Faculty of Science and Engineering
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Socio-Economic and Agricultural Potential of Cattle Manure Application for Crop Production in Uganda

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Declaration

This thesis contains no material, which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

Innocent Muhereza

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Abstract

Declining soil fertility coupled with minimal nutrient inputs have contributed to low crop yields in sub-Saharan Africa; a major constraint to food security and economic development in Uganda. The use of cattle manure in agriculture is increasing as an alternative source of fertiliser and as a means of increasing or preserving soil organic matter. Research presented in this thesis was undertaken to: identify socio-economic issues affecting the use of cattle manure and inorganic fertiliser in Uganda; determine the crop response of Brassica spp to cattle manure as a source of N compared to inorganic N; and model the response of Brassica spp to applications of N from cattle manure and/or inorganic fertiliser for two major agro-ecological zones; dry land agriculture in Western Australia and tropical peri-urban agriculture in Uganda. The socio economic, agronomic and environmental viewpoints were considered. A survey conducted in Uganda as part of this study, highlighted that fifty-five percent (55%) of respondents reported that cattle manure was not adequate to fertilize the whole farm in a single cropping season due to the few animals kept on limited land of 0.2 ha-0.8 ha or inadequate fodder as reported by 88% and 69%, respectively. A number of challenges associated with cattle manure use included weight and bulkiness of manure (75%), lack of labour (68%), high transportation and application costs (38%) and lack of storage facilities (33%) to maintain quality attributes of manure.

The quality attributes of cattle manure for canola (*Brassica napus)* production were investigated further using manure stored for four months (M_4) (1.31% N) and twelve months (M_{12}) (0.32-1.18% N) compared with inorganic N (urea 46% N) on light textured sandy soil, using different rates following a systematic experimental design. Cattle manure was obtained from a cattle feedlot at Ucarty 120 km East of Perth, Western Australia and used in two field experiments whereas urea as a source of N was used in both field and glasshouse experiments. The cattle manure N was predominantly organic, and hence the inorganic fraction available for crop uptake at all times was extremely low.

The growth response of canola (*Brassica napus*) to increasing rates of cattle manure and comparable rates of inorganic N as urea, to a maximum of 200 kg ha^{-1} was examined in the field for two growing seasons to determine a N response curve. Fresh and dry weight yields and N uptake in relation to organic N from cattle manure were statistically analysed by linear regression analysis and compared to respective yields from mineral N calibration plots. Linear models of the form $y = a + bx$ were fitted to the data where y is the yield (kg ha^{-1} fresh or DM or N uptake).

The percentage relative effectiveness (RE) was calculated for seasonal DM production and N uptake in canola during the 2009 and 2010 growing seasons. In the first year of canola, the RE for N uptake in cattle manure compared with top-dressed inorganic N ranged from 13% to 18% over the season and by harvest DM was 22%. In the second year, the RE for N uptake by canola in cattle manure averaged 28% for M_4 and 21% for M_{12} over the growing season compared with top-dressed inorganic N, and by harvest, the RE of DM was 33% for M_4 and 26% for M_{12}. Urea was more effective as a source of N than comparable N loadings for either M_4 or M_{12} as indicated by RE for fresh weight, DM and N uptake. Factors such as low mineralisation rate of N contributed to the lower effectiveness of cattle manure N under field conditions.

The progressive increases in RE in stored cattle manure may be due to a number of factors including N in cattle manure becoming more available with time, the manure N being accessed more effectively by larger plant roots, increased soil moisture and or higher rates of N responding to lower levels of soil N. There was no evidence to suggest that lower soil N contributed to improvement in percentage RE during the season since soil tests were not conducted after the conclusion of the experiments.

Dry cattle manure at 62 tonnes ha^{-1} of M_{12} and 44 tonnes $ha^{-1}$of M_4 would be required to achieve high potential yield. The calibrated computer model predicted the response of canola to N availability and quantified potential yield of canola under cattle manure and inorganic fertiliser application. The model was then adapted to high yield potential soils of Uganda and showed yield increases and returns from N additions on simulated potential yields of cabbage and other factors for crop growth to be constant. Maximum returns of A$3,041, A$3,518 and A$4,230 ha^{-1} would be obtained under manure N application rates of 360, 440 and 600 kg N ha^{-1} at a cost of A$1,188, A$1,452 and A$1,980, respectively. The cost of N would be A$800, A$960 and A$1,280 ha^{-1} under inorganic N at optimal levels at maximum returns of A$3,970, A$4,721 and A$5,837 ha^{-1} for low, medium and high potential yield, respectively.

The growth response of Brassica species including two cabbage varieties and canola was examined in the glasshouse. There were no growth differences among the three Brassica *spp* grown in adequate N, indicating that the canola model may be a suitable proxy for modelling cabbage production when it comes to N application response.

The model took into account rainfall, which in the first year season increased the maximum depth of the wetting front by about 46 cm resulting in N leaching further below the root zone as opposed to the second year.

Final rooting depth was less with lower rainfall and increased rainfall significantly reduced nitrate in the rooting zone in the weeks in which the rainfall occured due to increased leaching.

Based on the experiments conducted and the socio-economic survey, the research addressed the problem of soil fertility decline in sub-Saharan Africa, particularly in Uganda. It identified constraints to fertiliser use for crop production in peri-urban agriculture in Uganda, focusing on the use of cattle manure and/or inorganic N fertiliser. A bio-economic model developed predicted N fertiliser requirements to improve crop yields and economic returns for cabbage production. The thesis findings will contribute towards improved cattle manure utilisation in agriculture in sub-Saharan Africa. Although the research primarily investigated dry solid cattle manure applied to dryland agriculture in Western Australian soils, the results will be of relevance to any farming system involved in the land application of cattle manure, to increase food production and to make better use of N in crop production.

Further studies are required in Uganda to determine and verify the key coefficients in the bio-economic model before it can be used to make recommendations. This should include other N sources including cow's urine, poultry manure and goat manure.

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Symbols and abbreviations

ANOVA:	Analysis of variance
d	day (s)
DAS:	Days after sowing
DM:	Dry matter
DS	dry solids
DW:	dry weight
FYM:	Farmyard manure
h:	hour (s)
ha:	Hectare
IITA:	International Institute of Tropical Agriculture
MAAIF:	Ministry of Agriculture, Animal Industry and Fisheries
MFPED:	Ministry of Finance Planning and Economic Development
Min:	minutes
mL:	millilitre (s)
MWEDM:	Ministry of Water Environement Department of Meteorology
NAADS:	National Agricultural Advisory Service
OM:	Organic matter
PMA:	Programme for Modernisation of Agriculture
SOC:	Soil organic carbon
SSA:	sub-Saharan Africa
t :	tonnes
UBOS:	Uganda Bureau of Statistics
UK :	United Kingdom
WA:	Western Australia
y :	year

Chapter 1. Introduction

1.1 Background

Uganda’s economic development as well as the society’s livelihood depends on its agricultural sector (World Bank 2008; Salami et al. 2010). Agricultural output mainly comes from about 2.5 million smaller landholder units, who constitute three-quarters of total households in Uganda. The smallholder units are typically two hectares or less, have a low use of purchased inputs, realize low output relative to potential and are characterized by low utilization of credit (IITA 1993; Blackie 1994; Palm et al 1997; Dixon et al. 2003).

Farmers in sub-Saharan Africa (SSA), which includes Uganda, have traditionally cleared land, grown a few crops, and then moved on to clear more land, leaving the land fallow to regain fertility. The soil management techniques, particularly the long fallow periods under traditional cropping systems, which allowed soil nutrients to regenerate and soils to be protected from erosion, are no longer implemented . Population pressure now forces farmers to continuously crop, “mining” or depleting the soil of nutrients while giving nothing back (Henao and Baanante 2006; IFDC 2006; Wambi 2009). With little access to fertilisers due to costs, their unavailability and lack of knowledge of how to apply them at recommended rates, the farmers are forced to bring less fertile soils on marginal land into production, at the expense of wildlife and forests.

The declining fertility of Ugandan soils, particularly nitrogen (N) and phosphorus (P), is a major cause of decreased crop yields and per capita food production in Uganda, and in the mid to long term, a key source of land degradation and environmental damage (Nkonya et al. 2002). These low yields are a result of heavy reliance on low input technology, limited disease and pest management practices, limited use of fertilisers and suboptimal combination of inputs (Nkonya et al. 2002). In addition, there is high cost and waste of key agricultural inputs. As a result, farmers have substantially reduced use of quality inputs such as seed, fertiliser, and pesticides. For example, in 2006, it was reported by UNDP (2007) that the respective use of improved seeds, fertilisers, agro-chemicals and manure were only 6.3 %, 1.0 %, 3.4 % and 6.8%, respectively, of the parcel of agricultural land in Uganda.

Increased crop production needs adoption of improved input technologies, including use of more labour and more inputs like fertilisers. However, in SSA, because of inaccessibility of manufactured fertilisers and cost, livestock manure is the principal soil amendment available to a large number of smallholder crop-livestock farmers (Groove 1991; Powell and Williams 1993). Cattle manure is an important source of nutrients for many smallholder farmers in SSA, who cannot afford or use only limited amounts of manufactured fertiliser to attain more productive farming systems (Walaga et al. 2002; De Jager et al. 2007; Onduru et al. 2008). Cattle manure offers a number of benefits to the agricultural sector, such as increasing the water holding capacity of soils or buffering low pH soils (Benbi et al. 1998; Naramabuye et al. 2008; Haynes and Modi 2008; Hulugalle et al. 2009; Mpairwe et al. 2009). Smallholder farmers value dairy cows highly for the production of manure, in addition to their production of milk (Lekasi et al. 2001a; Kimani and Lekasi 2004; Randolph et al. 2007)). Peri-urban farmers of Kampala, Mukono and Wakiso identified insufficient cattle manure, labour shortage and/or knowledge as important constraints to using cattle manure (Muhereza 2005). Powell and Williams (1995) report increased nutrient losses, if the transition from open grazing to stall feeding is not accompanied by improved manure handling techniques.

1.1.1 The use and agronomic value of animal manures

The elemental content of animal wastes varies with the type of animal, age, diet, degree of decomposition, inclusion of non-wastes such as bedding and waste collection and management facilities (McCalla et al. 1977; Fontenot et al. 1983; McIntyre et al. 1992) with typical chemical composition for selected animal wastes given in Table 1.1. In mixed farming systems, manure and nutrient availability vary temporally and spatially, due to variations in crop/livestock ratio and livestock and manure management. In regard to plant nutrients, animal manures are considered lower in P and higher in potassium (K) than many organic manures/residues. Similar and higher values for these nutrients have been reported by Defra (2001b); Smith et al. (2003); Rigby (2008) and Kumar (2009) in the United Kingdom (UK) and India, respectively, due to supplementary feeds given to animals.

Table.1.1: Nutrient contents of various cattle manures in sub-Sahanan Africa

Manure type	% N	% P	% K	% C	C/N	Reference
Cattle manure	1.40	0.60	1.30	35	25	Lekasi et al. 2001a, Kenya
Manure/compost	1.12	0.30	2.40	24	23	Lekasi et al. 2003, Kenya
Farm yard manure	1.62	0.50	1.43	-	-	Kimani and Lekasi 2004
Cattle manure	1.40	0.53	1.54	-	-	Onduru et al. 2008, Kenya
Cattle manure	1.22	0.29	2.14	-	-	Onduru et al. 2008, Kenya
Cattle manure slurry	2.10	0.53	3.90	33	16	Snijders et al. 1992, Kenya
Manure solid	0.89	-	-	13	14	Nhamo 2004, Zimbabwe
Indoor manure	1.96	0.36	1.75	-	10	Jackson and Mtengeti 2005, TZ
Cattle manure fresh	1.40	0.50	0.50	-	-	FAO 2001
Cattle Kraal + litter	0.50	0.22	0.77	-	-	
Farm yard manure	0.32-2.2	0.04-0.92	0.4-1.2			Harris 2002, West Africa

Unlike in SSA, elsewhere, an estimated 103 million tonnes (fresh weight) of biodegradable wastes commonly known as organic residuals are recycled to agricultural land each year in the UK (Gendebien et al. 2001). Animal manure accounts for approximately 88% of these organic residues, 4% biosolids from waste water treatment, 1% is source segregated compost and 7% industrial biowastes. While in the United States of America (USA), it is estimated that more than 335 million tons (dry matter) waste is produced annually on farms, representing almost a third of the total municipal and industrial waste produced every year (USDA Agriculture Research Service 2006). The animal feeding operations annually produce about 100 times more manure than the amount of human sewage sludge processed in US municipal wastewater plants (Gerba and Smith 2004). Further, the livestock of the United States produces 20 times as much excrement as the entire human population of the country. For example, one dairy farm with 2,500 cows produces as much waste as a city with around 411,000 residents (USEPA 2004).

Optimal N requirement in Uganda is not widely practised. Over-fertilisation of a vital nutrient can be as detrimental as under fertilisation (Baker and Harris 2005) The supply of N to crops from fertilisers and organic sources must not exceed crop requirements because any excess of N beyond the needs of the plant will cause plant burn. This burn may become visible very soon after the fertiliser is applied or, in the case of manures, the effect may be delayed many weeks (Baker and Harris 2005). However, there is minimal information on the properties or agronomic characteristics of cattle manure in Uganda and the availability of N from cattle manure sources, hence the need for this study.

1.2 Problem statement

Declining per capita food production and soil fertility depletion are threatening the livelihoods of many small-holder farmers in East Africa, including Uganda (NEMA 2001; Nkonya et al. 2002). Arable land per capita is expected to decline from 1.1 ha in 1991 to 0.6 ha in 2015 (NEMA 2001). Increased application of organic inputs, along with appropriate rates of manufactured fertilisers, is considered essential to maintain soil fertility and productivity in intensive cropping systems. However, the application of inorganic inputs alone is not a feasible option to combat poor soil fertility (Zake et al. 1999; Pender 2002; Briggs and Twomlow 2002; Olson and Berry 2003). Considering the high cost of inorganic fertiliser and its associated effects on the environment, a combination of both inorganic and farmyard manure is a feasible option friendly to the farmer, soil and environment (Muriithi and Irungu 2004). This would enhace crop production that ultimately increases food production and productivity which are still low in Uganda.

Per capita food production in Uganda hit a low in 1980, and even with recent increases it has not reached the levels of the 1970's (NEMA 2001). Generally, agricultural productivity is low in Uganda compared to the potential yields produced at research stations. For example, the actual yields as a percentage of potential levels are 51% for maize, 68% for soybeans, and 55% for sunflowers (Bashaasha et al. 2001). Examples of other crops whose yields have decreased due to soil fertility decline in addition to other factors such as pests and diseases include bananas, coffee, and vegetables. For instance, most farmers in central, southern and southwest Uganda produce these crops particularly bananas. Indeed, Uganda is the world's largest producer and consumer of bananas. Banana production, however, has been stagnating over the past two to three decades with declines in outputs and yields. Any increases in production have come due to an expansion of the area under production. The traditional centres of banana production, Mpigi, Mukono and Wakiso districts in Central Uganda, have been experiencing declining yields and farmers are switching to cassava and sweet potatoes. Meanwhile, banana production is moving towards new land opening up in the West (Zake et al. 1999). There is a need therefore to investigate systems to improve crop yields through improved fertiliser use and management.

In Africa, average fertiliser use is 21 kg ha^{-1}, but in SSA (excluding the Republic of South Africa), use is only 10 kg ha^{-1}. the average application rates of fertiliser for arable crops in SSA are estimated to be 30 kg ha^{-1} $year^{-1}$ in Kenya, 14 kg ha^{-1} $year^{-1}$ in Ethiopia, 5kg $ha^{-1}year^{-1}$ in Tanzania and 1 kg ha^{-1} $year^{-1}$ in Uganda (Ariga and Jayne 2006; Smaling et al. 2006). An 18% annual increase is needed to supply the nutrients to produce enough food for the growing population, and to return nutrients to the soil (Wallace and Knausenberger 1997). Current agricultural practices mine soil nutrients, with average removal of more than 24 kg $ha^{-1}year^{-1}$ of N, P and K (Wallace and Knausenberger 1997). The world average fertiliser use is more than 100 kg ha^{-1} (Smaling et al. 2006); in developing countries as a whole (including Africa) it is more than 90 kg ha^{-1} (IFDC 1996). These average rates mask a key characteristic of fertiliser use: fertiliser use on most land is zero, and only moderate amounts are used on cash/export crops (IFDC 1996). These annual rates are low compared to other countries including Ireland of 595 kg ha^{-1}, Netherlands of 450 kg ha^{-1}, Egypt of 386 kg ha^{-1} and Costa Rica of 385 kg ha^{-1}, respectively, to mention a few (World Resources Institute 2011).

The effective use of cattle manure for soil nutrient amendment to agricultural land could be a significant step towards increased food production in SSA.

Importantly, 494 million hectares of land are affected by soil degradation, and of this 25% is highly degraded with a loss in its productive capacity. Significantly, Ayoub (1994) reported that an additional 39% was moderately degraded and faced a deforestation threat if there is no replenishment of depleted resources and sustainable use in the future. This decline has been attributed to many causes including continuous cropping, cultivation of marginal areas, and inadequate replenishment of nutrients (Kaizzi et al. 2002; Pali et al. 2005) and lack of yield-enhancing investments from improved science and technology that would come from agricultural research (Bashaasha et al. 2001). Invariably, this has led to a decline in soil organic matter, degradation in soil structure and loss of other bio-physical soil processes resulting in low soil fertility (Bekunda et al. 1997).

1.2.1 Justification of the study

The quality of the soil is an important determinant to yields in crop farming and therefore the practice of applying livestock manure to maintain soil fertility is a key prerequisite to sustain crop productivity in the tropics. With the increase in world population and the ongoing need for fertilisers to produce food crops, cattle manure offers an alternative fertiliser to manufactured fertilisers. Cattle manure as a soil amendment improves soil quality and thus crop productivity, but as a variable input, its levels need to be determined for economic efficiency. There is lack of soil testing and models to predict fertiliser need in Uganda hence the basis of the study.

It is envisaged that the productivity of smallholder farming could be enhanced if manure produced by cattle could be used more effectively for plant production. There are no empirical studies that have been carried out to assess the option of applying cattle manure on crop-livestock systems and livelihoods of smallholder farmers in Uganda or to find optimum levels of cattle manure to maximise crop productivity. The study was designed to determine the production functions for both cattle manure and inorganic fertilisers for nutrient replacement in smallholder crop-livestock systems in Uganda.

In the study, cattle manure was compared to inorganic fertiliser as a source of N to assess its economic efficiency for crop production and determine its optimal level of application. The study reviewed various factors affecting manure quality, manure handling techniques, socio-economic constraints and other options of nutrient replacement (organic).

The results of the study can be used by researchers, extension agents and policy makers in Uganda and countries with similar farming systems, who are in a position to advise the use applications of cattle manure to increase crop productivity. This is a major benefit to the farmers for they are required to develop and incorporate feasible and sustainable soil fertility management practices in line with their farming practices with limited quantities of inorganic fertiliser available.

The results from this study will enable farmers to allocate their limited resources more efficiently and ultimately make the agriculture sub sector more efficient and competitive and better able to feed the growing population.

1.3 Aims of research

1.3.1 General objective

To assess the potential of using cattle manure application for N replacement in smallholder crop-livestock systems in Uganda.

1.3.2 Specific objectives

1. To identify socio-economic issues affecting the use of cattle manure and inorganic fertiliser in Uganda.
2. To determine the crop response of Brassica *spp* to cattle manure as a source of N compared to inorganic N.
3. To model the response of Brassica *spp* to applications of N from cattle manure and inorganic fertiliser in Western Australia and Uganda.

1.4 Structure of the thesis

Figure 1.1 shows the structure of the thesis with the objectives of the research project highlighted.

Objective I. To identify socio-economic issues affecting the use of cattle manure and inorganic fertiliser in Uganda	Chapter 1. Introduction, justification, objectives of the project and problem statement. Chapter 2. Literature review on cattle manure and inorganic fertilisers and their effect on soil properties, nitrogen and its transformation processes and plant nitrogen uptake and utilisation.
Objective II. To determine the crop response of Brassica *spp* to cattle manure as a source of N compared to inorganic N.	Chapter 5. The relative effectiveness of cattle manure as a source of N for crop production compared to inorganic fertiliser-year 1. Chapter 6: Relative effectiveness of the nitrogen in cattle manure compared with an inorganic fertiliser-Year 2.
Objective III. To model the response of Brassica *spp* to applications of N from cattle manure and inorganic fertiliser in Western Australia and Uganda.	Chapter 3: Choosing models that assess economic returns to nitrogen fertiliser applications. Chapter 4: A socio-economic survey of cattle manure application by small-holder crop livestock farmers in Uganda. Chapter 7: Comparative growth response of cabbage (*Brassica oleracear* var Capitata) and canola (*Brassica napus*) under controlled conditions. Chapter 8: Modelling available N, N uptake, potential yield and economic returns in cabbage (Brassica *spp*) production Chapter 9: modelling for Ugandan situation using SYN model in cabbage (Brassica *spp*) production Chapter 10. General discussion, conclusions and recommendations of the project findings.

