – species, yield
4. Annual crop residue use e.g. for feed or mulch
5. On-farm plants – amount, for feed or mulch
6. Livestock and poultry type and number
5. Livestock and poultry manure use and storage
7. Meat, milk and eggs production – amount
8. External nutrient inputs – fertilizer and concentrate
9. Banana spacing
10. Estimated bunch weights
11. Number of bunches harvested
12. Household waste and consumption
13. Family size and composition
14. Labour (regular or casual) and working hours
15. Type of works and amount of time invested each: (general farm management (not related to crops or animals), herd and stable management, and crop cultivation)
16. Prices of commodities – meat, milk, eggs, cash crops, and banana
17. Cost of cultivation of banana and annual crops – de-suckering, pest management, fertilization, labour cost)
18. Cost for animal production –feeding, bedding, interest rate of capitals and other costs (manure, labour, fixed cost for land, assets such as building and machinery)

Appendix C. Yield

farmer's name	**total yield (t/ha yr)**			
Nakaseke	**control**	**mulch**	**manure**	**mulch+manure**
Mamatoru Justine	13.6	30	16	48
Musisi Godfrey	4	15	20	52.5
Musisi Peter	12	10.5	20	25
Nakayizah Robinah	8	16	30	50
Nankya Harriet	3	10	12	64
Nasazi Faith	8	9.9	12	30
Sauna Vincent	3.2	10	27	52
Emma Kwagala	18	40.5	60	84
Gingo Williams	6	14	20	50
Maluboga Mangederena	10	18	37.5	95.7
Manranda Gesga	4	10.5	18	60
Nsobya Moses	20	70	70	92.8
Nakiwu Ruth	13.8	30	43.2	69

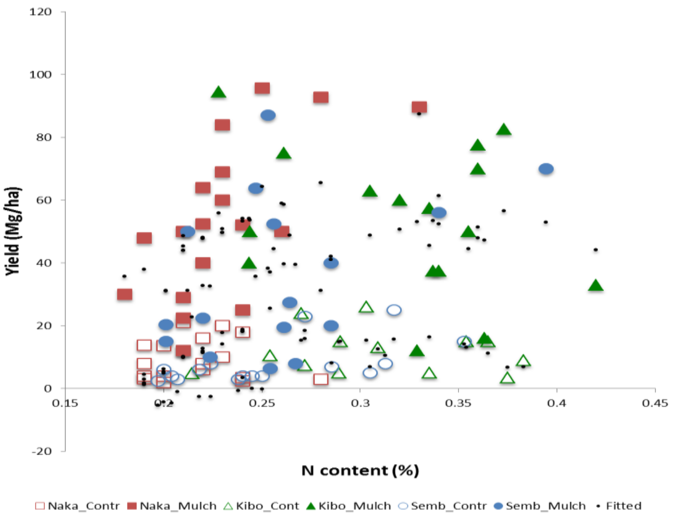
Lubega Emmanuel	2.5	12	3.6	22.5
Muyake Ayub	3.5	22.5	30	40
Nangozi Raphaela	2	20	5.6	29
Nasange Gloria Kasibante	16	2.5	15	12
Rose Kayanja	21	62.1	67.5	89.6