Figure 1.1: Structure of the thesis

1.5 Outline methodology

Having considered previous studies in the research area, the methodology produced to meet the specific objectives of the research is outlined in Figure 1.2, along with the research deliverables

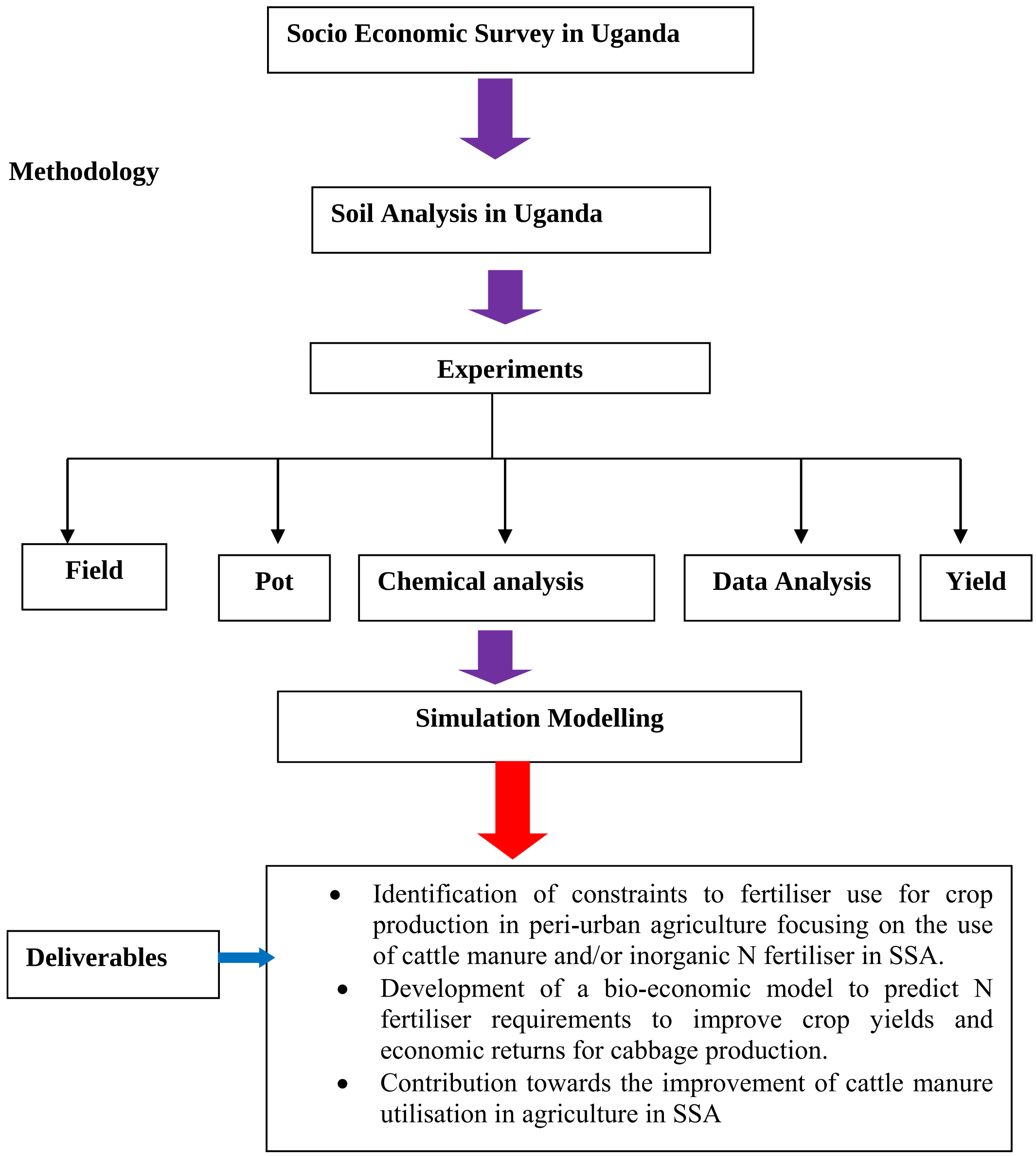


Figure 1.2: Outline of research methodology and deliverables

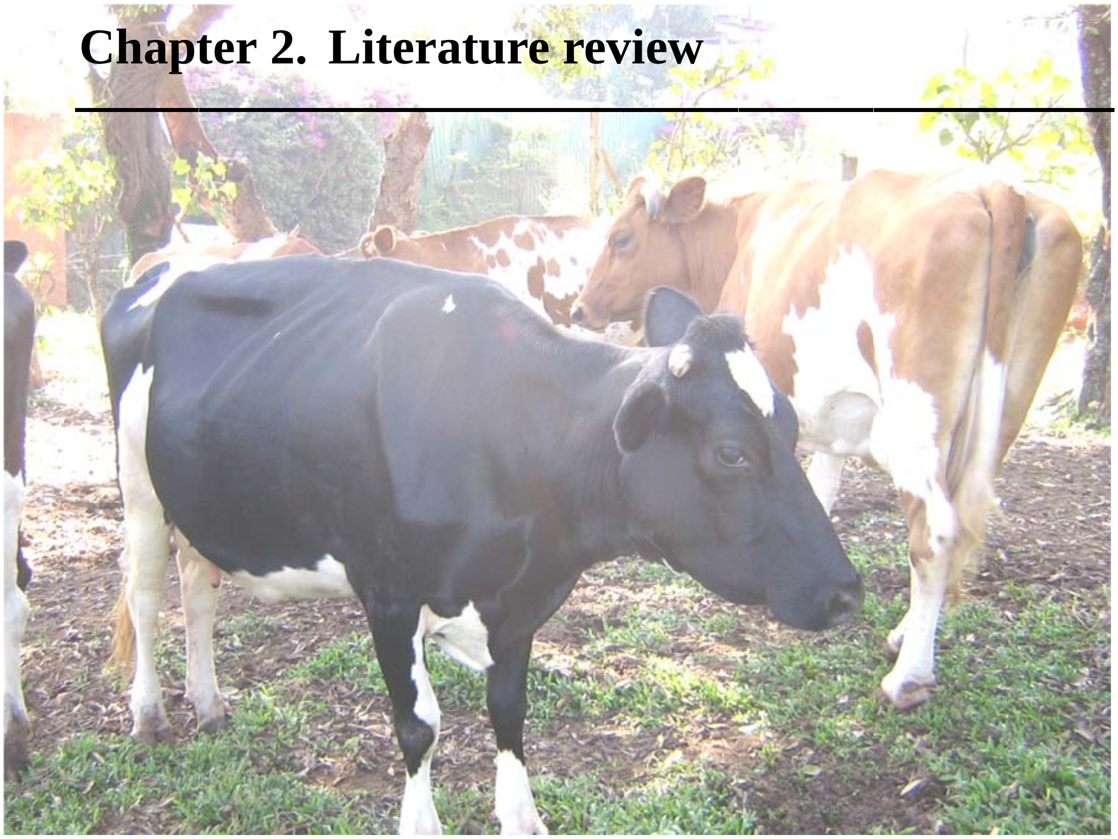
Determination of cattle manure analytical properties was required to assess the variation in properties of cattle manure stored at varying periods to indicate the capability of the manure to supply essential crop nutrients and their effect on yield attributes.

Experimental data were required for an accurate understanding of the relationship between applied cattle manure and inorganic fertiliser and resultant crop yield and N availability. Two types of experiments were concluded: field and pot. The field experiment was necessary to study the effects of cattle manure under actual farming conditions. This was essential in providing results, which could be extended to practical recommendations for cattle manure application to agricultural land, and could allow for a more accurate assessment of the economic costs and benefits involved.

The pot experiment was supplementary to the field experiment, aiming primarily to allow for more accurate determination of the growth response of different species of Brassicas grown in either Australia or Uganda. The simulation modelling using Select Your Nitrogen (SYN) was necessary to study the N availability, crop yield potential of the cattle manure under Australian and Ugandan conditions, and the agronomic benefits of cattle manure application to nutrient response.

An analysis of the economic modelling following SYN to predict N availability, N uptake, and potential yield involved in cattle manure utilisation in agriculture in Uganda was conducted to assess whether farmers applying the manure would realise economic benefits and thus warranting them to use this organic material on their land and or whether optimum combinations of manure and inorganic fertiliser as a source of N would increase economic returns in addition to likely carry over benefits of manure in subsequent years.

Chapter 2. Literature review



2.1 Background to Uganda

2.1.1 Topography, climate and population

Uganda lies astride the Equator between 4^o north and 1^o south and stretches from 29.5^o east to 35^o west covering an area of 240,000 km^2, of which 194,400 km^2 is land, 33,926 km^2 is open water and 11,674 km^2 is permanent swamps. Much of the country lies on the African plateau at an altitude of 900-1500 m above sea level; where it has an annual tropical rainfall of at least 750 mm and a temperature range of 10^{o}C-25^{o}C (UN Water 2006). The population is estimated at 34.5 million (UNFPA 2011), of which more than 80% is rural, with a growth domestic product (GDP) per capita of US$420 (Ssewanyana and Okidi 2007; World Bank 2011). Agriculture in Uganda accounts for 30% of GDP, 85% of export earnings and 70% of total employment. Most of the agriculture is of a subsistence nature and characterised by low production and low productivity (MFPED 2007). The influence of soils, topography and climate on the farming systems in Uganda has led to the dividing of the country into seven broad agro-ecological zones as shown in Figure 2.1 (MWLE 2003).

Rainfall patterns

In Uganda, rainfall is the most sensitive climatic variable because it affects many social and economic activities. The wettest areas are located within the lake basin of central Uganda (UN Water 2006). The western and northern districts occasionally experience long droughts, which are becoming more frequent. The eastern region receives moderate rainfall. The main stable rain season over most parts of the country is from March to May (UN Water 2006). The high variability of rainfall in some parts of the country results in high incidences of droughts and floods especially over the eastern parts of the country (UN Water 2006).

The southern half of Uganda has a bimodal type of rainfall, which allows farmers to grow two crops annually with adequate grazing for livestock throughout the year. Around Lake Victoria, the annual rainfall averages 1,350 mm, which is well distributed. To the north, the two rainy seasons gradually merge into one.

Dry periods become longer at the end of the year, with annual rainfall ranging between 900-1,300 mm, which restricts the range of crops that can be grown (MWLE 2003). These conditions are not suitable for perennial food crops such as bananas but favour extensive livestock production.

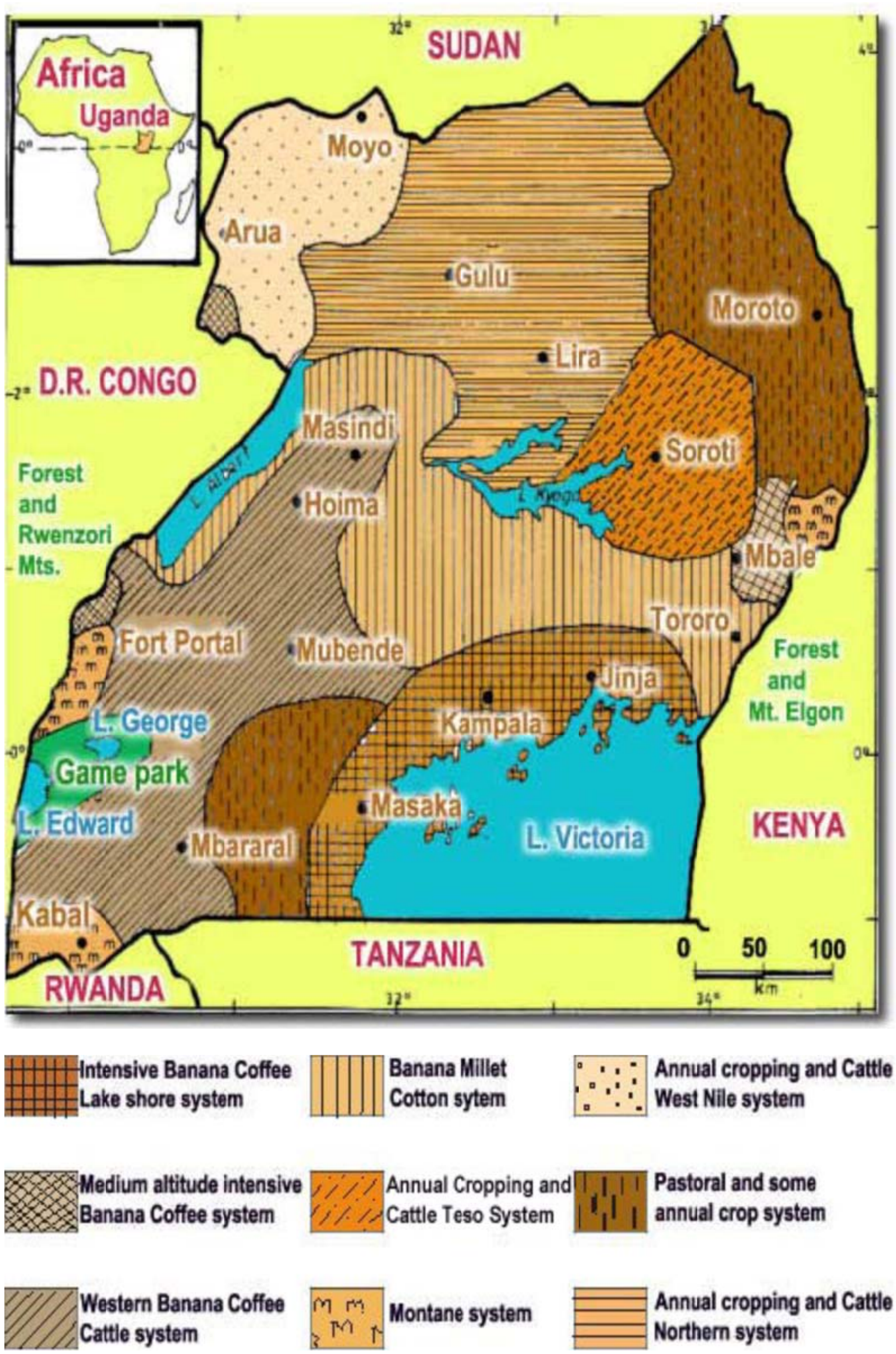


Figure 2.1: Map of Uganda showing agri-ecological zones

Source: (Mwebaze 1999)

Temperature

Uganda experiences moderate temperatures throughout the year with a long-term mean temperature of 21°C. Mean average temperatures range from a minimum of 15°C in July to a maximum of 30°C in February. In the highlands and around mountains, the elevated landmass exerts a local influence in climate producing rainfall and temperatures that are unique from the lowlands (UN Water 2006), with mean daily temperature of 28°C. Extreme temperatures as low as 4°C are experienced in Kabale district while temperatures below 0°C are registered on the higher mountain ranges of Rwenzori and Elgon situated in the western and eastern regions of the country, respectively. Rwenzori has a permanent ice cap, whose size is currently reducing due to global warming. Highest temperatures of over 30°C are experienced in Gulu, Kitgum and Moroto in the north and northeastern parts of the country, respectively (UBOS 2006).

2.1.2 Terrestrial and soil resources

Uganda has 7.2 million hectares of arable land under crop agriculture; less than 50% of the arable land (16.8 ha); however, this will run out in most parts of Uganda by around 2022, with eastern regions currently declining at the fastest rate. The annual cropping practices that encourage high soil erosion and increased reclamation associated with new crop enterprises; such as rice growing are responsible for the quality and quantity of the available land and soil resources (NEMA 2007); further aggravated by high population densities (MAAIF 2002). Uganda's soils are divided into six categories according to productivity including very high to high productivity, moderate, fair, low, negligible, and zero productivities. The high and very high productivity soils cover 8% of the area of Uganda (MWLE 2001), being minor compared to the size of the country. Therefore, the fair and low productivity soils must be managed effectively in order to sustain Uganda's agriculture.

The soils of Uganda are defined by their parent rock, age of soil and climate. The most dominant soil type is Ferralitic soil, accounting for about two-thirds of the soils in the country (MWLE 2001). Their reddish and yellowish colours are due to high concentrations of iron hydroxides, and aluminium oxides. While they are able to support agriculture initially, they are unfit for long-term crop farming due to high levels of acidity resulting from weathering (Brady 1996). In general, upland soils are deeply weathered and gravelly; they are acidic but also contain a good amount of organic matter due to leaf-fall and rapid decomposition. This region contains soil types such as Ferralsols, Nitosols, Acricols, and Afrenosols. The land also contains Cambisols, which are newer and more fertile, and Lithosols, which settle shallowly on steep slopes. The lowland soils exhibit characteristics of deeper, finer soils; and newer sand particles similar to those found along the coastlines. The soil is comprised mostly of Gleysols and Fluvisols, which are the deeper and finer types; and Regosols, which are the newer sand particles also common along coastlines (Sant'Anna 1994). Specific data on soil physiochemical analysis are lacking in Uganda for all regions.

2.1.3 Economy

The 1980s and 1990s were declared decades of global development, though an illusion in Africa, more especially SSA, with Uganda one of the poorest countries of the world (Fukuda-Parr 2002; MFPED 2004; World Bank 2011). In 1962, Uganda's monetary management was sound and the domestic savings rate was 15% of the GDP. However, the economy was grossly mismanaged in the 1970s and 80s and the social economic welfare of the ordinary people was badly affected. This situation was made worse by the liberation war of 1979 and the 1981-86 guerrilla war, which disrupted the economic recovery policies, which were by then being implemented by the World Bank and International Monetary Fund (IMF). In 1986, the National Resistance Movement (NRM) government, which is the current government, inherited a tattered economy surviving on a few cash crops for export, predominantly coffee. In 1987, with the assistance of the World Bank and International Monetary Fund (IMF), Uganda launched a macro-economic stabilisation program aimed at lifting the economy. Though progress is considerable in regard to macro-economic stabilisation, growth and development have not yet reduced poverty significantly among the rural poor.

In 2002/2003, 8.9 million persons were in poverty, (UNHS 2003; UBOS 2006) with the growth rate in poverty levels higher for urban than for rural areas. Poor people constitute 61% of the population, while 30% constitute the absolute poor with women the poorest of the poor, termed the "feminisation of poverty" (Chant 2006). Kabeer (1998) argues that "not all the poor are women and not all women are poor. It is reported that 30% of households in Uganda are headed by women and that these are generally poorer and more vulnerable to hunger and disease among others, than most male headed households".

Poor people have defined poverty as not only lack of incomes but also inability to meet basic and social needs and a feeling of powerlessness to break out of the cycle of poverty and insecurity of person and property (MFPED 2000; Okidi and Mugambe 2002). In Uganda, poverty is mainly a result of long standing inappropriate policies compounded by external factors (Okwira 1999). However, the World Development Report 2000/2001 identifies institutional, social, economic and human factors as the major causes of poverty. Okidi and Mugambe (2002) futher report that lack of human and technical skills to exploit available income generating and life improving opportunities are both a cause and symptom of

poverty. With the bulk of Uganda's population in the subsistence sector utilizing unskilled labor, it is essential that for growth to be pro-poor it should focus on labor-intensive techniques. But labor intensive production of goods and services in today's competitive world requires that the abundant labor be abundant in skills. Inability to access and process information about available income generating and life improving opportunities is a major constraint to poverty reduction.
More so, lack of affordable comprehensive insurance mechanisms to enable people to ward off economic, health and other related shocks, can lead to slippage into poverty at the occurrence of any such shocks (Okidi and Mugambe, 2002). Vulnerability to shocks can therefore be a cause or symptom of poverty. In Uganda there are no effective state operated safety nets as mechanisms for mitigating risks of natural and man-made disasters.

Furthermore, vulnerability and poverty per se can be exacerbated and perpetuated by insecurity of life and property. This is particularly important in the Ugandan context where the postindependence era has been characterized by civil strife and political instability. The violent political changes and the guerilla wars that plagued the post-independence Uganda have deprived many households of able-bodied persons and caused severe problems associated with internal displacement of people (World Bank, 2000). .Chapter 4 deals with socio economic factors influencing cattle manure and fertiliser use in Uganda.

The role of agriculture in Uganda's economy

Agriculture is the backbone of Uganda's economy involving 2.5 million farm families, accounting for approximately half of the country's GDP and nearly all export revenues. Over eighty percent of the population in Uganda live in the rural areas and derive a livelihood from farming (Ayoo 2000; MFPED 2007). However, the challenges still facing the Uganda farmers are enormous. The Ministry of Agriculture Animal Industry and Fisheries (MAAIF) and the plan for modernisation of agriculture (PMA) identified the lack of access to resources such as land and capital, lack of employable skills and gender discrimination (MFPED 2007; 2008) as the major obstacles towards achieving the UN Millennium Development Goals (MDGs).

2.1.4 Crop yields

Average farmer crop yields for common crops in Uganda are alarmingly below potential yields obtained at its national research stations, with coffee, beans and maize yields at 25% 22.9 and 32% relative to potential yields, respectively (Table 2.1). For example, banana yields in Uganda declined from 8.4 t ha^{-1} in the 1970s to 5 t ha^{-1} in the 1980s (Gold et al.

1999). This may be a result of complex interactions between several factors including soil fertility, pests, diseases, climate and management (Sserunkuuma et al. 2001; Bekunda et al. 2002; Nkonya et al. 2002). While there are no data to apportion the contribution of each factor to the low yields, evidence from long-term trials in Kenya, shows that continuous tillage of land results in soil infertility and consequent yield decline (Bekunda et al. 1997). Thus the general trends in crop yield decline in the east African countries are likely related to soil fertility decline. The major constraints to crop production in Africa have been attributed to soil nutrient depletion (Stoorvogel et al. 1993; Smaling 1993; Sanchez et al. 1997; Drechsel et al. 2001; Sanchez 2002; Nziguheba et al. 2010), ravages from insect pests and diseases (Karungi et al. 2006) and lack of adoption of improved crop germplasm or even the absence of appropriate varieties for the continent (Sanchez 2002).

Table.2.1: A comparison of research station yields and on-farm yields of selected staple and cash crops grown in Uganda

Crop	Yield t ha^{-1}		
	Potential	**On farm**	**% Relative to potential**
Banana	40-60	5.7	9.5
Maize	5-7	1.6	22.9
Beans	2.5	0.8	32
Cassava	50	8.5	17
Coffee	2.0	0.5	25

Source: (Van den Bosch et al. 1998; Bekunda et al. 1998) (data for 3 districts)

Common vegetables grown in Uganda

Vegetables are an important component in the diet of rural families in Uganda providing essential vitamins and minerals (Muyonga et al. 2008) In particular, cabbage (*Brassica oleracea*) and Amaranthus *spp* are the commonest grown vegetables because they require limited land. Muyonga et al. (2008) further report that Amaranthus spp, which is commonly known as Dodo is an easy crop to grow andis a nutrient rich food that can help to improve nutrition and food security among communities that heavily depend on subsistence agriculture; has a short growth period (one month), is resistant to common insect pests, can grow over a range of soil types and is easily grown by farmers.

Cabbage has gained popularity as a cash crop among peri urban farmers in Uganda, as evidenced by a 30% increase in land under production in recent years (Lekasi et al. 2001; Ssonko et al. 2005). Cabbage production has; however, only increased by 23%, indicating an overall decline in productivity (Ssonko et al. 2005).

2.2 Farming system management in Sub-Saharan Africa

Human population pressure on the limited land resource has led to the evolution of mixed crop-livestock farming systems as an efficient and sustainable means of producing food (McIntyre et al. 1992; Rufino 2008). Crops and livestock are no longer viewed as separate and inevitably competitive enterprises but complementary to each other. Though livestock is not a major driving force of the global economy, it plays a crucial role in food security and supports the livelihoods of approximately 1.3 billion people (Antwi et al. 2010).

In SSA, the smallholder system widely spread in the heavily populated regions where human food and livestock feed are produced on the same piece of land. Evidently, in many parts of the tropics, as the percentage of land under cultivation increases, so does the number of livestock (Bourn et al. 1986; Bourn and Wint 1994).

Intensification of livestock makes animals play important roles including traction (power)**,** income (cash) and manure (fertiliser). Delgado (1989) observed that mixed farming is a practice that permits higher labour inputs per unit of land in a profitable manner. As crop-livestock interactions become closer, the unit cost of livestock production declines which allows higher stocking rates per unit of land, which may increase competition for labour between livestock and crops. The increased competition for labour may be temporary as eventually intensification leads to private ownership of land and investment in land improvements. This in turn leads to increased use of perennial crops (trees) to produce products for sale and the planting of multipurpose trees (fuel and fodder) leading to further integration between crops and livestock (Tiffen and Mortimore 1992). These changes result in increases in household income unless a growing human population causes sub-division of holdings in the absence of alternative employment opportunities outside agriculture.

2.2.1 Crop-livestock integration and nutrient cycling

The depleted soil nutrients in the central districts of Uganda can be replenished with addition of fertilisers; however, most farmers use little mineral fertiliser, due to the high cost/prices compared to the price of crop output and/or poor distribution of rural markets. Therefore, the efficient management of nutrients through manure recycling within the crop-livestock system is necessary to support food production. Various animal manures including goat manure, chicken manure, rabbit manure and cattle manure can be used to improve soil fertility in SSA, with the latter used widely. Cattle manure, either aged or fresh manure is applied prior to crop establishment and by a few farmers in combination with inorganic fertilisers at planting (Muhereza 2005). However, Mazza et al. (2010) recommend that fresh manure must be used with caution in the garden because it may contain pathogenic bacteria such as *E. coli, Listeria*, and *Salmonella*.

Conversion of traditional cultivation into no-till or using a combination of animal manure and fertilisers, and improved fallows (mixed and natural) has been recommended by Vagen et al. (2005). These technologies are important in crop-livestock systems and benefit farmers as they fit the farm livelihood despite the constraints encountered by smallholder farmers (Vagen et al. 2005; Rufino 2008). Moreover, most farming systems in SSA rely on organic matter recycling to maintain soil productivity (Haque et al. 1995; Murwira et al. 1995; Bationo et al. 2006; Ncube et al. 2006; Tittonell et al. 2007; Zingore et al. 2007b); whereby crop productivity gains are achieved by concentrating organic matter and nutrients in home fields, at the long-term expense of declining productivity in remote fields and common lands. Table 2.2 lists the variation in some animal manure in terms of sources of plant nutrients with poultry layer farmyard manure having the highest N content of 5%, while cattle slurry has an N content of 2.3%.

Table.2.2: Typical nutrient content and availability in livestock manures and slurries

		Total nutrient contents (%DS per mg kg^{-1} FW)				
Manure type	**DS (%)**	**N**	**P**	**K**	**S**	**Mg**
Cattle FYM*	25	2.4	0.61	2.66	0.29	0.17
Pig FYM *	25	2.8	1.22	1.66	0.29	0.17
Poultry layer FYM*	30	5.3	1.89	2.49	0.51	0.44
Poultry litter *	60	5.0	1.81	2.49	0.55	0.44
Cattle slurry†	6	2.3	0.52		0.32	0.44
Pig slurry†	4	4.0	0.87	2.08	0.28	0.24

Source: (Defra 2001b).

*Nutrient contents in % dry solids (DS)

†Nutrient contents in mg kg^{-1} fresh weight (FW)

FYM= Farm yard manure

2.2.2 Importance of livestock manure in farming systems

In Africa, farmers keep livestock for many purposes including meeting their meat consumption, as a source of capital, for social status and for manure production. Livestock manure application to soil is a means of retaining nutrients on farms in Africa and its use can reduce expenses for commercial fertilisers (Lupwayi et al. 1999; Lupwaya et al. 2000; Harris 2002). In Kenya, nutrient losses from small Kenyan farms often greatly exceed nutrient inputs (Van den Bosch et al. 1998); also likely in Uganda. Smallholder farmers in Africa recognise the important role of manure in maintaining soil fertility (Rufino 2008) because much of their land is poorly productive due to continuous cultivation on soils that are often inherently poor in nutrients and receive little fertiliser. Therefore, the management and application of manure may slow nutrient depletion on these farms. Although manure is seen as a problematic waste in intensive agricultural systems in developed countries, it is a key resource to sustain crop productivity of the majority of smallholder farming systems in Africa (Giller et al. 2002; Rufino 2006).

In many developing countries, manure is often considered as important as milk, meat or draught power. Romney et al. (1994) quote a study in Zimbabwe which recorded that farmers reduced grazing time by keeping cattle penned longer in order to collect more manure, even though this meant a reduced feed intake and thus adversely affected animal production. Organic inputs may also enhance crop yield by providing nutrients that are in short supply and provided insufficiently by synthetic fertilisers.

Animal manure as a soil amendment and soil conditioner can serve as a low-cost source of organic fertiliser for crop production (Sommerfeldt et al. 1988; Okwuagwu et al. 2003; 2011; Uzoma et al. 2011).

More than two-thirds of the agricultural land in SSA is severely degraded (GEF 2003; Pender et al. 2004; FAO 2006; Nkonya et al. 2008; Pender 2008). In Africa and Asia, past erosion has reportedly reduced average yields by 10 to 20 percent over the past 100 years (Freney 1996). To increase agricultural production in the region; Henao and Baanante (2006) recommend intensification and use of inputs in efficient manner; to counteract negative nutrient balance as noted in Table 2.3 in soils of SSA, underpinned by poverty, affecting 95 million hectares of arable land which have reached such a state of degradation that only huge amounts of investments in soil restoration can make them productive (IFDC 2006).

The cumulative effects of negative nutrient balances in SSA are alarming and a few examples are listed in Table 2.3. In the central district of Mukono in Uganda, negative net balances are given. The net annual nutrient depletion was estimated at 68 kg of N, 10 kg of

P, and 21 kg of K per ha for the region. Benneh (1997) estimated a lower net loss of about 7 kg N, 1 kg P, and 4.5kg of K per ha of cultivated land in SSA.

Bekunda et al. (2004) quoted a study by Nkonya and Kaizzi (2002) who report that nutrient balances in farm plots of eastern Uganda varied as shown in Table 2.3. Stoorvogel et al. 1993 had earlier estimated an average of 22 Kg N, 2.5 kg P and 15 kg K ha^{-1} as negative balances for SSA region.

Table.2.3: Nutrient balance in sub-Saharan Africa

Location	**Balance kg ha^{-1} $year^{-1}$**		
	N	**P**	**K**
Uganda, Magada & Buyemba, Mayuge district[1]	-25	-8	-13
Uganda, Mukono district[2]	-49	-13	-17.3
Uganda, Arua[2]	-33	-6	7.3
Uganda, Palisa district[3]	-21	-8	-43
Uganda, Kamuli, Iganga & Mpigi districts[3]	-31	-4	-38.9
Uganda, Magada village, Mayuge district[4]	-108	-14	-94
Eastern Uganda (average 8 villages) [4]	-83	-10	60
Western Kenya [5]	-76	-4	NA
Kenya, Machakos district[6]	-53	-1	-9
sub-Saharan Africa (Average)	-68	-10	-21

Sources:

[1]Schreinemachers et al. 2007, [2]Aniku et al. 2001, [3]Wortmann and Kaizzi 1998, [4]Kaizzi et al. 2002, [5]Shepherd et al. 1995, and [6]De Jager et al. 2001

Livestock manure can replace soil nutrients; although, concentrations of nutrients vary due to different types of animals, animal weights, diets, livestock production, and nutrients (Levington Agriculture 1997; Lander et al. 1998; Sheldrick et al. 2003; Hepperly et al. 2010). Lekasi et al. (2003) report that a percentage of total soil nutrient inputs, manure N accounts for 14%, manure P for 25% P and manure K for 20%. For many developing countries, manure will remain the main nutrient input (Levington Agriculture 1997). Manure is now used by over 95% of all smallholder farmers in the Kenya Highlands despite the fact that from the 1960s, when the use of organic fertilisers, particularly livestock manure, was considered to be at a nadir (Harris et al. 1997). However, manure use in developed countries has reduced due to fertiliser use. Nevertheless, for some developed countries, such as the Netherlands and Japan, with large livestock industries, the percentage of manure is expected to increase and fertiliser demand will fall.

Studies on the utilisation of composts and farmyard manure or on crop production in East Africa have been reported since the 1930s (Beckley 1934 and 1937; Mehlich 1965). Many crop response trials have looked at methods of application, effects on soil chemical and physical properties and effects on soil moisture (Dagg et al. 1965) and more recently biological properties and soil organic matter (Kapkiyai et al. 1999). The research conducted to date have not considered the relative effectiveness of cattle manure N application compared to inorganic N, developed a model to predict N availability, or established optimal N levels especially in the Ugandan context under cattle manure N application in crop farming (hence the basis of this study).

Although livestock provide many benefits highly valued by farmers, especially animal manures that contain large amounts of available N (Nzuma and Murwira 2000; Schlecht et al. 2006; Fronning et al. 2008; N'Dayegamiye 2009) Giller et al. (2006) suggest that making most efficient use of animal manures depends critically on improving manure handling and storage, and on synchrony of N mineralisation with crop uptake. Overall, manure is considered an excellent soil amendment as it contains multiple nutrients and can overcome deficiencies of P, S, Ca, Mg, Zn etc which are widespread in the sandy soils that cover a large part of the African land mass (Giller et al. 2006).

Nutrients other than those usually supplied by common synthetic fertilisers, such as sulphur (S), zinc (Zn) and calcium (Ca), have been reported to limit cereal production in parts of the Guinea savannah (Agbenin 2003). However, the extent to which these nutrients limit crop yields, and the role organic inputs may play in relieving them, are poorly documented.

2.2.3 Contribution of livestock manures and slurries in soil fertility maintenance

The contribution of cattle to the external N balance varies from 0 to 56 kg N per cow year^{-1} including young stock, while the contribution to the "net" N balance ranges from -39 kg N to +29 kg N per cow. Nitrogen and manure availability for land application vary widely, ranging from 5 to77 kg N and 0.4 to 1.8 tonnes of manure on dry matter (DM) basis per cow year^{-1} (Snijders et al. 2008; Snijders et al. 2009). Large crop yield increases can be obtained when inorganic fertilisers are used in SSA, for example, maize yield increased by 150% relative to control due to NPK fertiliser application with reported rates of 176 kg N ha^{-1} in Nigeria (Heisey and Mwangi 1996) and by 184% when the soil was amended with lime and manure. Higher improvements have been observed in east and southern African countries (Bationo et al. 2006).

According to Carter and Murwira (1995),mineral fertiliser accounts for 64% of the entire N used by smallholders, while manure accounts for 36%. Manure provides 57% of the mass and 87% of the total N content of locally available inputs. Further, it contributes significantly to the overall N budget, even on farms that use large amounts of mineral fertiliser. Therefore, there is a need to determine rates of cattle manure that will make it more effective as a soil amendment.

Presently, fertiliser recommendations in the UK are based on research into N and P availability in manures and slurries as affected by the effect of timing, soil type and methods of application (Smith et al.1984; Jackson and Smith 1997; Nicholson et al. 1999). The fertiliser value of slurries is considered to be equivalent to their NH_4-N content, which is 40–60 % of total N and for farmyard manure (FYM)is 10-25 % of total N. It is recommended that 50-60% of crop N requirement is met by supply from organic manures in the UK (Defra 2001b); this is of economic benefit and means that there is no risk of incurring yield deficit by variable manure N supply. When crops are newly sown, additional mineral fertiliser may improve crop utilisation of nutrients from organic manures because the high availability of nutrients will stimulate root growth and establishment (Khan et al. 2004; Antil and Singh 2007; Myint et al. 2010).

Although organic manures provide a number of nutrients that are essential for plant growth and improve crop yields, they are not considered full substitutes for synthetic fertilisers (Vanlauwe and Giller 2006). The combined application of organic inputs and synthetic fertiliser in crop production resulted in synergistic positive effects on crop yield and soil fertility status (de Ridder and van Keulen 1990; Agbenin and Goladi 1997; Iwuafor et al. 2002).

2.2.4 Nutrient contents in animal manure under different storage systems

The total N and soluble N content of manure has been reported to range from below 0.5% to over 4% (Lekasi et al. 2001b; 2003) depending on the type of management systems (Snijders et al. 2008). There is a large variation in N, P, K and C contents of livestock manure from Africa, including cattle slurry. Lekasi et al. (2001a; 2003))report that total N contents on DM basis varies from 0.3-2%, with averages of about 1.4% and 1.12% N less than ranges reported in the UK (Table 2.2). In another study, Lekasi et al. (2001b) found N values ranging from 1.3% to 1.5%. Nitrogen losses may range from less than 10% to about 90% and tend to be lower for more compact and anaerobic manure storage systems and for manures with higher C to N ratios.

Mean N content of 25 cattle slurries from Central Kenya, stored in a covered lined pit for less than a week, was about 50% higher than in the FYMs (Snijders et al. 1992). Onduru et al. (2002) report strongly varied C/N ratio of FYM from the surveys in central Kenya. They established that about 5% of total N in FYM is NH_4-N.

Nitrogen contents in slurries and FYM from temperate countries are often higher, due to higher protein contents in feed rations and more favourable collection and storage conditions, including lower temperatures. In the Netherlands, for example, average N contents in cattle slurry and FYM of about 4-5% and 2.5% with about 50% and 25%, respectively, of total N in the form of NH_4- N (Anonymous 1997; Oenema et al. 2011).

The variation in N content in urine is stronger than in FYM. It may vary from well below 5 to more than 10 g N l^{-1} (mainly mineral N), depending on ration composition, dilution with water, and storage and weather conditions (Bannink et al 1999; Kőlling et al. 2001; Rufino et al. 2006; Kölling 2010). However, the total nutrient contents in cattle manure will depend on the handling methods among which are fully discussed in sections 2.3.1 and 2.3.2.

2.2.5 Soil fertility management options in crop livestock farming systems

Rapid population growth in SSA, including Uganda has caused land scarcity, hence requiring adoption of intensification-oriented technologies (Pingali et al. 1987; FAO 1999). Intensification involves use of more labour, improved technologies and more inputs such as fertilisers in order to increase output from a unit of land. Given that smallholder farmers have been unable to access mineral fertilisers, with livestock manure being the principal soil amendment available though scarcer (Powell and Williams; 1993; Gachimbi et al. 2007) alternative sources of fertiliser warrant investigation. Among many types of organic amendments available, the use of poultry manure, sewage sludge, crop residues, improved fallows and crop rotation have been reported further.

Poultry manure

Numerous studies (Chae and Tabatabai 1986; Nicholson et al. 1996; Chadwick et al. 2000 and Nicholson et al. 2003) as quoted by Rigby (2008) report that poultry manure contains higher concentrations of available N, Ca and P than other manures with typical total N contents of 5.0 % and 5.3 % DS for poultry litter and poultry manure, respectively. In field investigations, Nicholson et al. (2002) established that N fertiliser replacement values of poultry litter are between 33-36 % of inorganic N; dependent on the crop type and timing of application. Likewise, in a number of laboratory incubation studies, Chae and Tabatabai (1986) and Chadwick et al. (2000) report that the organic fraction is less stabilised in poultry manures having mineralisable N contents of between 25-40 % (Sims 1986) and up to 67 % of N. Bitzer and Sims (1988) assert that the low C: N ratio of poultry litter (<10:1) signifies that organic N is readily mineralised because it is a mixture of faeces, bedding material, feathers and uneaten food and is therefore dry and collectable and a useful fertiliser source (Stephenson et al. 1990).

Sewage sludge

Recycled organics such as sewage stabilised sludge have been used in agriculture, forestry, landscape and mine rehabilitation as a source of N and P; for example, in Australia, and offer significant fertiliser potential (Wilkinson et al. 2000). The reuse of composted sludge as a soil conditioner in agriculture and horticulture returns nutrients essential for plant growth back to the soil. Less chemical fertilisers are required and the organic carbon helps to improve soil structure for soil aeration, water percolation and root growth. The N and P are released gradually for plant uptake compared to the more soluble chemical fertilisers. The potential of leaching of the nutrients to ground or surface water by rainfall run-off is much reduced. Sludge applied to infertile agricultural and acidic soils increased earthworm abundance (Baker et al. 2002) responsible for soil forming properties. The sewage sludge also reduced runoff and increased surface retention of rainfall due to improved conditions for better infiltration (Joshua et al. 1998). Raw sewage sludge, however, is not suitable due to potential damage to human and livestock health through contamination of soil and crops with pathogens (Joshua et al. 1998; Lang et al. 2007; Lang and Smith 2007).

Crop residues

Crop residues are increasingly gaining importance as a way of augmenting soil fertility and as a precursor to soil organic matter. Poulain (1980) report that organic residues contain appreciable amounts of nutrients; however, Nandwa (1995) and Snapp et al. (1998) found that low quality crop residues immobilise N and P temporarily exacerbating nutrient deficiencies. Crop residues of maize stovers, beans, sorghum, millet, tobacco, pigeon peas and cowpeas are potentially used as soil amendment in SSA.