Kiboga	**control**	**mulch**	**manure**	**mulch+manure**
Damba Charles	15	30	60	60
Furaha Ruth	n/a	6	1	16
Kate Nakimpi	24	48	22.5	57.5
Kiyinji Fred	15	30	30	37.5
Nakibunga Norah	26	40.5	40	77.5
Nankabirwa Fatumah	13.2	51	20	63
Ssekabira Benard	n/a	n/a	n/a	n/a
Ssekaneli Mauthas	7.5	20	n/a	50
Ssemyimbe David	4.9	7.2	10.8	12
Kudishasha Debrah	9	37.5	60	70
Mayambala Salongo	15	27	63.8	82.5
Nakabonge Goratz	5	12	20	37.5
Nakitende Margrate	15	40	165	94.5
Nalumansi eres	3.5	8	21	50
Namatovu Gladys	6.4	12	40	60
Nono Fred	10.5	20	80	75
Serugo Akayanda	0.9	14	25	33
Shamim Tumubwoine	5	14	30	40
Sembabule	**control**	**mulch**	**manure**	**mulch+manure**
Lwanyaga Manisur	3	12	10	22.5
Mudathiruk Ssenyoula	3.5	11.9	15	20.4
Muganda Kabito Henry	1	13	15.6	63.8
Nibibuya Yudaya	15	22.5	30	50
Ssemwigere Hannah	24	62.1	40	87
Ssemwodere Jamada	20	20	24.2	52.5
Bayita Robert	9.6	28.5	15	6.4
Byakatonda Raphael	12	30	55	70
Matovu Leonald	24	24	30	56
Namawejje Ruth	9	15	20	15
Semujju Sulaiman	0	3.2	12	20
Semuju Faziri	7.2	13.5	22.5	40
Eley Rutakagutwa	2.8	27	12	36
Kinsambwe Yasin	4.8	8.8	11.7	27.5
Nakayagaba Angella	3.5	13	16.9	19.5
Namirembe Annet	n/a	2.25	8.5	10
Rutahigyca Elly	1.6	4.2	6.4	8

Appendix D. Yield vs. soil parameters

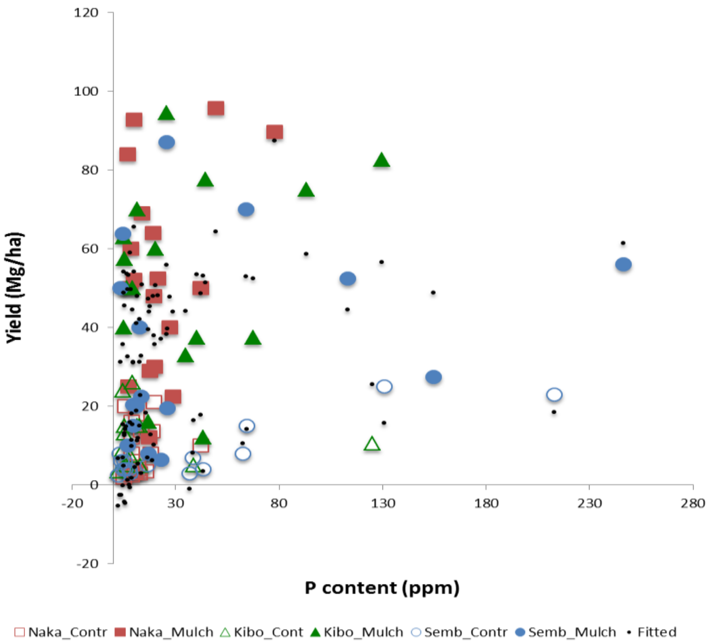


```
> lmfit = lm( Yield ~ Ncontent + Pcontent + Kcontent + District + Treatment + Di
> summary(lmfit)

Call:
lm(formula = Yield ~ Ncontent + Pcontent + Kcontent + District +
    Treatment + District:Ncontent, data = mrd)

Residuals:
    Min      1Q  Median      3Q     Max
-41.085 -10.347   0.842   9.223  48.741

Coefficients:
                            Estimate Std. Error t value Pr(>|t|)
(Intercept)                 34.63424   19.54620   1.772  0.07987 .