Farmers in SSA and Uganda, currently use crop residues for various purposes including feeding livestock, incorporating them into the soil, mulching, burning to clear off the land, fuel for cooking, selling to neighbours, and constructing trash lines in high altitudes and using them as livestock beddings (Gachimbi et al. 2003). Nzuma and Murwira (2000) established that crop residues were dominantly used for constructing trash lines followed by fuel for cooking or burning them to clear the ground before tillage. The latter practice can help destroy pests, pathogens and weed seeds, and the resulting ash can enhance plant growth by reducing the acidity of the soil. However, when crop residues are burned most of the N and S and part of P are lost (Giller et al. 1997). For example , Heard et al. (2006) report that burning spring wheat, oat, and flax straw resulted in 98 to 100% loss of N, 70 to 90% loss of S, and 20 to 40% loss of P and K in the northern great plains of Manitoba, Canada .

Gupta (2011) report that, the effect of absolute loss of nutrients from stubble burning may be greater than the temporary tie-up of nutrients during the decomposition in the southern Australian cropping regions; however the significance of these effects vary depending upon stubble load, time and type of burning and other agronomic factors. The study further states that reducing C inputs through stubble burning, removing stubble by over grazing and export of residue would impact on the level of biological activities related to nutrient cycling (mineralization, timing nutrient release and free-living N fixation), disease suppression and contribute to losses in soil organic matter.

Improved fallows and biomass transfer

Improved fallow and biomass transfer involves planting of fast growing plant species that produce easily decomposable biomass (Kwesiga et al. 1999) and have been recommended to improve soil fertility in Eastern Africa (Sanchez 1999; Fischler and Wortmann 1999; Rommelse 2000).

In Uganda, these technologies were introduced into farming systems in the eastern district of Tororo (Waata et al. 2002; Nyende and Delve 2004). The shrubs and tree species introduced into farming systems included *Mucuna pruriens, Canavalia ensiformis, Tithonia diversifolia, Sesbania sesban, Crotalaria ochroleuca, Calliandra calothrysus, Dolichos lablab, and Tephrosia vogelli.* However, elsewhere the adoption of these systems has been hindered by increased demands on production factors such as land, labour and capital (Fischler and Wortmann 1999).

Sanchez et al. (1997) and Rattray and Ellis (1952) recommend fallowing as a better option for soil fertility management to increase yields of the subsequent crops; however, due to population increase this is decreasing because of land shortage. Only short periods of fallow exist in SSA and Uganda and can no longer restore soil fertility. Elsewhere, attempts have been made to develop improved fallows by using legumes and shrubs such as Sesbania, Tephrosia and Tithonia species with considerable success in Western Kenya, Zimbabwe and Zambia, among other countries (Onduru et al. 2002; Abunyewa and Karbo 2005; Basweti et al. 2011), which could be adopted in the central Ugandan districts and other areas with similar farming systems.

Abunyewa and Karbo (2005) identified the management of pigeon pea and its biomass as a promising means of improving many abandoned arable fields in Ghana. They compared three pigeon-pea management options and a natural fallow (two-year fallow period) in terms of maize grain yield and changes in Soil Organic Carbon (SOC), total N and cation exchange capacity (CEC). Pigeon pea grain yield averaged 646 and 550 kg ha^{-1} in the first and second year of fallow, respectively. In the first year after fallow, maize grain yield averaged 1.41 t ha^{-1} significantly influenced by the fallow system. After the two-year fallow period, increase of SOC on the pigeon pea fallow plot compared with the natural fallow plot (30.5%), total N (48.5%) and CEC (17.8%).

A number of trees are recommended for improved fallow by Thangata and Alavalapati (2003), for example, in western Tanzania, the major leguminous tree species include *Sesbania sesban* and *Gliricidia sepium*. Various studies have shown the potential of agro forestry as an approach to sustainable agriculture production and soil management, especially in the tropics (Nair et al. 1999).

Matata et al. (2010) note that lack of farmer awareness of improved fallows and inability of farmers to wait for two years before obtaining direct benefits are the major constraints to this system. The study identified farmer training through workshops and seminars, enforcement of village by-laws on animal grazing, and facilitation of farmers' access to credit as the major approaches to enhance adoption. Kwesiga et al. (1999) similarly concluded that improved fallow was a sustainable option to replenish soil fertility within the shortest possible time.

Green manuring and legume cover cropping as part of improved fallowing are also amongst the recommended techniques of maintaining soil fertility through the addition of decomposing plant material. However, the latter is mostly hampered by inadequate information on its use and technologies for incorporating it into the soil in SSA (Ofori 1980). Gachene et al. (1999) report that the adoption of legume cover crops (live-mulch) is constrained by availability of land, labour, cash, and inputs and knowledge of legume cover crops and their appropriateness in the farming system. However, potential benefits of adopting legume cover crops include improved soil productivity through increased soil organic matter content, good quality soil physical and microbial properties, suppression of weeds and pests, and erosion control (Palm et al. 1997).

Crop rotation

Crop rotation is the successive planting of different crops on the same land to maximise soil fertility and help control pests and diseases by interrupting their life cycle; harmful pests and diseases are unable to build up to damaging levels either in the soil or on the host plants (Sustainable Gardening Australia 2011).

Although grain legumes should be promoted as sound crop rotation, certain crops such as beans, soybeans, and groundnuts take most of their fixed N away in the grain, leaving little for the subsequent crop. For instance grain legumes in Malawi are estimated to add about 30 kg N ha^{-1} to the subsequent crop (MDG Africa Steering Group 2008), a very desirable amount; but not sufficient to replace total mineral N applications.

Therefore, to appreciate the role of organic manures in crop-livestock farming systems, combined mineral and organic fertiliser sources of nutrients and good soil management practices are often recommended for better results to ensure adequate and balanced nutrients are supplied for crop growth and will be discussed further and investigated in chapter 4.

2.3 Cattle manure handling and storage methods

2.3.1 Application and storage methods of cattle manure in crop-livestock systems

The method of application of cattle manure plays a significant role in maintaining the quality of the manure and subsequent release of nutrients. Three principal methods recommended for field application of manure include: spreading of solid material when soil and crop permits, injecting the slurry of water and manure into the soil or spraying it on the surface, and if using irrigation, injecting the slurry into a sprinkle irrigation system. The spreading of solid material is the most common in SSA.

Nutrient loss, particularly N, is greatly affected by the method of application. Immediate incorporation minimises the volatilisation of the N (Tisdale et al. 1999; Nzuma and Mugwira 2000; Mtambanengwe and Mapfumo 2006; Pidwirny 2006).

Iwuafor et al. (2002), Vanlauwe et al. (2002) and Seran et al. (2010) report that application of manures increases yields and improves soil characteristics together with inorganic fertilisers. The amounts of N, P, K and micronutrients in the manure, as well as its net value are influenced by the method of storage, type of manure application system, housing and bedding system, diet of the cattle and environmental temperature (Kirchmann 1985; Lander et al. 1998; Tisdale et al. 1999; Lekasi et al. 2001; Hepperly et al. 2010). In order to optimise and maintain manure quality, best practice, manure collection, storage and utilisation to minimise nutrient loss and allow the nutrients to be readily available to the plants are required. Hence, it is necessary to analyse manures derived from different diets with different organic materials added and with storage in pits or heaps, covered or not covered at varying storage times, with data often limited in studies in SSA.

Rufino (2008) established that collected manure is commonly composted in a heap or pit, alone or together with bedding, crop residues and household waste. Some collected fresh manure is also applied directly to crops, though in Western Kenya this amount is estimated to be small in proportion to the total amount of manure produced (Shepherd et al. 1995). Compost heaps are usually not protected from rain or sun, but are often mixed once or twice during the storage period of six months. In the same study, it was noted that changes and losses occur during composting. Thus, the composting process and the organic materials that are added determine the quantity and quality of the final manure and, to a certain extent, the crop response to the manure N (Rufino 2008). However, in Zimbabwe, Nhamo et al. (2004) found that most farmers heap the manure to compost before application to croplands. However, literature on composting manure is very scarce for Africa because research has concentrated on crop response to composted manure and mostly the origin of that manure or nutrient content is not specified. Yet, what happens to the manure between excretion and application to fields has a large impact on N availability for crops.

Rufino (2008) analysed farm-scale nutrient cycling efficiencies and further established that farmers store the manure in an unroofed heap, uncovered or covered with branches, in a shaded area with a sandy/solid floor. For most farmers, on average, the storage period ranges from either 6 or 12 months, implying one to two applications to the fields each year, depending on the crop. Table 2.4 shows the characteristics of manure under different management during storage in an experiment conducted at Kawanda Agricultural Research Institute (KARI), Central Uganda. In the study Rufino (2008) report that covering the manure heaps with polythene film had a stronger effect on mass and N losses than the presence of a roof. The uncovered heaps underwent aerobic decomposition and lost about 55% of the initial dry mass and 50% of the initial N, whereas those that were covered and roofed lost about 30% of their mass and about 20% of their N during the 7 months of storage.

Rufino (2008) further reported initial larger losses of N than C, which explains the reduction in N concentration for the treatments. This is because losses of C occur gradually and continue throughout the storage period (Lekasi et al. 2001b; Rufino 2008) whereas N is volatilised. Large losses of N also occur as urine. Lekasi et al. (2001a; 2003) and Onduru et al. (2008) established a large variation in housing and manure management systems in Central Kenya.

Table 2.4: Characteristics of uncovered manures under unroofed and roofed conditions at KARI, Central Uganda

Days of storage	DM (%)	Total N (%)	NH_4 (mg kg^{-1})	NO_3 (mkg^{-1})	OC (%)	C:N ratio	DM (%)	Total N (%)	NH_4 (mg kg^{-1})	NO_3 (mkg^{-1})	Org C (%)	C:N ratio
	Unroofed- uncovered manure						**Unroofed-covered manure**					
0	25	2.63	2259	4742	n.d	n.d	25.2	2.8	2523	4565	n.d	n.d
27	29.8	1.80	2429	503	56.3	31.4	26.6	2.6	4065	618	56.4	22.1
63	35.1	1.97	93	528	53.4	27.7	26.6	2.1	166	766	57.6	27.5
149	27.4	3.03	9	1020	44	14.7	29.6	3.2	96	1775	44.6	14.1
178	31.3	2.67	119	759	30	11.5	30.4	2.8	183	958	25.9	9.5
	Roofed-uncovered manure						**Roofed- covered manure**					
0	24.1	2.43	2526	3743	n.d.	n.d.	25.0	2.33	2343	4141	n.d	n.d
27	29.8	2.37	2177	598	56.5	23.9	26.0	2.30	3050	592	56.8	24.8
63	38.4	1.93	67	644	54.4	28.2	27.2	1.96	116	735	57.4	29.8
149	43.5	2.28	64	1859	33.2	14.1	28.0	2.83	97	1806	45.0	16.2
178	52.4	2.52	239	982	29.6	11.6	26.9	2.72	189	929	28.9	10.5

n.d.: not determined

Source: Rufino 2008 (with standard error mean removed)

Markewich et al. (2010) monitored storage methods such as containment, shading, and manure addition methods for 30 days and over 112 days; origin of and time in storage were the variables that affected manure mineral N content in small-scale Kenyan farming systems. Manure N derived from cows fed a higher quality food (Medium quality manure) disappeared faster than manure N derived from cows fed a lower quality food (Low quality manure) concluding that more N may be available for uptake by plants during one growing season if manure from better-fed cattle is used as a soil amendment, similar to the findings of Franke et al. (2008).

Further, cows fed higher quality diets (lower in lignin and indigestible fibre, higher in digestible energy and protein) produced faeces with more labile N compounds than poorly-fed cows that consume diets with less digestible energy and protein and more lignin and indigestible fibre (Markewich et al. 2010). The faeces of cows of high quality diets, when placed in storage, may produce manure that contributes more to the soil mineral N pool and to soil fertility during a single season. Lekasi et al. (2001) observed a direct relationship between diet quality and manure quality previously under similar conditions where feeding grain concentrates resulted in elevated concentrations of manure N and organic C.

2.3.2 Recommended practices of handling cattle manure

Atallah et al. (1995) recommend a number of practices for handling manure including storing in pits, which produce manure with more NH_4-N and N than piles, because of less exposed surface area, resulting in a smaller area from which NH_4-N may volatilize. Storing manure in the shade will produce manure with more NH_4-N and less refractory N than units exposed to full sunlight, for manure exposed to the latter is warmer than shaded manure. The volatilization of NH_4-N increases with warmer temperatures. In addition, units to which fresh manure is added daily produce manure with more NH_4-N and less refractory N than units with manure of a single age. According to Atallah et al. (1995), fresh manure contains more readily degradable N and C compounds than older stockpiled manure and fresh manure degrades more quickly in soil than older manure. It is reported that large N losses from stored manure occur within the first month of storage. Luebbe et al. (2008) report losses of 12.5% of the initial manure N content observed in beef cattle manure stockpiled for 42 days. Atallah et al. (1995) and Calderón et al. (2004) found that when manure is applied to the soil, manure NH_4-N disappears in the first 2 weeks. They report that NH_4-N in manured soil falls to trace levels only 1-2 weeks after application.

Atallah et al. (1995) concluded that stockpiling or thermophilic composting of cattle manure resulted in significant carbon losses of 17% and 26.4% and relative nitrogen gains of 25% and 32.7% for stockpiled and composted manure, respectively. Consequently, C/N ratios decreased with increasing time of storage or composting. However, neither the pH nor the mineral nitrogen and organic carbon contents of the 0-50 mm fractions were significant indicators of the transformations of these materials.

Although the above storage practices are recommended, they should be adopted with care, particularly with containment and shading practice; because Lekasi et al. (2003) in a study in eastern province of Kenya showed inconsistencies between farms using the shading practice and containment method as ways of storing manure. They further note that varying trends exist between the frequency of turning the manure, the type of exogenous organic materials that are added to the manure, and how long the manure is allowed to remain in storage. Murwira et al. (1995) and Van den Boscha et al. (1998) echo this where they note that major nutrient losses from manure, especially N losses, have been observed during storage and transport before the manure is applied to the soil.

2.3.3 Recommended practices to improve the quality of cattle manure

A number of practices that are environmentally friendly which can increase the attractiveness of manure as a nutrient resource and reduce the risk to water quality are composting and the use of cover crops.

Composting manure results in a significantly reduced volume product that is more stable, with fewer pathogens and weed seed (Rynk 1992). This would help smallholder Ugandan farmers who maintain that cattle manure spreads weeds and diseases and that it smells, as amongst the factors detrimental to cattle manure adoption and or use in the central districts (Kampala and Wakiso) of Uganda (Muhereza 2005). It is urged that total transportation costs are reduced, and the product becomes more attractive to producers. However, such a process may lead to significant losses of C and N to the atmosphere in the form of CO_2, CH_4, N_2O, and NH_3 resulting in less available C and N needed by crops and contributing to the total atmospheric greenhouse gas load (Eghball et al. 1997; Hao et al. 2001; Markewich et al. 2010).

In a three-season study of maize growth, Fening et al. (2011) established that plots fertilised with composted manure produced significantly higher grain yields compared to un-composted and the control plots. However, discontinuing the application of compost the following season resulted in decreased yields. Fening et al. (2010) reported that composting improved the fertiliser value of cattle manure (at an application rate of 50 kg on DM basis) resulting in improved yields.

Differences between fertilised and unfertilised plots, compost and un-composted manure could be used to attract the attention of farmers and help them understand easily the need to improve upon the nutrient quality of cattle manure to increase crop production.

Elsewhere, Mtambanengwe and Mapfumo (2006), also recommend pre-application treatments, such as composting, as it enhances seasonal N benefits from these materials on maize yields on sandy soils in Zimbabwe. The NH_4+-N concentration in plots that had received high quality organic resources increased by 10-20% 1 week after the first sampling and an NH_4+-N bulge, which was significantly higher under manure than for all other treatments, was observed in the 45–60 cm depth of the soil profile. At another site, within 5 days, the relative position of this bulge had become apparent at 60-90 cm depth. Maize yields increased linearly with total N added (e.g. >20 t ha^{-1}) for cattle manure, fresh litter and composted litter used by farmers who often achieve high crop yields on such coarse sandy soils in Zimbabwe.

According to Carter and Murwira (1995), giving animals more, better quality feed and using more efficient composting techniques improve the quality and thus contribution of manure and crop residues to soil fertility management. This involves changing the way that residues are collected and processed, and focuses on reducing nutrient losses, improve the on-field management of organic materials by changing the methods and rates of application, applying this scarce resource more efficiently, and combining with mineral fertilisers.

2.4 Effects of cattle manure on soil properties

2.4.1 Effect of cattle manure on soil chemical properties

The effect of cattle manure on soil properties has been well been documented (Rekhi et al. 2000; Nyamangara et al. 2001; Lithourgidis et al. 2007; Hulugalle et al. 2009; Nyiraneza et al 2009). Cattle manure application increases the soil organic matter pool that may lead to higher cation exchange capacity (CEC) and a higher soil pH (de Ridder and van Keulen 1990; Naramabuye et al. 2008) thus enabling it to exert immediate and wider ranging beneficial effects on soil quality properties than inorganic fertilisers alone (Min et al. 2003; Khan et al. 2007). The use of cattle manure as organic amendments to improve soil quality is important where soil moisture and organic matter maintenance under conventional tillage are major constraints for economic crop production (Min et al. 2003).

Various studies; Pocknee and Sumner (1997); Mokolobate and Haynes (2002) and Fronning et al. (2008) have established that cattle dung has a pH between 7.0 and 8.0 and its large Ca^{2+} and Mg^{2+} content contributed to improved soil quality providing a medium for plant growth and biological activity, regulating water flow and storage in the environment and serving as a buffer in the formation and destruction of environmentally hazardous compounds (Stockdale et al. 2002; Van der Vossen 2005).

Manure exhibits variation in its pH value depending on the type and diet of the animal. For example, the pH of cattle manure in Alberta, Canada, was found to be around 9 (Schoenau et al. 2002), while an average pH value of 7.2 was reported for cattle feedlot manure in southern Alberta (Chang et al. 1991). The ability of manure application to induce a change in soil pH depends on its content of buffering agents including carbonates and organic matter, as well as the production of organic acids and acidity during decomposition (Assefa et al. 2002; 2004; Panda 2008; Kumar and Shivay Kumar 2008).

Because the effect of manure on soil pH is variable, repeated applications of fertiliser containing N may lead to soil acidification due to acidity produced in the nitrification process (microbial oxidation of ammonium to nitrate). For instance, Chang et al. (1990) observed a decrease in soil pH with time and suggested that some soils might eventually become acidic with continued application of manure. However, Whalen et al. (2000) in an eight week short term laboratory study reported an immediate increase in the pH of two acid soils from northern Alberta following fresh cattle manure application and concluded that the effects of manure on soil pH would depend on the manure source and soil characteristics. Manures of high organic matter and carbonate content are most effective in raising the pH of an acid soil and buffering against changes in soil pH. Castillo et al. (2003) obtained a similar result.

2.4.2 Effects of cattle manure on soil physical properties

The majority of smallholders' farms in SSA region are on inherently infertile sands or sandveld soils subject to widespread degradation and declining fertility caused by loss of organic matter, breakdown of soil structure and erosion (Elwell and Stocking 1988; Smalling et al.1997). Added organic matter coats clay particles and increase adhesion between soil particles (Addiscott et al. 1991). There are general views that inorganic fertiliser, when applied alone, only improves soil nutrient status. By contrast, organic materials such as cattle manure contribute positively to the soil nutrient pool, improve soil physical conditions, increase soil biological activity, encourage vigorous plant rooting systems and enhance crop performance (North Carolina Agricultural Extension Service 1973; Gollin 1991). Other benefits include reduced compaction and surface crusting and increased C sequestration

(Khan et al. 1975; Min et al. 2003; N'Dayegamiye 2009. Further, they help to retain moisture and bind nutrients against leaching, especially if applied as mulch, smother small weeds and prevent soil from drying out, hence reducing soil erosion. Compared to inorganic N fertilisers, which are quickly converted into soluble N forms, and are therefore susceptible to leaching, organic inputs release nutrients more slowly and continuously throughout the growing season. Some inorganic fertilisers may not only acidify the soil, especially in the rhizosphere, but also affect its physical properties adversely (Jen-Hshuan 2008).

2.4.3 Effect of cattle manure on soil biological properties

Additions of cattle manure can stimulate the activity of micro-organisms because they contain readily mineralisable organic compounds, such as sugars, organic acids, cellulose, and hemicellulose. Cattle manure application improves soil structure, by creating soil conditions (aeration and moisture) favourable for the growth of micro-organisms for an increase in their biological activities result in an increase in soil fertility (Chantingny et al. 2000). This is because microorganisms eat the carbon from manure as an energy source. However, the ability of organic wastes to promote soil aggregation is linked to the rates at which they are decomposed by micro-organisms and, therefore, to their capacity to stimulate the soil micro flora and to produce humic substances (Cheshire and Chapman 1996). Organic manure/wastes that are rich in N and with C/N ratios below 20 are accompanied by high levels of microbial activities and decomposition in the soils.