Ncontent                   -76.09850   63.67961  -1.195  0.23529
Pcontent                     0.05648    0.05762   0.980  0.32967
Kcontent                     0.01963    0.03040   0.646  0.52011
DistrictNakaseke           -94.71659   29.61151  -3.199  0.00192 **
DistrictSembabule          -59.95573   26.85173  -2.233  0.02810 *
TreatmentMulch+manure       35.19171    3.60074   9.773 1.05e-15 ***
Ncontent:DistrictNakaseke  393.03552  115.87172   3.392  0.00104 **
Ncontent:DistrictSembabule 174.39571   95.88742   1.819  0.07235 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 17.05 on 88 degrees of freedom
Multiple R-squared:  0.6317,     Adjusted R-squared:  0.5982
F-statistic: 18.87 on 8 and 88 DF,  p-value: 3.486e-16

> anova(lmfit)
Analysis of Variance Table

Response: Yield                                         R2 explained
                  Df  Sum Sq Mean Sq  F value    Pr(>F)
Ncontent           1  3272.1  3272.1  11.2589  0.001171   3272    4.7%
Pcontent           1  1747.2  1747.2   6.0118  0.01618    1747    2.5%
Kcontent           1  2564.3  2564.3   8.8235  0.003833   2564    3.7%
District           2  2694.5  1347.2   4.6356  0.012188   2695    3.9%
Treatment          1 30163.6 30163.6 103.7880 < 2.2e-16  30164   43.4%
Ncontent:District  2  3420.5  1710.3   5.8848  0.003993   3421    4.9%
Residuals         88 25575.2   290.6                     25575
---                                                      69437   63.2%
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

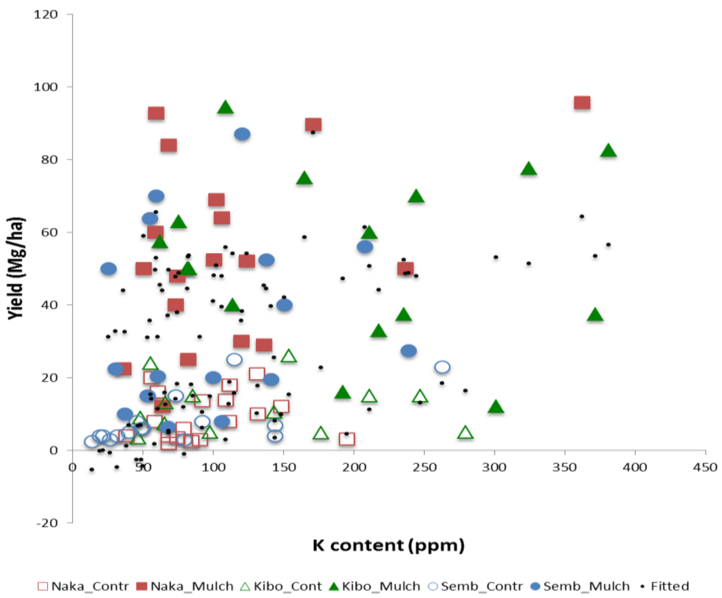
Yield (Mg/ha)



Yield (Mg/ha)
N content (%)
Naka_Contr Naka_Mulch Kibo_Cont Kibo_Mulch Semb_Contr Semb_Mulch Fitted



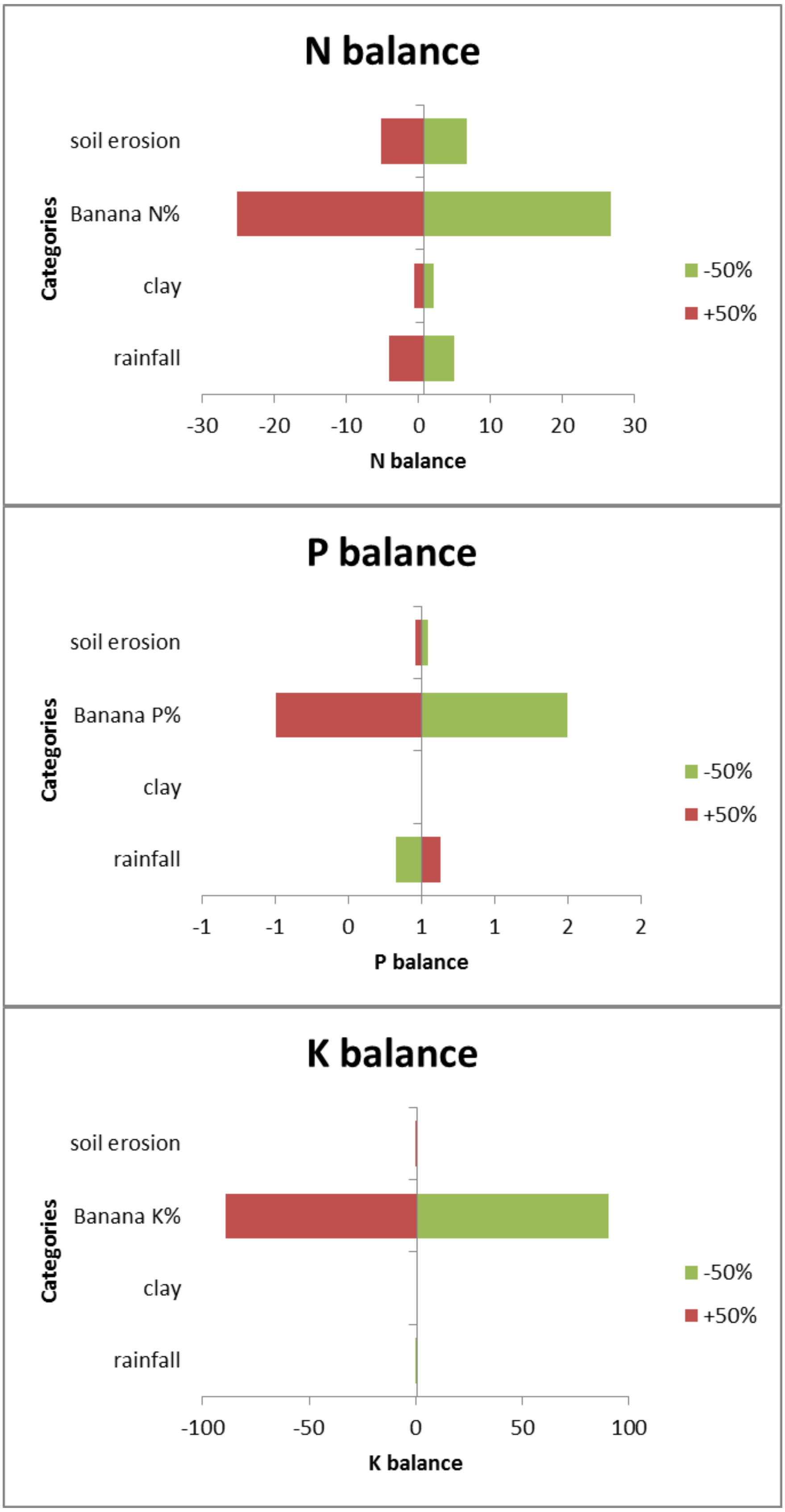
Yield (Mg/ha)
P content (ppm)
Naka_Contr Naka_Mulch Kibo_Cont Kibo_Mulch Semb_Contr Semb_Mulch Fitted



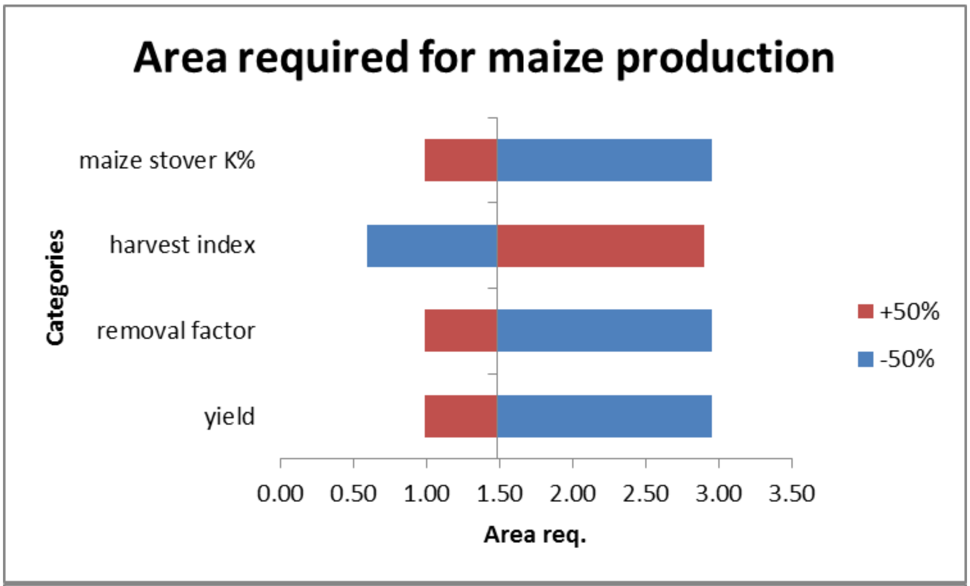
Yield (Mg/ha)
K content (ppm)
Naka_Contr Naka_Mulch Kibo_Cont Kibo_Mulch Semb_Contr Semb_Mulch Fitted

Appendix E. Sensitivity analysis

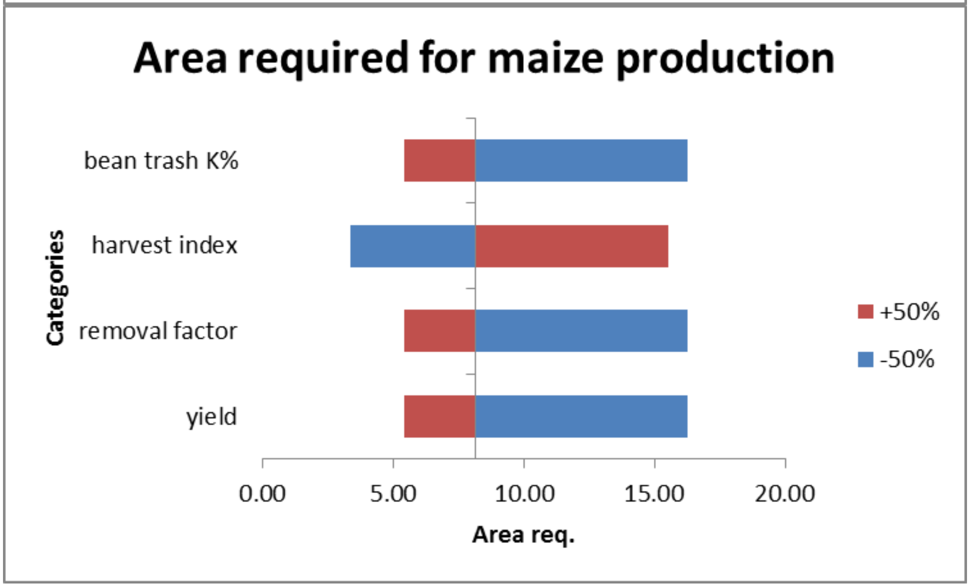
a.



b.

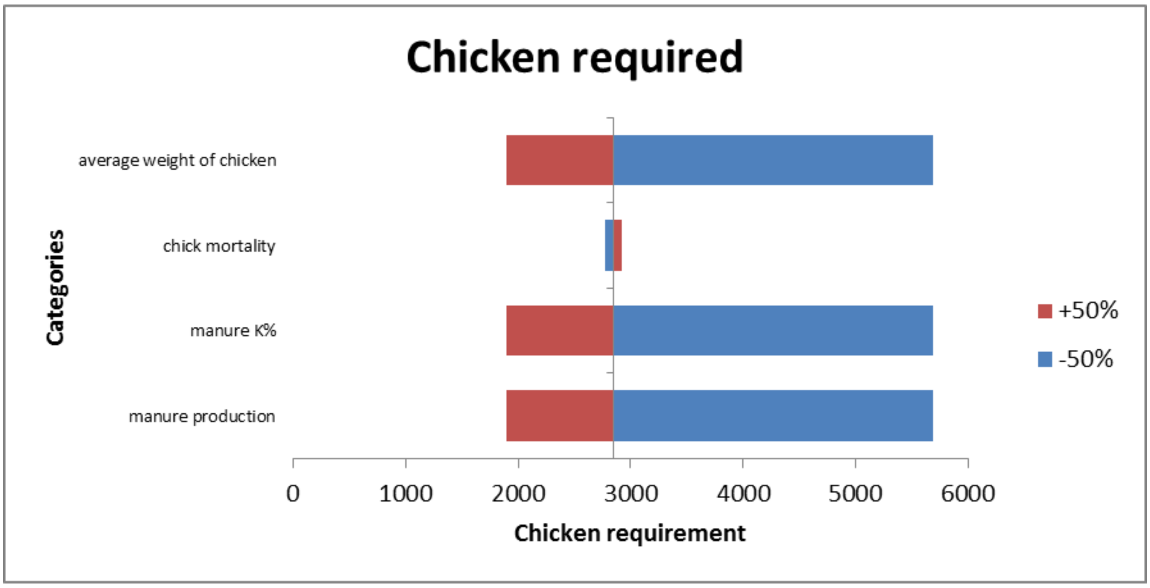


Area required for maize production
Categories
maize stover K%
harvest index
removal factor
yield
+50%
-50%
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
Area req.