N'Dayegamiye (2009) reported that dairy cattle manure in addition to mineral fertiliser applications significantly increased mineralised soil N levels, which improved biological properties of the soil thereby enhancing microbial activity. It should be noted however, that where there are large soil mesofauna populations present, a significant portion of manure applied as a soil amendment may be degraded and/or displaced by the soil insects (Seastedt 1984; Kaneko and Salamanca 1999; Esse et al. 2001). This is relevant for many areas in SSA including Uganda with large indigenous populations of termites and ants in the soil. Termites have gut cellulases used to degrade the fibrous manure material. Termites and ants use the fibrous manure material in their mounds, so the activity of these insects may result in the relocation of manure from the soil as they transport it to their mounds (Potts and Hewitt 1973; Diamond 1998).

2.4.4 Negative effects of cattle manure application on environment

Over application of inorganic and organic fertilisers is estimated to have boosted nutrient capacity in the soil by about 2000 kg of N, 700 kg P, and 1000 kg K ha^{-1} of arable land in Europe and North America during the last 30 years (Roy 2001; Bhattacharyya et al. 2008).

The oversupply of nutrients can lead to environmental contamination, which often has negative consequences for humans and animals in regard to pollution and eutrophication of surface water (Donovan and Casey 1998; King and Torbert 2007; King et al. 2008; Hepperly et al. 2010).

Sewell (l975) observed nitrate leaching to shallow groundwater where excess quantities of dairy cattle manure were applied. In addition to surface water concerns, nitrate leaching can affect ground water sources (Chang and Janzen 1996; Whalen and Chang 2001; Hansen et al. 2007; Benke et al. 2008; Eriksen et al 2008).

Phosphorus from manure is the primary cause of eutrophication of fresh waters (Sharpley and Moyer 2000; Keplinger and Hauck 2006), although N may also contribute to this problem (Burkart and James 1999; Boesch et al 2001; Hepperly et al. 2010).

Application of manure at agronomic rates is compounded by the fact that the manure nutrients come in proportions which do not match crop requirements. The N: P ratio required by crops is typically several times higher than the N: P ratio in manure. Manure application at a rate meeting crop N requirements provides more P than crops can utilize (Hepperly et al. 2010) and may result in soil P build up and increased P runoff into surface waters. In America, the state and federal regulatory changes portend a switch from N based to P-based manure application policies (Kaplan et al. 2004; Keplinger and Hauck 2006) highlighting the importance of management to prevent over application of nutrients.

Haines and Staley (2004); Rogers and Haines (2006) and Dwight (2009) recommend options in which movement of manure pollutants to the environment can be reduced including effective management of livestock, treatment of manures produced to lower pollutant concentrations, and land application and run off management practices to reduce pollutant movement from agricultural fields to the environment. However, this requires skills, which are lacking in developing countries. Pittaway et al. (2001); Birchall et al. (2008) recommend considering timing of nutrient applications to coincide with crop nutrient requirements so that nutrients don’t leach past the root zone before they are taken up by the plant.

2.4.5 Nitrogen

Nitrogen is one of the most important essential plant nutrients (Panda 2008; Hepperly et al. 2010). Unlike N in inorganic fertilisers, the organic N in animal manures, crop residues, or other organic inputs must be mineralised to become available to plants. Utilisation of compost, fertiliser, cover cropping and manure have different effects on soil N movement, and soil quality and fertility (Hepperly et al. 2010). Sub-Saharan agricultural soils, including

Uganda, have become depleted in N and OM over time, and in many situations are unable to supply sufficient N to meet crop requirements **(**van Straaten 2002**)**. Understanding C and N cycles is seen as an appropriate approach to optimize soil fertility equilibrium over time and to improve N management (Delgado and Follett 2002).

Nitrogen supply is a key factor in food and fibre production (Mosier et al. 2004); the higher the yield, the greater the nutrient requirement (Panda 2008; Kumar and Shivay Kumar 2008). A shortage of one or more nutrients can inhibit or stunt plant growth (Russell 1988; Aerts et al. 1995; Van Duren and Pegtel 2000). By 2000, N fertiliser had tripled global food production over the half century, with world grain production 631 million tons in 1950 (247 kg person^{-1}) and 1840 million tons in 2000 (303 kg person^{-1}). Optimization of the C and N cycles is the most important management objective for ensuring high productivity and long-term environmental sustainability.

2.4.6 The soil nitrogen cycle

Nitrogen, the most intensively used element, is available in virtually unlimited quantities in the atmosphere and is continually recycled among plants, soil, water and air (Ange 1992; Kumar and Shivay Kumar 2008). It is essential to understand the N cycle and soil N dynamics, which vary according to soil and environmental conditions, to ensure applications of N in cattle manure are correctly managed. Figure 2.2 is a generalised view of the N cycle that includes soil inputs, transformation processes and outputs. According to Pidwirny (2006), N is classified as either inorganic or organic. At any given time, most of the N in the soil is in the organic form. Inorganic N compounds are unstable and N is constantly returning to the atmosphere in gaseous forms. The conversion of N_2 to N compounds and from N compounds, back to N_2 is called the *NITROGEN CYCLE* (Hodges et al. 1992).

According to Halvin et al. (2005), Pidwirny (2006), and Barbarick (2011), N in the air is the ultimate source of all soil N accounting for 78%. Nitrogen may enter the soil through rainfall, plant residues, and N fixation by soil organisms, animal manures and commercial fertilisers. For this study, only N transformation from cattle manure and inorganic fertiliser are discussed.

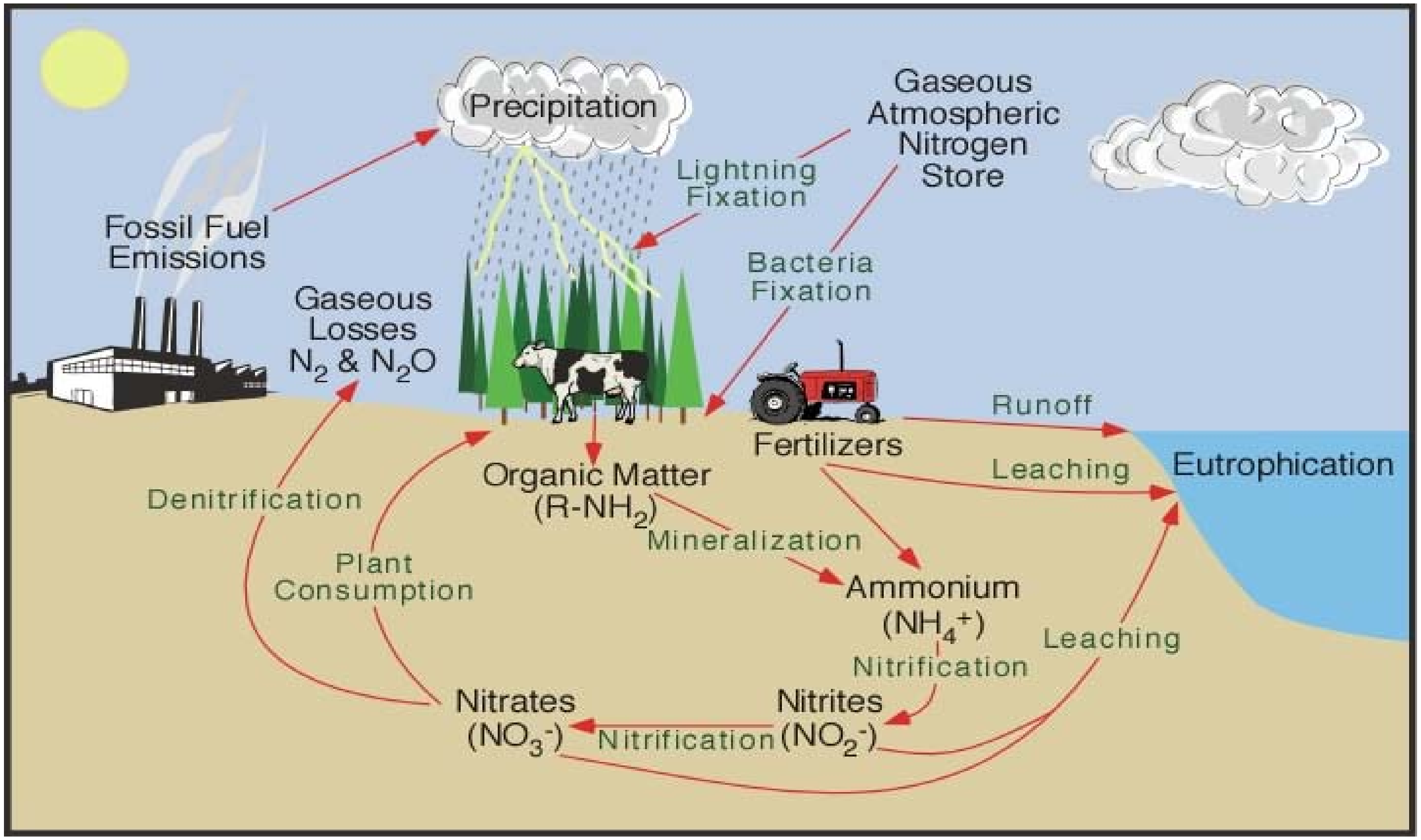


Figure 2.2: The nitrogen cycle reproduced from Pidwirny (2006**)**

Barbarick (2011) reported that manure contains an appreciable amount of N. However, most of this N is in organic forms: protein and related compounds. Cattle manure contains about 4.5 to 18 kg of N per tonne (Barbarick 2011). About half of this N is converted to forms available to plants during the first growing season. Lesser amounts are converted during succeeding seasons. Each tonne of applied manure is equal to about 2.3 to 9 kg of commercial fertiliser N (Barbarick 2011).

2.4.7 Nitrogen transformation processes

Nitrogen exists in a number of chemical forms and undergoes chemical and biological reactions. The following transformation processes take place in cattle manure as shown in Figure 2.2.

Mineralisation

Mineralisation or ammonification is the conversion of organic N to NH_4-N. This is the hydrolysis of proteins and conversion to ammonium ions (NH_4^+) by soil microorganisms, a process mediated by heterotrophic soil microorganisms (Pierzynski et al. 2005). Ammonium is not leached to a great extent. Since NH_4^+ is a positively charged ion (cation), it is attracted to and held by the negatively charged soil clay. Ammonium is therefore available to plants (Hodges 1992; Pierzynski et al. 2005; Milton 2011).

In effect, organic N comprises over 95% of the N found in soil. The micro-organisms get C and energy from the breakdown of OM, while N is released at the same time. According to Pierzynski et al. (2005), organic N from soil humus, organic residues or organic fertiliser sources such as cattle manure is present in the form of proteins, chitins, amino sugars and nucleic acids; before it is available for crop uptake, it must first be converted into mineral forms by *mineralisation or ammonification*.

Mineralisation increases under warm, moist conditions (Stanford and Epstein 1974; Pdwirny 2006), and with increasing pH (Chae and Tabatabai 1986). However, mineralisation can occur under anaerobic conditions, and at a wide range of soil temperatures and moisture contents, but is optimal at a temperature range of 25-35^{o}C and soil moisture content of 50-75% (Pierzynski et al. 2005; Pdwinry 2006).

Chadwick et al. (2000) report that organic N fraction of manures can represent up to 99% of the total N content in some FYMs, and be as low as 14% of the total N content for example in pig slurries. In their study, the organic N fraction that was readily mineralizable (KCl extractable) varied between manure types.

Chemical fractionation data showed that on average the mineral N fraction was increased by only 7±8% of the total N content for pig FYMs and broiler litters by refluxing with hot KCl. The organic N content of cattle slurry, cattle FYM and layer manure appeared to be strongly bound. Therefore, it is important to provide farmers with reliable guidance on the supply from the organic N as well as supply from the mineral N content.

Nitrification

According to Gasser (1970) and Milton (2011), nitrification is the conversion of NH_4^+ into NO_3^- through microbial oxidation. Nitrification is a two-step process in which NH_4^+ is converted to NO_2^- and then further to NO_3^- by *Nitrosomonas* and *Nitrobacter* bacteria, respectively. The resulting NO_3^- is highly mobile in soils and is easily lost from the soil with water that moves downward laterally through a soil profile and is a potential pollutant if it reaches surface and ground water supplies. However, NO_3^- is also taken up by some plants as reported by von Wiren et al. (1997) under the right circumstances.

Nitrification being a microbial process, therefore, is highly dependent on the soil environmental conditions. Several factors influence the rate of nitrification including supply of NH_4^+, population of nitrifying organisms, soil pH, moisture and temperature as well as tillage system, cropping system and presence of other nutrients (Havlin et al. 2005). Havlin et al. (2005) report that soil pH of 8.5 is optimum for nitrification, although the process can occur between the pH ranges of 4.5 to 10.

Hodges et al. (1992) report that these processes require molecular oxygen; that is, they take place most rapidly in well-aerated soils. Poor aeration due to soil wetness or lack of pore space will slow or stop the mineralisation process. This has practical implications when organic wastes are soil-applied as fertilisers. The rate at which N is released by organic wastes is dependent on the soil environment as well as the characteristics of the waste itself. Soils which have a coarse texture or that have large macro pores related to aggregation can facilitate rapid gas exchange. When soil moisture is at or close to field capacity, (70-80% of total pore space) nitrification rates are maximized (Havlin et al. 2005). The process of nitrification can occur over a wide range of soil temperatures (5-35ºC) with maximum nitrification rates observed between 25 to 35ºC (Havlin et al. 2005).

Denitrification

Vallejo et al. (2005) and Burgin and Hamilton (2007) define denitrification as the biological reduction of soil NO_3^- under anaerobic conditions. It occurs mainly when there is little or no oxygen in the soil, such as when the soil is waterlogged. During the denitrification process, the oxides of N such as NO_3^- and NO_2^- are converted into gaseous N, which is removed from the soil system; this process can result in large losses of N in waterlogged soils receiving manure applications, following nitrification as reported by McCormick et al. (1983). Although water logging is not a common characteristic in the soils of central districts of Uganda given that swamps are being reclaimed, it is imperative to note that in other areas of eastern Uganda, it occurs during the rainy season.

Human activities have severely altered the N cycle, for instance in livestock farming, animals waste release a large amounts of NH_4+ into the environment leading N to enter the soil system and then the hydrologic system through leaching, ground water flow and run off as reported by Pidwirny (2006).

Plant nitrogen uptake and utilisation

Nitrogen uptake is limited by N availability, but also by plant N demand. Nitrogen uptake efficiency thus depends on factors affecting plant growth (varietal characteristics, and the availability of light, water and other nutrients) in relation to N availability (Janssen 1998). Many studies have looked at crop responses to manure application, but studies that address the synchronisation of N release from manure with crop uptake, attempting to minimise the risk of N loss, are rare. This should be explored further under Ugandan conditions.

Whereas, cattle manure is an essential input for organic crop production, it is reported that the availability of N for plant uptake as part of the N supplied through organic inputs is immobile and not directly available for plant uptake (Powell et al. 1999). Organic inputs, especially those with a high C/N ratio, may immobilize some of the N supplied through synthetic fertilisers. However, when immobilized N is mineralized over the course of the growing season, an improved synchrony between soil N availability and plant uptake may result in a higher N use efficiency of applied fertiliser (Powell and Wu 1999; Powell et al. 1999; Munoz et al. 2004).

2.4.8 Nitrogen losses

Nitrogen can be easily lost from an agricultural system by various pathways regardless of the source by plant removal, denitrification, volatilisation, leaching and erosion (Hodges et al. 1992; Pierzynski et al. 2005; Pidwirny 2006; Barbarik 2011). It is imperative to understand N properties and transformations in order to get the maximum benefit from N fertilisation with a minimum pollution hazard. The first alternative, absorption by crops, is the desired goal.

According to Hodges et al. (1992) and Zehnder and DiCostanzo (1997), crop removal is a very important, but often overlooked way of N loss. Many crop materials contain 2% to 4% N on a dry weight basis. If these crop materials are exported from the farm in the form of grains, forages, or meat there is a net loss to the farm's N balance. However, if crop residues and manures are saved and returned to the soil, some of the N will be recycled for future crops.

Nitrogen losses from cattle manure heaps are influenced by a number of factors. Losses of N occur from labile N pools, and are thus more likely when there is a high proportion of labile material. Gaseous losses of N may occur as NH_3 when ammonium concentrations and pH are high in the heap. The process is controlled by the availability of easily decomposable C and N, and N losses decrease abruptly as soon as the NH_4-N is immobilised. Murwira (1995) observed that NH_3-N losses did not exceed 4% of total N for a 30-day period, coincided with maximum microbial activity and appeared to reflect the size of the labile N pool.

Although NH_4-N is the predominant form of mineral N in cattle manure heaps, NO_3^- may be formed in the surface, more aerobic layers, and is susceptible to loss by denitrification. Denitrifying bacteria require anaerobic conditions, and denitrification of labile N is only likely if oxygen becomes depleted in zones of heaps where nitrate-N is present, or in microsites within it. Denitrifiers also require sufficient moisture; at low water content, oxygen availability appears to have a negligible effect on N losses during composting (Kirchmann and Witter 1992).

2.5 Fertiliser replacement value of cattle manure

The effectiveness of cattle manure as a source of N compared to inorganic fertiliser and or N fixation is low and variable and depends on many factors including the mineralisation rate. Beauchamp (1983) established that N fertiliser replacement values of cattle manure are between 10%-60 % and dependent on timing of application, while Barker (2010) report that if a single application of cattle manure is made, about 50% is available to crop.

However, more frequent manure application may increase the synchrony between soil N availability and the uptake by the crop. For example, annual applications of manure to a maize-legume rotation in Zimbabwe resulted in greater N uptake efficiency in the first and second season after application than the recommended practice of applying 35-40 t manure ha^{-1} once every four years (Nyamangara et al. 2003). However, they concluded that net recovery from composted manure was low and that combined application of manure and N fertiliser enhanced N recovery where high rate manure and low rates of inorganic N were used.

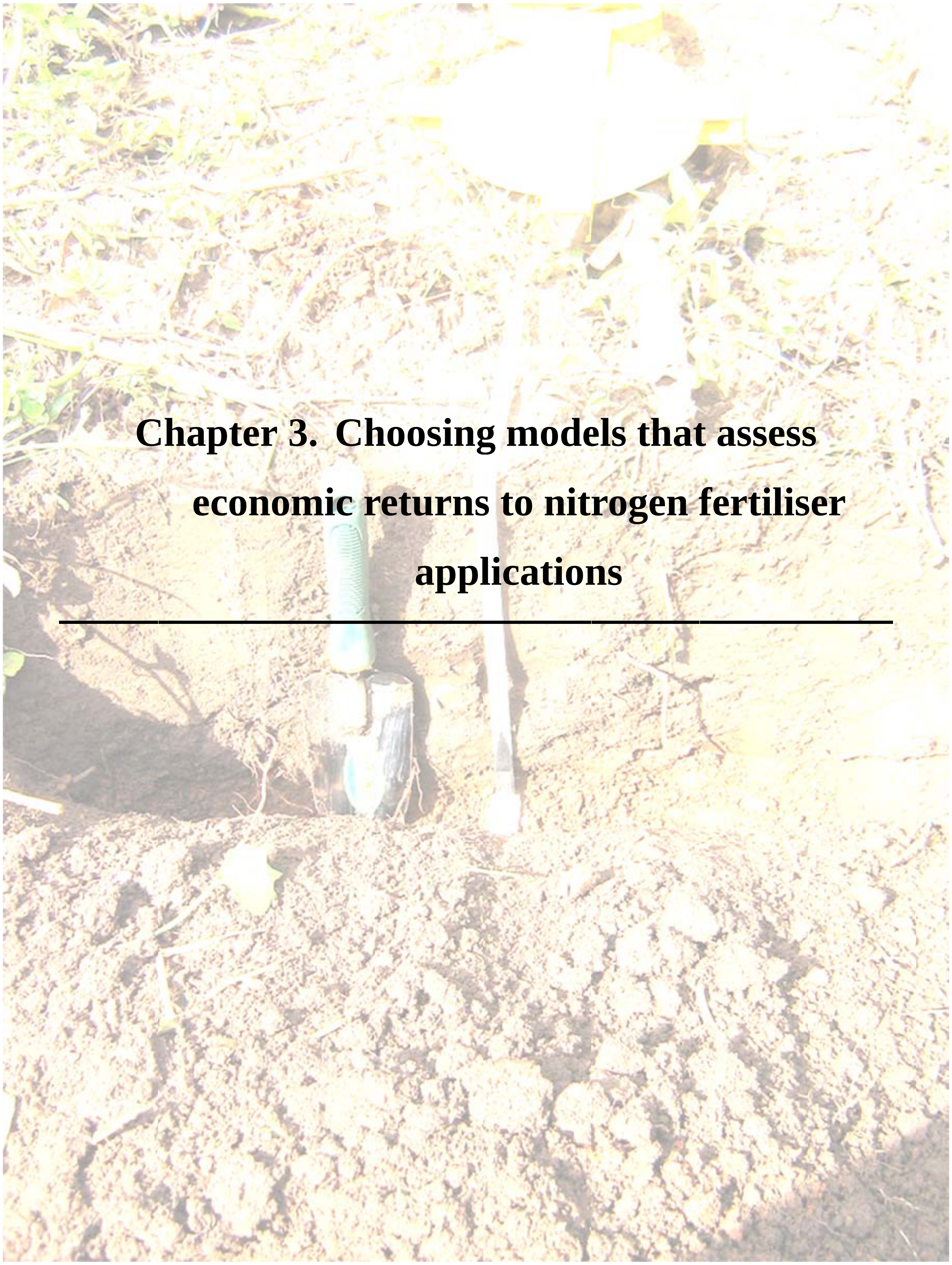
Giller et al. (1997) report that crop response to manure N in the first season depends on the amount of mineral N and labile N in the manure. Nitrogen uptake from manures in the second and subsequent seasons also depends on manure quality. In old manures much of the

N is in stable forms that are only mineralised slowly, and N uptake efficiency can be greater after the first season. However, the more stable N pools may not be mineralised within a useful time scale, and it is more common to see greater uptake efficiency during the first season. Powell et al. (1999) compared the N uptake efficiency from legume leaves with that from faeces from sheep fed with the legume leaves as a supplement. All faeces, except those, which came from supplementing with *Vigna unguiculata*, resulted in higher N uptake efficiencies (5-14%) than the corresponding leaves (1-9%). However, there were no clear relationships between measured faecal chemical components and N uptake. This needs to be evaluated in cattle manure.

Von Wiren et al. (1997) in a study on the regulation of mineral N uptake report that the form of N uptake is mainly determined by its abundance and accessibility, which makes NO_3^- and NH_4^+ the most important forms of N for plant nutrition under agricultural conditions. They further note that N uptake is also subject to plant preferences, by which plants maintain their cation/anion balance during uptake, thus affecting its form. However, some plant species seem to have an obligatory preference, which even prevents their growth on certain other N sources.

2.6 Conclusions

While the over application of inorganic and organic fertiliser has led to environmental contamination in a number of areas in the developed world, insufficient application of nutrients and poor soil management, along with harsh climatic conditions and other factors, have contributed to the degradation and erosion of soils in SSA. Rapid water evaporation and inadequate and highly variable rainfall, for example, deprive plants of the water necessary for growth. High temperatures, strong light, and heat-retentive, sandy soils can combine to make the local environmental too hot for optimum plant growth (Kumar and Shivay 2008). Efficient N management is arguably the most challenging aspect of tropical smallholder agriculture in sub-Saharan Africa (Chikowo et al. 2004a; Mtambanengwe and Mapfumo 2006). Yet, mineral fertiliser use in smallholder cropping systems remains insufficient to meet crop N demand on a sustainable basis, partly because of prohibitive costs and/or lack of availability. A modelling approach is one useful way to understand N dynamics in a given environment. This requires choosing a suitable model that can help predict N availability to crop, hence the basis of the following chapter.



Chapter 3. Choosing models that assess economic returns to nitrogen fertiliser applications

3.1 Introduction

Balanced levels of plant nutrients are required for optimal crop production. Insufficient levels of any of the nutrients can hamper plant growth; likewise, too much may cause a nutrient imbalance in the soil and in the plant, which may be toxic (Freney 1996; Tisdale et al. 1999; White 2006).

Farm management should aim to obtain the profit maximising level of crop production with profit maximising firms being also cost minimising firms (Chiang 1988; Doll and Orazem 1992). The general rule is that a firm maximises profit by producing that quantity of output where marginal revenue equals marginal costs. The profit maximisation issue can also be approached from the input side, which is the profit maximising usage of the variable input (Samuelson and Marks 2003). To maximize profits the firm should increase usage up to the point where the input's marginal revenue product equals its marginal cost (Samuelson and Marks 2003). Both profit maximisation and cost minimisation are referred to as optimisation. In effect, optimisation is the quest for the best. The farm firm minimises cost by combining inputs in such a way that, for every input used, the value of the marginal product of the input is equal to its price.

This section presents the conceptual framework of crop production, highlights the theory of production functions, beginning with the theory of production functions, production function under one variable input and one product, average physical productivity of inputs, marginal physical productivity of inputs, stages of production function, the economic level of resource utilisation, and production function with two or more variable inputs.

3.2 Production functions

3.2.1 The theory of production functions

A production function portrays an input-output relationship (Beattie and Taylor 1985; Derbertin 1989; Felipe and McCombie 2005a; Miller 2008). It describes the rate at which resources are transformed into products. According to Derbertin (1989) and Doll and Orazem (1992), a production function is a technical relationship that transforms inputs into output given the existing level of technology available to the farmer. It is an important tool in the explanation of input-output relationships (Boehje and Eidman 1984; Beattie and Taylor 1985). There are numerous input-output relationships in agriculture because the rates at which inputs are transformed into outputs will vary among factors such as soil, animals, technologies and rainfall.

Under given technological conditions, farm output is viewed as a function of farm area, labour, capital (Naik 1965) and other variables, such as quantity of cattle manure and inorganic fertiliser to be applied, as is the case for this study.

In a production function, there are variable and fixed inputs. The fixed inputs have varying capacities to absorb and transform variable inputs into outputs (Beattie and Taylor 1985; Miller 2008); for example, a sandy soil can absorb less water than a clay soil. The existence of a functional relationship between crops and soil nutrients is well established (Doll and Orazem 1992); however, biological laws of growth are not uniform. In addition to nutrient supplies, numerous other factors affect crop yields such as weather, plant population, soil type and management practices. Heady et al. (1961) used a production function to determine the response of corn to applications of N and P fertiliser and the economic optima for fertiliser use.

3.2.2 Production function under one variable input and one product

Production functions in agriculture are highly specialized (Arnold 1951). In general, if a variable input is essential for plant growth and is not present in the soil, crop yields would be zero when the amount of the variable input is zero (Beattie and Taylor 1985). However, this is unlikely to occur because most soils contain residual amounts of nutrients. If however, the variable input is say plant population, then yield will be zero when the variable input amount is zero; that is when the crop is not planted. A production function may apply only to a certain soil type, soil fertility level, seed variety, technology, growing season and level of fixed inputs (Chirwa 2007). To be useful the production function must be appropriate for the production process and growing conditions being studied.

3.2.3 Average physical productivity of inputs

According to Beattie and Taylor (1985); Dillon and Anderson (1990); Dillon and McConnell (1997), the average physical productivity (APP) is obtained by dividing the total amount of the output (Y) by the total amount of the variable input (X). The average physical product (Y/X), is defined geometrically in terms of the slope of a particular straight line passing from the axis through the production function at the particular levels of Y and X.

The slope represents the average rate at which the input, X, is transformed into product, Y. As more of the variable input is combined with the fixed inputs, efficiency of the variable input increases and eventually decreases. Therefore, it is the measure of the physical or technical efficiency of the variable input, which is distinct from economic efficiency.

3.2.4 Marginal physical productivity of inputs

On the other hand, Beattie and Taylor (1985) define the marginal physical productivity (MPP) of an input as the change in output resulting from a unit increment or unit change in variable input. It measures the amount that total output increases or decreases as input increases. The MPP represents the slope of the production function (Beattie and Taylor 1985). Usually the incremental change is taken to be one unit; hence, marginal physical productivity is the change in output associated with a unit increase in input use. Abler and Shortle (1995) and Ma et al. (2007) further show that the marginal productivity of input, x_i is calculated using the geometric means of the sample values of x_i. Thus, MPP is computed by dividing the change in output by the causal amount (change) of input. It represents the average of all the slopes on the total physical product (TPP) curve between input levels. The MPP equation is the first derivative of the production function taken with respect to the variable input. The equation for the exact MPP is dy/dx (Doll and Orazem 1992). The application of MPP to the production function gives an interesting scenario and should always be considered. MPP increases to a maximum at the point of inflection of the production function, and decreases as input is increased further (Beattie and Taylor 1985; Derbertin 1989). MPP is equal to zero, where output is at maximum and is negative for larger input amounts.

3.2.5 Stages of production function

The crop response to input levels differ. Their growth expressions can be depicted using a production function, which may exhibit up to three stages of production; namely III, respectively (Figure 3.1) and I, II. However, for economic efficiency, stage II is relevant because it contains the profitable region of production (Doll and Orazem 1992) when funds are unlimited and input and product prices are positive and their markets are perfectly competitive. While this model is a simplification of reality, because amongst other things it ignores environmental variation and the plateau response of crops to fertilisers beyond the optimum point, it is a useful starting point for determining optimum input levels (Doll and Orazem 1992).

According to Arnold (1951) and Beattie and Taylor (1985), stage I of the production function is defined as that region over which average physical product (APP) is increasing; stage II is that area over which APP is declining but MPP is positive; and stage III is that region where MPP is negative. However, for a sigmoid response curve in stage I, the variable input is being used with increasing output per unit, the latter reaching a maximum at point of inflection since the average physical product is at its maximum at that point. Because the output per unit of the variable input is improving throughout stage I, a price-taking firm will always operate beyond this stage. In Stage II, output increases at a decreasing rate, and APP and MPP are declining. However, the average product (AP) of fixed inputs is still rising. In this stage, the employment of additional variable inputs increases the efficiency of fixed inputs but decreases the efficiency of variable inputs. Most nutrient response curves are monotonic decreasing curves and as such begin in stage II. Arnold (1951) explains that this stage is the economic region of production where the optimal solution must occur. The conventional wisdom holds that the profit maximising firm facing positive prices will operate only in stage II (Beattie and Taylor 1985). The economic optimum input/output combination will be in stage II and occurs where the value of the marginal product equals the marginal cost. In Stage III the efficiency of variable inputs and fixed inputs decline and it is therefore beyond the production and economic optimum levels of production (Beattie and Taylor 1985).

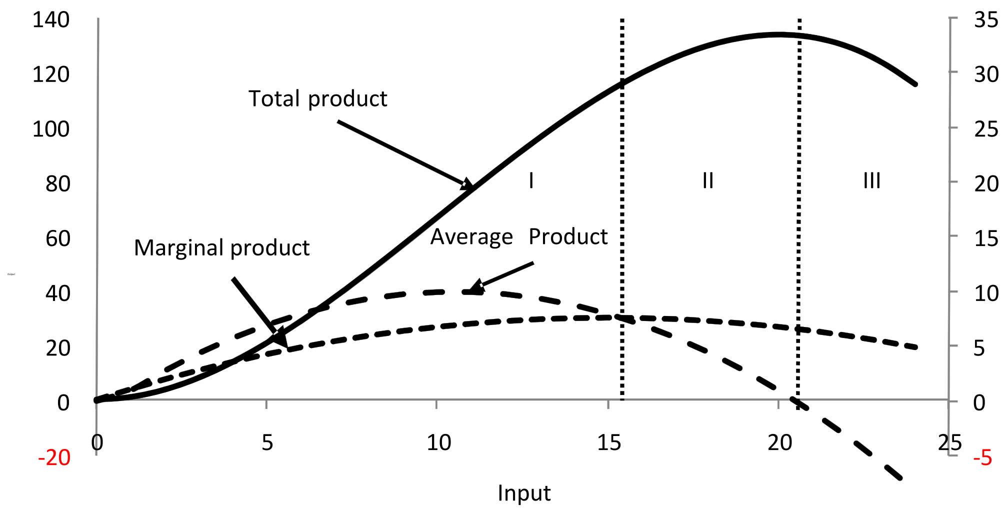


Figure 3.1: The three stages of production in a classical production function

3.2.6 The economic level of resource utilization

The most profitable point of operation for an enterprise can be described mathematically in a profit objective function thus; Profit in \$ = f (N input, weeds, disease, residual value, build up of OM, water holding capacity, yield potential for example). This can be optimised either numerically or analytically to determine the most profitable amount of input or level of output (economic optimum) (Doll and Orazem 1992). The production function is vital to the computation of profit as it relates total value product to the amount of input and total costs to the amount of output and it is important for sustainable crop production in a crop livestock farming system to enable the optimal level of the inputs, including cattle manure application to be established.

Production function models have been used in numerous studies; (Hopper 1965; Tyner and Tweeten 1966; Chennareddy 1967; Sahota 1968) to determine resource allocation efficiency in agriculture for they provide a direct test on the existence of rational production behaviour.

Paris (1992) showed that the optimum rate of application of inputs, particularly fertiliser, is determined by the difference between the cost of fertiliser input and the value of the crop. In developing countries, the value/cost ratio is often much less favourable because of higher costs of fertiliser and lower farm prices, although the response to fertiliser under good growing conditions may be similar.

3.2.7 Production function with two or more variable inputs

According to Beattie and Taylor (1985); Chiang (1988), Battese et al. (1997) and Dillon and McConnell (1997), a production function with two or more variable inputs describes the fundamental relationships among one output and two or more variable inputs. The optimum or most profitable combination of inputs will be determined "as more than one variable input is used" that of finding the "right" combination of inputs will be analysed. Output increases until the value of the product added by increasing the two inputs along the expansion path is equal to the combined cost of the added amounts of the two inputs. This is when the value of the marginal product (VMP) of each input is equal to the unit price of that input or when the marginal cost (MC) equals marginal revenue (MR) which gives maximum profit.

3.3 Theory of crop growth expressions and types of crop nutrient models

3.3.1 Crop nutrient models

Various mathematical models to describe or define plant growth have been developed and are useful in predicting crop yields for given fertiliser applications. Plant growth is a function of various environmental or growth factors, which may be considered as variables, the magnitude and combination of which determine the amount of growth that will be made; expressed as:

$$G= f\,(X_1, X_2, X_3 \ldots\ldots\ldots\ldots\ldots\ldots X_n)$$

Where G is a functional relationship between growth factors (X_1, X_2, X_3…… X_n).

Further, if all but one of the growth factors is present in adequate amounts, an increase in the quantity of the factor that is not (the limiting factor), will generally result in increases in plant growth. This, however, is not a simple linear relationship as shown in von Liebig's experiments, which show linear responses over a portion of the yield response curve. More often, the addition of each successive increment of a growth factor results in progressively smaller increases in growth (Russell 1988). Various models have been developed to help and guide farmers to apply the right amounts of fertilisers and are discussed in this chapter.

3.3.2 Types of functional forms used to model agricultural processes

The productivity of various input factors is established using the concepts of elasticity of production and marginal productivity (Naik 1965; Johnston 1972). Various types of production functions have been used in agricultural production systems including the Spillman, the neo-classical, the transcendental (Kislev 1966), the constant elasticity of substitution (CES), the Cobb-Douglas (Douglas 1948)**,** the Cobb Douglas with variable input elasticities (Griliches 1957), the translog and the quadratic function (Derbertin 1989). Thamodaran et al. (1982), Thakur and Kumar (1984) and others have studied the resource use efficiency using a Cobb-Douglas type of production function. Due to its advantages over the other functional forms, which include those listed in Table 3.1, it is widely used in frontier production function studies (Kalirajan and Flinn 1983; Dawson and Lingard 1989; Bravo-Ureta and Evenson 1994). Other studies have employed linear programming techniques to determine optimal levels of resource use (Upton 1979; Just and Pope 1979; Just et al. 1990). However, with increased computing power, numerical iterative procedures have been used to optimise objective functions.

Optimization using coefficients from Cobb-Douglas function also gives optimal levels (Gowa et al. 2001). It should be noted that management plays a big role in determining the production function in that poor management practices such as failure to control weeds and diseases, will ultimately affect crop growth and yield.

From the viewpoint of production theory, the transcendental or inverse double log function (Johnston 1972) may be selected because both functions incorporate all the three stages of the neo-classical function. However, the (economic) optimum decisions are considered to lie only in the second stage of production function (Beattie and Taylor 1985; Debertin 1986); under assumptions of perfect competition. Of the various assumptions of perfect competition, there is uncertainty regarding output expectations due to weather effects.

Most studies based on statistical models for predicting optimal N rates have been conducted on corn (*Zea mays* L.) (Cerrato and Blackmer 1990; Bullock and Bullock 1994) and a few studies have been reported on potato (Neeteson and Wadman 1987; Bélanger. 2000).

Despite the evidence favouring alternative functional forms; linear and polynomial specifications are still commonly used because there is always limited experimental yield data available for analysis, which restricts further evaluation. For instance, the Mitscherlich-Baule model requires at least six levels of one input and four levels of another to allow estimation. One possible approach to dealing with data limitation and to allow for further comparisons between alternative functional forms is to use simulation techniques. This study uses both experimental and simulation data to evaluate the functional forms of cabbage as detailed in Chapter 8, as was the case with Paris (1992) who used simulated irrigated corn yield data from western Kansas. The Select Your Nitrogen (SYN) model (Diggle et al. 2003) is a type of production function model that allows a growth plateau, such as the von Liebig and Mitscherlich-Baule response functions and was selected for this study. A number of functional forms together with their characteristics are summarised in Table 3.1.

Because of the behaviour of the various responses by the crops to different factors, and, bearing in mind that inputs are scarce resources, to develop an empirical model, two field experiments (Chapters 5 and 6) and a glasshouse experiment (Chapter 7) have been conducted to generate the required data for optimal input combinations suitable to the Ugandan situation, which in this study is cattle manure in cabbage crop production.

3.3.3 Inorganic fertiliser models

Many crop models have been developed to describe the relationship between inputs and outputs, the response of crop yield to nutrients being the commonest in agriculture (Llewelyn and Featherstone 1997). The response curve prediction models mainly include: simple regression based models, flexible response curve prediction models, complex simulation models of growth, water balance and N balance, Crop Environment Resource Synthesis (CERES) (Jones and Kiniry 1986), and Simplified Dynamic Models that are listed in Table 3.2.

Crop response models have been evaluated focusing on functional forms that allow for a growth plateau, such as the von Liebig and Mitscherlich-Baule response functions. These are more appropriate for this study of cabbages where inputs are not high enough to cause yield depressions of biomass as reflected in stage III of Fig 3.1 above. These functions, in contrast to polynomial specifications, such as the quadratic or square root forms, allow for a growth plateau following von Liebig's 'law of the minimum (Ackello-Ogutu et al. 1985; Grimm et al. 1987).

3.3.4 Modelling organic manure nitrogen

A number of fertiliser models have been developed that provide a reliable estimate of the fertiliser N value of farm manure spread to arable land as listed in Table in 3.3. The full details can be found in the origional papers where their strengths and weakneses are discussed.

Hower SYN model was selected for this study as it was more convenient and relevant to the field trial work. There is scope to compare the results of this study from SYN model, as the other models may have given a different answer. SYN model would make agood project in Uganda, however, this requires to be validated as discussed in the general discussion (Chapter 10).

Table 3.1: Summary of the characteristics of the functional forms

Production function	Characteristics
Quadratic	Imposes zero elasticity of substation among factors with no growth plateau and diminishing marginal productivity, not homogeneous. Isoquants are elliptical i.e. have areas of positive, negative, infinitive and zero slopes and it is strictly concave, exhibits stage II & III for each individual factor.
Square root function	Imposes zero elasticity of substitution among factors with no growth plateau and diminishing marginal productivity, Allows for sharper curvature near the maximum TPP and less rapid decrease in total product in stage III than quadratic, it is strictly concave .
Linear von Liebig	Imposes an elasticity of substitution of zero a priori and growth plateau, right angle isoquants.
Mitscherlich-Baule	Similar to von Liebig formulation except that it allows substitution of factors, exhibits stages II production only, has asymptotic yield plateau, allows for convex but not right angle isoquants and allows only for technical complimentary factors.
Nonlinear von Liebig	Weakly concave .
Spillman	Strictly concave and similar to Mitscherlich Baule function.
Generalized Cobb-Douglas	Complimentary factors only, no ridge lines, negative slope, convex to the origin & exhibits stage II only for each individual factor and with respect to scale given strictly concavity .
Transcendental	Complementary factors in regions of negatively sloped isoquants; independent factors on the ridgelines; and competitive factors in regions of positively sloped isoquants, rectangular ridge lines and it is convex to origin. Exhibits stages I, II, & III with respect to each factor and scale given quasi-concavity restrictions.

Source: (Beattie and Taylor 1985)

Table 3.2: Inorganic nutrient models

Model type/name	Reference	Application /Comments
Quadratic model	Michael 1990; Frank et al. 1990; Cerrato and Blackmer 1993; Tembo et al. 2008	Applicable to N response determination to crops
Square root model	Paris 1992; Llewelyn and Featherstone 1997	Applicable to N response determination to crops
Linear von Liebig model	Davidson and McKinnon 1981; Grimm et al. 1987; Finger and Werner 2007	Water and N crop response model
Nonlinear von Liebig model	Llewelyn and Featherstone 1997	Allows for the possibility of factor substitution
A fertiliser production surface model	Heady and Pesek 1954	A fertiliser production surface model
Quadratic & quadratic-plus-plateau models	Cerrato and Blackmer 1990; Bullock and Bullock 1994; Greene 2008	Can determine N application rates in crops
The Mitscherlich-Baule model,	Michael 1990; Cerrato and Blackmer 1990; Llewelyn and Featherstone 1997	Applicable to N response determination to crops
TOMGRO model	Gallardo et al. 2009	Simulation of transpiration, drainage, N uptake, nitrate leaching, in tomato grown in open substrate
TRITSIM model	Matthfius et al. 1986	Winter wheat crop model
Moisture-nitrogen-yield management model	Bolton and Glenn 1980	Static model
Flexible response curve prediction models	Myers 1984	Static model
Flex model	Burgess et al. 2003	Static model

Table 3.2 cont.