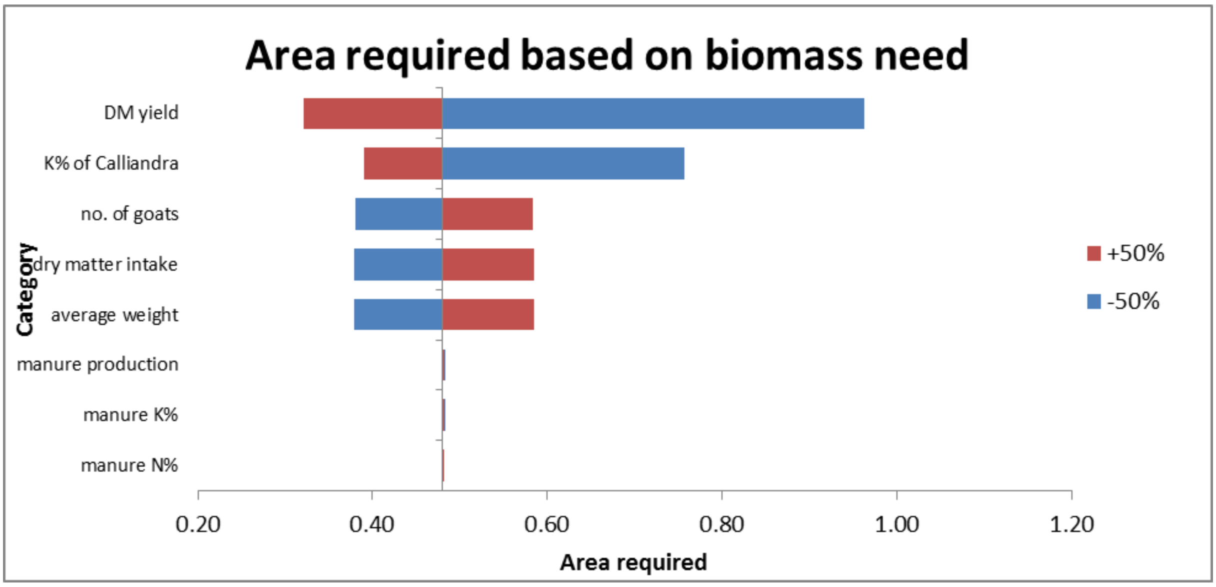
Area required for maize production
Categories
bean trash K%
harvest index
removal factor
yield
+50%
-50%
0.00
5.00
10.00
15.00
20.00
Area req.

c.



Chicken required
Categories
average weight of chicken
chick mortality
manure K%
manure production
+50%
-50%
0
1000
2000
3000
4000
5000
6000
Chicken requirement

d.



Area required based on biomass need
DM yield
K% of Calliandra
no. of goats
dry matter intake
average weight
manure production
manure K%
manure N%
Category
+50%
-50%
0.20
0.40
0.60
0.80
1.00
1.20
Area required