SYN model	Bowden and Diggle 2002; Diggle et al. 2003	Predicts N response curves of cereal and canola crops
NAVAIL model	Angus et al. 1993	Calculates N availability
EPIC model	Sharpley and Williams 1990	Erosion-productivity impact calculator
AnnAGNPS model	Hession et al. 1988;Heathman et al. 2008	Cropping systems, fertiliser application rates, water and dissolved nutrients from point sources
The ANIMO model	Rijtema and Kroes 1991	Assesses the N and P behaviour in soils
A nitrogen leaching model	Vereecken et al. 1989	Estimates N leaching with regional applicability
N-response prediction model	Angus et al. 1993	N-response prediction model
Crop Environment Resource Synthesis (CERES) model	Jones and Kiniry 1986; Carriker and Williams 1990 ; Hasegawa et al. 2000; Hasanein et al. 2009	A simulation model for cereals growth and development & can handle manure
Nitrogen sub model of CERES-Maize	van Keulen and Seligman 1987; Bowen et al. 1993	Can be applicable to manure
Dynamic model	Greenwood et al. 1987 ; Angus et al. 1991	Applicable to N response in cereal crops
WHEATMAN model	Woodruff 1992	Decision support for wheat management
SWACROP model	Kabat et al.1992; Wesseling et al. 1989	Soil water and crop production model
A summary model	Keulen et al. 1992	Estimates crop growth
DSSAT	Xiong et al. 2008	Simulates crop growth and yield responses to cereals, potato and cassava

Table 3.2 cont.

APSIM -Agricultural Production Systems Simulator	Keating et al. 2003; MacLeod et al. 2007; Delve et al. 2009;Whitbread et al. 2010.	Simulates crop growth and yield responses, legume beans, peas, nuts & Weed
A cohort model	Zyskowski et al. 2004	Simulates forage Brassica crops
SUCROS (Simple and Universal CRop growth Simulator)	Laar et al. 1992	Mechanistic crop growth model under ample supply of water and nutrients in a pest, disease & weed-free environment
ORYZA 2000 model	Bouman and Van Laar 2006; Das et al. 2007	Simulates crop growth and yield responses of rice
WOFOST model	Marletto et al. 2007	Mechanistic model: simulates potential crop growth and yield under limited and unlimited nutrients and water supplies in cereals, root tubers & legumes
The SIMPOTATO model	Hodges et al. 1992	Growth simulation model for potato & tomatoes
CROPSYST-SIMPOTATO model	Alva et al. 2004	Yield & N uptake in potato production systems

Table 3.3: Types of manure models for estimating available nutrients to crops

Model name	Reference	Application/comments	Country
MANNER*	Chambers et al. 1999	Determines the fate N in manure	United Kingdom
DECOMPOSITION model	Gale et al. 2005; Vadas 2011		USA
MARC model**	MARC 2008	Determines N availability	Canada
Manure value calculator	Henry et al. 2010	Calculates available nutrients	
Organic fertiliser calculator	Andrews and Foster 2007	Calculates application rates	
Simple mass balance model	Bhat et al.1980	Determines N availability	Netherlands
DAISY model***	Hansen et al. 1990; Hansen et al. 1991	Plant system model	Denmark
Manure Nutrient Availability Calculator	Joern and Hess 2004	Calculates N availability	
A simple prediction model	Beauchamp and Paul 1989	Predicts the fate N availability	United Kingdom

*: MANure Nitrogen Evaluation Routine

**: Manure Application Rate Calculator software

***: Danish simulation model

3.4 Choice of a response model for this study

Production functions are an important tool in the explanation of input-output relationships; therefore, decisions regarding optimal rates of fertiliser involve fitting a model to yield data where several rates of the applied fertiliser have been tested. Despite the fact that several different models of production functions are commonly used to describe crop yield response to fertilisers, normally one model is selected as being better than others (Cerrato and Blackmer 1990). Both inorganic and organic fertiliser recommendations should be derived using the most appropriate model. A number of different response models have been employed to identify economic optimum rates of N fertilisation by many researchers including Abraham and Rao (1965), Anderson and Nelson (1971), Cerrato and Blackmer (1990); Makowski et al. (2001); Makowski and Wallach (2002) and Mooney et al. (2008).

3.4.1 Reasons for the choice of select your nitrogen model

A decision support tool for farmers is essential given the variation in crop response to N with season, soil type and cropping history and management (Bowden 1989; Angus et al. 1993; Chambers et al. 1999; Burgess et al. 2003; Chambers et al. 2010). The prediction of N response curves is basic to the development of a system for recommending fertiliser N that assists farmers to make choices of source, amount and timing in the context of seasonal and price variations. The SYN model is, unlike many of the other models listed in Tables 3.2 and 3.3, well designed, easy to use and requires only easily available input data. It suits the local environmental conditions in Western Australia (WA) and is user-orientated, requiring only Excel software. Smith et al. (1997) have suggested that farmers will use organic manure models only where the required input information is easily available. However, this model may be useful to agricultural extension officers and advisors given the level of technical knowhow of Ugandan smallholder farmers hence the basis for the choice of the model.

The SYN model allows the availability of N from many sources to be compared at the same time (Burgess et al. 2003). Furthermore, the model provides a quick estimate of N availability and losses for a range of agricultural circumstances. It accounts for denitrification and immobilisation as important factors during the process, total urea, ammonia, nitrate, ammonification rate, nitrification rate, and amount attributable to N for crop growth.

Although models can reproduce response curves for any seasonal situation, they provide only a probability of response because they cannot predict which situation will arise. However, mechanistic models allow flexibility to determine the impact of non nutritional factors relevant to the fertiliser decision (Bowden 1989). In addition, the current study focuses on the use of a nutrient model for N application leading to N management advice at a scale of a single field, rather than fundamental research on detailed processes such as those at the plant-soil interface, or for solving regional problems such as nutrient release into a groundwater system.

Whilst SYN has to date been tested only under Western Australian field conditions, it has the potential to be adapted for other farming systems (Burgess et al. 2003). To use the system successfully for manures spread in tropical climates, there is need to validate the model under such conditions including Uganda. This will enhance its adoption once replicated under Ugandan growing conditions.

3.4.2 Criteria for choice of a response model

Comparative assessment of alternative algebraic forms for the (expected) response forms is of importance to researchers. Many studies have emphasized the comparison of quadratic polynomials in X_i and Xi_5 and variants of the power Mitscherlich and hyperbolic functions including Johnson (1953); Heady et al (1961); Cady and Laird (1969); Jonsson (1974) and Colwell (1976). Stemberger (1957) has also compared quadratics and the form-free model proposed by Hidreth (1957), while Ackello-Ogutu et al. (1985) have compared polynomial and Liebig-type specifications of the response function (Berck and Helfand 1990; Michael 1990; Bélanger et al. 2000; Finger and Werner 2007; Finger and Hediger 2008). However, in all cases, the usual criterion applied has been an amalgam including statistical measures of goodness of fit and "significance", a priori considerations relating to the biology and economics of the response process, subjective judgement and computational ease. Quadratic function in all cases has been favoured against other forms, with some preference for the square-root quadratic attributable to its non-symmetrical and flatter shape in X_i space (Dillon and Anderson 1990). These conclusions are not unexpected since the true response function is always unknown and the polynomial form can be justified as a Taylor series approximation of the unknown function, as shown by Heady et al (1961).

Other studies on the choice of the functional form have been presented by Denny (1974); Gallant (1984); Griffin et al. (1985); and Shumway (1989). Anon (1974a) and Perrin (1976) argued in extending the ideas of Anderson (1968a) and Havlicek and Seagraves (1962) on response model evaluation; the criteria for choosing between alternative models or theories of response analysis should relate to the value of the information they provide. Expected profit provides a workable and reasonable surrogate giving, for risk averse decision makers, an upper bound on the value of information. A variety of algebraic functions are available (Pesek 1966). These functional forms are frequently used in the literature and have proved to accurately capture the underlying relationships (Heady et al. 1961; Yadav et al. 2003; Jalota et al. 2007; Rajsic and Weersink 2008). The choice of function depends on the extant biological theory. Crop yield response to N follows the von Liebig law of the limit (linear up to a maximum) or, for example, the Spillman function, determines how the experiment is designed, and how the recommendations are made to producers (Swanson 1963; Pesek 1966). For example, a linear response can be efficiently estimated with observation at the "no treatment" level and at the maximum level; estimation of nonlinear responses requires intermediate observations.

When such biological theory is not available or has not been elaborated, the researcher may use statistical criteria; however, in practice these criteria are often inconclusive. Furthermore, the slope of the response function is likely to depend on the season and rate of the input, in this case N application. Crop responses may also be due to differences in soil productivity and climatic conditions, the number of years the crop has been grown in an area and type of rotations.

3.4.3 Select Your Nitrogen (SYN) model

A computer program called NPDECIDE was developed by the Western Australian Department of Agriculture to assist with decisions relating to the use of N and P fertilisers on cereal crops including a N only model for cereal and oilseed crops, 'Select Your Nitrogen (SYN)". The part of NPDECIDE and SYN that calculates N availability is called NAVAIL.

The SYN model estimates the response of the crop to N fertiliser and calculates the likely profit from its use. It calculates the availability to the growing plants of N from the fertilisers applied and from organic material in the soil (Burgess et al. 2003). It is a decision tool for quantifying N availability and crop response in broad acre farming systems. The model simulates a weekly time step that is designed to give the user a quantitative feel for how different components of the farming system affect available N, grain yield and grain quality as well as the dollar returns. The main purpose of SYN is not to recommend a fertiliser rate; rather it is to show the consequences of any possible N management strategy in any cropping situation (Diggle et al. 2003).

In NAVAIL, the 'availability' of N is represented by the amount of mineral N from a particular source that is in the root zone of the plants in a form that can be used by the plants, at a time when the plants can use it. This 'availability' depends on the rates of transformation of the N sources to and from plant available forms, the movement of N by leaching, and on the growth of the plant roots.

The amount of N available is affected by leaching, rainfall, soil type, rooting depth, rate and duration of mineralisation of organic matter, immobilization by soil microbes and the nature of the N sources used (Bowden and Diggle 2002). This N availability model is then integrated with a crop response to N model to give the model known as SYN.

The SYN predicts N response curves of cereal and canola grain crops and is helpful in assisting farmers to make choices of source, amount and timing of N inputs in the context of seasonal and price variations (Angus et al. 1993). The SYN model predicts the response curve in the following stages. First it calculates the amount of inorganic N (N_i) supplied by pools of residue and stable soil N (Bowden and Burgess 1993). Second it uses a simple simulation model to calculate an N availability parameter (K_{Ni}) for each of the sources (i) of soil and fertiliser N. K_{Ni} is the summed average, through time, of mineral N derived from a particular source which is resident within the crop's root zone. In the third stage, the product of the availability, K_{Ni}, and amount, N_i, of all sources of N in the system is summed to give the potentially available N or Navail, for a given situation. Fourthly, the amount of mineral N in the root zone, Navail, taken up by the crop (Nupt) depends on the demand characteristics of the crop parameterised by maximum N uptake, M_N, and modified depending on crop variety, time of sowing, supply of other nutrients and the level of weeds, diseases and pests. This phase marks the end of predicted N availability for biomass production.

For crops that produce grain, grain yield (GY) is determined by N uptake and the potential yield of the crop (A) which is dictated by factors affecting maximum N uptake and water stress during grain filling. This is stage five of the model. In the second last stage, grain protein is calculated from Nupt and an assumed value of harvest index for N. Lastly, grain yield as a function of applied N is calculated and is influenced by combinations of the main factors including the amount of K_N and M_N. The N response curves can be combined with a P response curve so that the relative value of various NP compound fertilisers can be assessed (Burgess 1988). This approach has been used over a number of years in Western Australia and is credited with having addressed the most common issues related to the use of N fertilisers for cereals in Western Australia, albeit at a semi-quantitative level. The final stage of SYN is to not only produce yield responses to fertiliser N inputs but also grain quality outputs such that the input/output economics outlined in an earlier section can be calculated for any stated situation.

3.4.4 Parameters and features of the model

This section highlights the parameters and features of NAVAIL, the part in SYN that calculates N availability. There are two types of inputs required for NAVAIL: rainfall and source inputs. Rainfall inputs include leaching rainfall, field capacity, wilting point and initial depth of wetting front. The source inputs consist of week added, organic N, ammonium N, nitrate N, ammonification rate, nitrification rate and microbe capture and release as defined in appendix A1.

3.4.5 Theoretical background of the model

A simplified representation of N transformations and losses with their rates following the land application of fertilisers is shown in Figure 2.2. The model predicts the fate of organic N and takes account of each of the pathways of N transformations and losses following application which gives an estimate of the amount of N available to the crop (Burgess et al. 2003). The specific rates of the processes involved are presented in Table 3.4.

Table 3.4: Soil and fertiliser nitrogen transformation processes modelled in NAVAIL

Process	Rate
Ammonification	Ammonification rate is usually 0.002%/week for stable organic N, 0.04% for residue N, and 0.9 %/ week for urea.
Nitrification	Nitrification rate is typically 0.4% per week for urea, 0.35% /week for diammonium phosphate (DAP) and ammonium nitrate, 0.3%/ week for organic residues, Agras I and Agras 2, and 0.25%/week for ammonium sulphate.
Capture and release	Microbe capture and release: These figures are generally set at 0.15%/week for the capture rate, and 0.2%/week for the release rate.

Source: Burgess et al. (2003).

3.4.6 Assumption and limitations of the SYN model on N availability

Although mathematical models may be used to provide the rate at which N is released, the system is complex and requires to be modelled because it involves uncertainty, i.e. stochastic elements. Therefore, simulation is needed to provide realistic information about N availability and allows testing various scenarios in often only a couple of minutes or hours.

However, it should be noted that simulation in comparison to exact mathematical methods cannot naturally be used to find an optimal solution. This study has employed SYN model as described above; however, it has inherent assumptions and limitations as follows;

In soil, N appears in a number of forms as mentioned in Chapter two, of which only the NO_3^- and NH_4+, or mineral nitrogen, can be taken up by plants. The transformations between the various forms are highly complex. Most of the organic types, including urea, become available originally as NH_4+, which is mineralised to NO_3^-; both are then steadily reutilised by micro-organisms, i.e. immobilised, and the resulting microbial biomass is then remineralised with time. In NAVAIL, only the NO_3^- is specifically immobilised, and immobilisation of NH_4+ is accounted for by adjusting mineralisation rates.

The N transformations in NAVAIL are assumed to occur at constant rates. Again, this is not the case in reality, where factors such as temperature and soil water content often have an important effect (Burgess et al. 2003). In Western Australia, this is not particularly a problem after the break of the season, as the soil can be counted on to be wet, and temperatures are generally cool. In the event of summer or early autumn rain, however, rates and times are adjusted as described in the 'Week added' and 'Leaching rainfall' sections.

In NAVAIL, it is assumed that only the NO_3^- is mobile, whereas urea and NH_4+ can also be leached in some circumstances (Burgess et al. 2003). Leaching of urea is potentially as rapid as for NO_3^-, but because urea is quickly converted to NH_4+ this factor is not significant. Ammonium N is generally regarded as immobile, but it has been shown to leach in several of the coarse textured Western Australian soils. This is not likely to cause NH_4+ to move out of the root zone because it moves much less rapidly than NO_3^-, but even a modest amount of movement can cause the NH_4+ to migrate to the subsoil where nitrification rates may be different. NAVAIL is only capable of dealing with this situation by altering the nitrification rate in anticipation of NH_4+ leaching where it is likely to be a factor. This factor has been considered during the calibration of the model in Chapter 8.

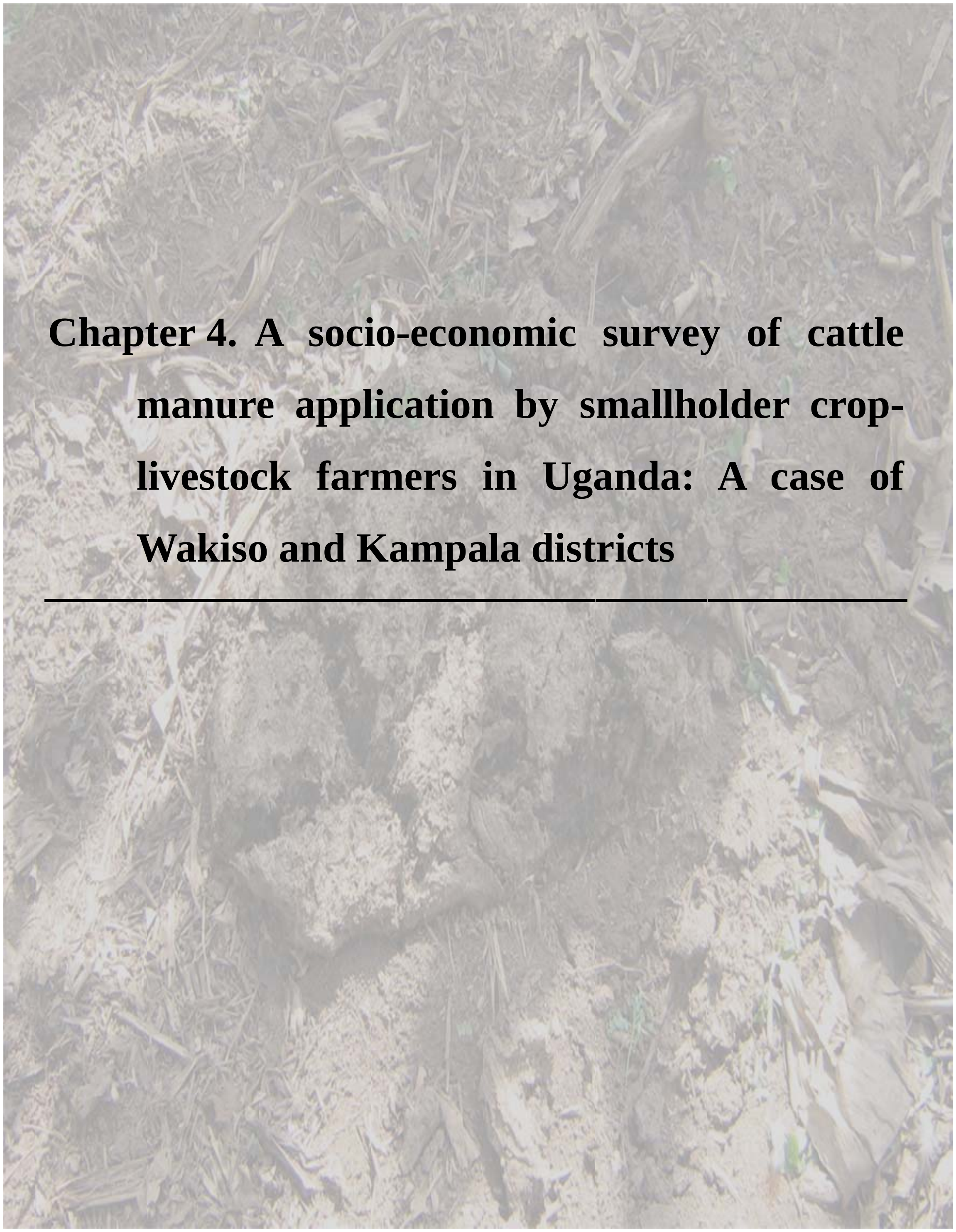
NAVAIL does not calculate the amount of an N source, which will be taken up by a crop; it only estimates the proportion, which will be available to the plants. This is done by specifying a period when the crop demand for N is high, and calculating the average of the proportion of the source, which is in mineral form in the root zone during that time. The period from 4 to 15 weeks has been found by trial and error to be suitable for typical grain crops.

3.4.7 Information needed to adapt the model for cabbage and cattle manure

The SYN model is a comprehensive tool, which is designed to support management decision making and allows resource users to understand the effects of various factors (rainfall, effect of delaying fertiliser application, using no tillage operation) on available N (Diggle et al. 2003). In Western Australia, it is used to show the consequences of any possible N management in any cropping situation on grain yield. Since the SYN model requires both input and yield attributes of a crop as well as information on soil data and rainfall, two field experiments and a glass house experiment were conducted over the 2009 and 2010 growing seasons in Western Australia (Chapters 5 and 6). The data needed to adapt the model to Uganda and cabbage and cattle manure includes rainfall inputs such as leaching rainfall, field capacity, wilting point and initial depth of wetting front and source inputs, mainly fertilisers: cattle manure N itself with its attributes including organic N, ammonium N and nitrate N from cattle manure, ammonification rate, nitrification rate, microbe capture and release, week cattle manure added, N application rates and price of cattle manure N.

The data required to adapt for cabbage includes production/yield data (fresh and dry matter), N concentration, N uptake and the price of fresh cabbage heads and relative effectiveness (RE) values (nitrogen availability index) of cattle manure N compared to inorganic fertiliser.

Based on the above, a study was designed to determine the optimum level of cattle manure application in smallholder crop-livestock systems in Uganda and then to compare the environmental and socio-economic benefits and costs of applying cattle manure with inorganic fertiliser; the basis for chapters 4, 5, 6 and 7. A simulation model of predicting available N, N uptake, and potential yield after application of cattle manure is developed and described for cabbage in Chapter 8. The focus in the study was on two crucial production factors; cattle manure N and inorganic N fertiliser.



Chapter 4. A socio-economic survey of cattle manure application by smallholder crop-livestock farmers in Uganda: A case of Wakiso and Kampala districts

4.1 Introduction

Declining soil fertility coupled with minimal nutrient inputs has contributed to low crop yields in sub-Saharan Africa (SSA) (Kanonge et al. 2009); a major constraint to food security and economic development in Uganda (Zake et al. 2005). Crop production needs to be intensified to meet these challenges, which requires a supply of nutrients. However, the annual inorganic fertiliser application rates in Uganda contain less than a kilogram of nutrients per hectare. Consequently, many farms suffer from negative nutrient imbalances (Wortmann and Kaizzi 1998; Kaizzi et al. 2002; Nkonya et al. 2002; Ssali 2002; Zake et al. 2010). Fertiliser application level is low in Uganda compared to the average for SSA of 9 kg ha^{-1}, which in turn is only 5% and 20% of that used in East Asia and Latin America, respectively (Jayne et al. 2003; Panda 2008). One alternative to improve soil fertility is through the use of cattle manure, which is used widely as a crop fertiliser and a soil amendment in SSA.

There is lack of data in Uganda as to cattle manure use, identifying application, handling and storage methods of cattle manure as well as key constraints to manure use, identifying alternative soil fertility management options to cattle manure and inorganicfertilisers and characterising the physical and chemical properties of soil to identify nutrients and soil constraints limiting crop production in the area by smallholder crop-livestock farmers. In this study, a socio economic survey of smallholder farmers was conducted in Uganda in the central districts of Wakiso and Kampala, to ascertain the current situation of smallholder crop-livestock farms with respect to the requirements and options for nutrient applications, including cattle manure. The aim of this research is to identify strategies to improve resource use in smallholder crop-livestock farming systems including cattle manure management decisions in order to better meet the nutrient requirements for crop production.

This chapter comprises several investigatons being: farmer survey using a semi structured interview, focus group discussions, field observations and collection and laboratory analysis of soil samples from farms.

4.2 Materials and Methods

4.2.1 Farmer survey

The survey design was cross-sectional and descriptive, aimed at capturing the different methods of cattle manure application, information on crop production and reasons for non-use or limited use of inorganic fertiliser in the study area. Both quantitative and qualitative approaches were adopted, targeting farmers especially those who apply cattle manure in vegetables, specifically cabbage (*Brassica oleracea*) and dodo (Amaranthus *spp*). The survey focused on key constraints to manure use, soil nutrient status in the area, available soil fertility management options, strategies/criteria used to apply cattle manure, key enterprises, source of cattle manure, major reasons for keeping cattle and cost of applying cattle manure in comparison to inorganic fertilisers.

Study area and population of interest

The survey was carried out in the two most densely populated peri-urban areas of Wakiso and Kampala districts. Kampala is the largest city in Uganda with over 3 million people and lies astride the equator in the Lake Victoria crescent. It is about ten times larger than Jinja the second largest town (UBOS 2008). For Wakiso, an area within 2-20 km radius of each town was surveyed. In Kampala, the area was between 5-25 km along major arterial roads. These areas provide markets for the agricultural products from different parts of the country. They experience moderate average temperatures slightly above 20^{o}C and receive a unimodal annual average rainfall above 1,320 mm (MWEDM 2011). Rainfall in areas bordering on Lake Victoria is between 1750 mm and 2000 mm, with two wet seasons from April to May and October to November. The principle peak is in April and a minor one in November,10 average monthly days of rainfall (Uganda Department of Meteorology 2009).

Crop cultivation, livestock rearing and fish farming are the main activities characterizing urban agriculture in Kampala and neighbouring districts (Atukunda et al. 2003). Land availability is increasingly constraining the productivity and the small land area available in urban and peri-urban areas is often used to its maximum. The farmers are not able to fallow the land and this eventually results in soil degradation (Snapp et al. 1998). There is not enough land to grow animal fodder and the livestock keepers lack the capital to purchase feed supplements. The other major activities include civil service, service sector (sand and stone quarrying, commercial business, transport and carpentry) in addition to both commercial and semi-intensive farming, bananas, flowers, potatoes and vegetables are the major crops grown.

Cabbage and dodo enterprises were selected for this study, because they are commonly grown. Farmers adopted zero grazing as the most applicable and productive system of livestock rearing (Tumutegyerize et al. 1999).

Kampala and Wakiso districts were purposively selected because peri-urban agriculture is well-established (Maxwell 1995; Mugisa 2002; Nsubuga 1992; Ssembalirwa 2008). Peri-urban agriculture has always been part of Kampala’s economy and neighbouring districts and an important livelihood strategy for the city’s urban poor, especially women (Hooton et al. 2007). Nevertheless, the policy environment has been unfavourable or hostile because of the perceived nuisance and public health risks that animal and crop wastes pollute the air and water that people breathe and drink. Since these peri-urban areas are located within the same ecological zone as Intensive Banana Coffee Lakeshore zone, farmers use more or less the same technology in crop production.

In this study, the population surveyed was smallholder farmers, who account for more than 80% of the population in the study area. A smallholder farmer is defined as one whose farm size is between 0.5 ha to 2.0 ha of land from which the farm family derived a majority of its food and income. Smallholder farmers were further selected from those who owned only a few head of livestock and who specifically grew vegetables, particularly cabbage and dodo and thus were likely applying cattle manure.

The farmers were all members of the Kulika charitable trust organisation, an NGO promoting organic farming in the area. The mobilisation was conducted by the field extension officer-Kulika charitable trust. The meetings were publicised through local community channels including road and village posters and notices, to ensure that farmers and or groups that do not usually participate in community level meetings such as women, poor households and youth were reached. The contact farmers chose the appropriate time of the day for the meetings with specific flexibility to accommodate women’s time constraints. The meetings were scheduled outside periods of peak labour demand, to ensure that the group discussion were inclusive of all farmer categories. In consultation with contact leaders, venues were chosen that were centrally located within the target community for equitable access by all farmer members of Kulika especially women and persons with disabilities.

Choice and design of the survey instrument

Face-to-face interviews were conducted with forty (40) smallholder crop livestock farmers through a semi-structured questionnaire. The semi-structured questionnaire was considered appropriate for the sample as it is less time consuming and is cost effective in terms of its administration to capture the needed information. The design of the survey instrument ensured that relevant information that pertains to manure and or fertiliser use including limitations to fertiliser use and cattle manure application, economic benefits of cattle manure application to crop production and methods of manure application in the area were captured. The approved draft copy of the research instrument by Curtin ethics committee was then piloted on five farmers. After pretesting, minor improvements were made; the final interview guide is in Appendix A2.

A number of observations were made during the survey including how cattle manure is handled, stored, and applied. Notes of responses from farmers were recorded in a note book and replies were recorded on questionnaire sheets. Physical observations of crops grown without fertiliser application and pictures of a range of plants, including stunted crops and or with leaves yellowing were taken during field visits. Piles of heaps of manure both covered and uncovered manure as storage methods were recorded.

Sampling procedure

Purposive, stratified and random sampling methods were used to obtain one mutually exclusive group (Peil 1995) of farmers: only those who apply cattle manure (users) in the production of selected crops (cabbage and dodo). Two divisions/sub counties/ in each peri-urban area of Kampala and Wakiso districts where farming takes place were purposively selected. Two parishes were selected in each division/Sub County. A parish being the lowest administrative unit of local government to represent the use of cattle manure in the area. Heifer Project International, a Non Governmental Organisation (NGO) introduced zero grazing animals in these areas and so a large amount of cattle manure was expected to be produced. Selection of district and divisions/Sub counties was purposive while random sampling procedure was applied in selecting farmers.

A list of farmers was provided by the staff of Kulika charitable trust organisation. The list comprised names of farmers who had experience in vegetable growing with cattle manure application and were the only ones who were interviewed. Twenty (20) farmers from each district of Kampala and Wakiso were selected. Two divisions per district were selected of which each division of Kampala, 10 farmers (including 5 farmers from each parish who applied cattle manure to their gardens) were randomly selected from the list.

In addition, 20 farmers (including 5 farmers form each parish who applied cattle manure to their gardens) from the peri-urban areas of Bikka and Nangaabo town councils/sub counties of Wakiso district were also randomly selected for the interview. In total, 40 crop-livestock farmers comprising men (25) and women (15) farmers that grew cabbage and dodo were selected. This number was deemed adequate as explained by Ranjith (2011) and in addition, only two weeks were allotted for the survey exercise.

Conduct of the interview

Primary data were collected using a pre-tested structured questionnaire that was verbally administered to individual farmers. Pretesting was done on five farmers from Kampala district to test the suitability of the questionnaire. The questionnaire was used to document qualitative and quantitative data. Field interviews were supplemented by on-farm observations by the researcher. Respondents were interviewed on appointment, which was made through the Kulika staff.

The type of data collected include farmer characteristics (age, farming experience), type of farming systems, kind of enterprises promoted by farmers, land size holding, type of livestock reared by farmers, methods of manure application and practices employed to apply cattle manure. Others included socio-economic benefits of cattle manure application and reasons for non use of fertilisers, quantity of manure applied, crops where manure is applied, quantity and price of outputs, farm size, labour availability, agricultural input prices and yield data, crop husbandry practices, types of farming activities, and problems and constraints encountered in crop production.

The study captured both qualitative and quantitative data in order to get an indepth analysis in a structured way. The former and the latter were obtained through focus group discussion and a structured questionnaire.

The interviews and group discussions were conducted between January and February 2010. The identity of the farmers, who took part in the research, was kept strictly confidential and participation was voluntary. All the responses were recorded on questionnaire sheets. The survey exercise took approximately one hour and ranged from 45 minutes to 1.5 hours per survey. The field technical support was provided by David Collins of the Muresk campus of the Department of Environment and Agriculture, Curtin University.

Data analysis

Data were entered into Excel and then simple univariate analysis using excel spread sheets for entering data and SPSS was used to generate simple statistical information including frequency distributions of the different variables of the study. This was used to detect possible outliers and errors in data entry, which were corrected.

The content analysis method was used to analyse qualitative key informant data. Categories for the open-ended questions were developed to be mutually exclusive and exhaustive based on themes that emerged from the replies during the study. However, discreet single categories were in other cases combined into more general categories to enable cross tabulation. Categories were re-examined and after cross-examining the original questionnaires, some adjustments were made to categories and coding. Categories were combined or deleted as deemed necessary, especially if a cell had an expected frequency of less than one.

Due to the infeasibility of accurate measurements at the farm level, a close approximation of the quantity of cattle manure used by a farm in a season was used. A basin was taken to weigh 13 kg. For standardization of output, average weights for each crop enterprise were computed including 3.5kg and 9.2g for cabbage and dodo, respectively, for the farmers surveyed. A comparison of the outputs for the selected crop enterprise under cattle manure application and outputs of similar enterprises under inorganic fertiliser application was made.

4.2.2 Soil sampling

Soil sampling from three selected farmers within the study group was conducted to identify nutrients and soil constraints that were limiting in the study area. Six sites were selected as listed in Table 4.22.

The six sites were randomly selected, two from each parish to provide the soil samples. Soil samples (composite of ten cores) with a 20 mm diameter, 0-10 cm depth were taken from each site. While additional samples of 10-20 cm and 20-30 cm were from two of these sites. Soil properties such as texture, colour and pH were conducted in the field and EC was conducted at Makerere University. Plates 4.1 and 4.2 show the different types of soil sampled.

Soil samples were air-dried, sieved to pass a 2 mm mesh and 300g of each then air freighted to Australia from Uganda under the Australian Biosecurity Authority Control. On arrival, soil samples were treated with gamma irradiator in the quarantine laboratory at the Chemcentre, Bentley. The gamma irradiator technology is a Cobalt 40 radioactive source, which is a quite efficient and effective quarantine tool for destroying microorganisms, pests, weeds and diseases (ChemCentre report 2010) (accredited by the National Association of Testing Authorities (NATA) for chemical analysis).

The soils analyses conducted included pH, electro conductivity (EC), Al ($CaCl_2$), organic carbon, total N, ammonium and nitrate, BIC-P (Plant Available), BIC-K (Plant Available), total phosphorus, Phosphorus Retention Index (PRI), Mehlich-3 extractable elements, Al and Fe extracted in ammonium oxalate and exchangeable cations (Table 4.22). The methods of soil analysis used are outlined in Chapter 5. Plates 4.3 to 4.6 show various tests that were conducted during the survey including EC, texture, and pH.

In addition, four samples of cattle manure were selected from four farmers one in each sub county. The manure included biogas slurry, aged manure, fresh manure and uncovered manure. All cattle manure samples were analysed at Makerere University, Kampala, Uganda, for total N.

Plate 4.1: Sampling of soil (0-10cm) at Kulika site

Plate 4.2: Sampling of soil (20-30cm) at Nangabo site

Plate 4.3: Testing soil pH in the laboratory at Makerere University, Kampala, Uganda

Plate 4.4:Testing soil texture in the field by farmers (Gobero site)

Plate 4.5: Testing soil pH in the field for farmers at Bikka site

Plate 4.6: A farmer testing soil texture at Kyengeza site

4.2.3 Focus groups meeting

The aim of the focus group meetings was to provide insight into the application of fertilisers for crop growth, including cattle manure and to capture soil fertility management options in the area, the source of fertiliser and or manure in the area, and possible factors that affect use of cattle manure.

Design of focus group meeting

Focus group meetings were conducted with farmers from Kawempe division (equivalent of a Sub County) in Kampala and Nangaabo Sub County in the Wakiso district. These two Sub Counties were chosen to provide information across the farming community specifically about the attitudes towards the use of fertilisers. Four focus groups were planned, but only three conducted, involving 27 participants. Each group had an attendance of nine participants. McIntosh (1993), Kitzinger (1995) Jon and Leinbach (1996), Morgan (1996) and Cohen and Crabtree (2006) recommend between 6-10 participants per group. All family members involved in making decisions about the farm business were encouraged to attend. The meetings focused on the use of inorganic fertiliser and how fertilisers are used in the area. Others included handling and application methods, source of cattle manure in the area, strategies of manure application and socio-economic factors influencing cattle use among others. The focus group guide is attached in Appendix A3. Transcriptions of the meetings were categorised into themes derived from farmers' responses as listed in Table 4.23. Category of responses followed themes that occurred more often than others. Data coding followed major patterns and common themes that emerged as recommended by Berkowitz (1997).

4.3 Results

Findings of the study survey/documentation of the use of cattle manure and /or fertilisers, soil sampling and focus group meetings conducted in the central districts of Kampala and Wakiso in Uganda include the demographic characteristics of the respondents, major farming enterprises, system of rearing cattle in the area, cattle manure application and handling methods, the key strategies employed by farmers in manure application and economic benefits of cattle manure application in crop production. Further, it contains the factors and or reasons for the non-use of inorganic fertilisers and challenges that are associated with cattle manure application and or use and the costs of cattle manure and inorganic fertiliser application in cabbage production.

4.3.1 Farmer survey

Demographic characteristics of the sample

The 40 respondents were all smallholder farmers whose livelihood largely depends on crop-livestock farming with twenty-five (25) men (62.5%) and 15 women (37.5%) interviewed. From the study, nine (9) of the male farmers were less than 35 years (36%) and 16 were more than 35 years of age (64%). Of the female respondents, 6 were less than 35 (40%) and 9 were more than 35 years of age (60%). The majority of farmers (62.5%) were over 35 years of age.

Table 4.1: Age characteristics and marriage status of the respondents by gender

Characteristics	**<35 Years**		**>35 Years**	
Age by gender	**Count**	**%**	**Count**	**%**
Male	9	22.5	16	40.0
Female	6	15.0	9	22.5
Marriage status by gender				
Male married	6	15.0	13	32.5
Male single	3	7.5	3	7.5
Female married	4	10.0	8	20.0
Female single	2	5.0	1	2.5

n=40

Overall, 10 married farmers were less than 35 years of age, while 21 married farmers were older than 35 years. Three (7.5%) men and one (2.5%) female were single and less than 35 years whereas also, 3 (7.5%) men and 1 (2.5%) female were single and older than 35 years.

Major farming enterprises

Table 4.2 shows the major enterprises by different categories of farmers in the study area. It indicates that banana is the most important food and cash crop in the area. Other crops include cereals such as maize, root crops including sweet potato, legume crops mainly beans as well as tree legumes. Major vegetables include cabbages and dodo. It can be seen from the results that these crop enterprises were allocated more land compared to other crops.

Table 4.2: Mean farm size and utilization by smallholder crop livestock farmers

Men enterprises	Count	% of respondents	% of responses	Size (ha)	% land allocated
Pasture	22	88	22.9	0.20	11.8
Cabbage	20	80	20.8	0.20	11.8
Dodo	16	64	16.7	0.13	7.7
Bananas	14	56	14.6	0.44	26.0
Cover crops	12	48	12.5	0.12	7.1
Maize	12	48	12.5	0.60	35.5
Total	**96**	**384**	**100**	**1.7**	**100**
Women enterprises					
Beans	15	100	22.4	0.07	6.9
Dodo	15	100	22.4	0.19	18.8
Potatoes	15	100	22.4	0.40	39.6
Cabbage	13	86.7	19.4	0.30	29.7
G/nuts	9	60	13.4	0.05	5.0
Pastures	0	0	0.0	0.0	0.0
Total	**67**	**446.7**	**100**	**1.01**	100

(n=25 for men and 15 for women)

Men were more involved in cash crop enterprises compared to their female counterparts who relied more on food crop enterprises. Plate 4.1 shows an example of gardens of vegetables grown in the area fertilised with cattle manure. Plate 4.7 shows a garden of dodo applied with cattle manure.

Farmers also practice bio intensive gardening (BIG) because of limited land. These are back yard gardens that involve use of containers such as gunny bags, empty tins and plastic jerry cans. Other gardens are prepared around the homestead verandas to maximise household wastes and daily water from cleaning utensils (Plates 4.8, 4.9 and 4.10).

Plate 4.7: Cabbage garden applied with cattle manure

Plate 4.8: Gardens of Amaranthus *spp* (dodo) at Kyebando Kampala

Plate 4.9: A back yard garden of Amaranthus *spp* (dodo) growing near the homestead

Plate 4.10: Kale/cabbage grown in gunny bags under bio-intensive gardening (BIG) system

Male farmers are involved in cash generating enterprises with most of the income derived from maize and vegetables (cabbage and dodo) which account for 35.5% and 19.5% of the land allocated to the major crops, respectively (Table 4.2). Male enterprises, particularly maize (0.60 ha) and bananas (0.44 ha), were allocated a big share of land while women preferred vegetables (0.49 ha) and potatoes (0.40 ha). The percentages of men growing cabbage, dodo and pastures, were 80%, 64% and 88%, respectively, while all women were growing both potatoes and dodo and 87% grew cabbages.

Men participate in planting, manuring and selling produce that accounts for 15.3%, 14.1% and 15.3% of their time, respectively. Men reiterated that their enterprises are labour demanding and so need more physical lifting as opposed to women's enterprises. All women indicted that they participate in all activities and where they can't afford they employ hired labour. A good number use family labour especially during school holidays, although this depends on season and the crop. In all cases, both men and women employ family (55%) and hired labour (45%) regardless of the enterprise.

Type of cattle kept and the reasons for keeping cattle

A total of 77.5% of farmers (in the survey) keep cattle (Table 4.3) of these, 67.7% are local breeds kept predominantly for milk production (90.3%), but also as a source of manure (51.6%) and cash (32.3%). Cattle can be readily converted to cash to cushion farm enterprises against unstable commodity prices and to provide cash income in times of need.

Table 4.3: **Number of farmers, type of cattle kept and reasons for keeping cattle**

Farmers	**Count**	**% of respondents**	
Don't keep cattle	9	22.5	
Keep cattle	31	77.5	
Total	**40**	**100%**	
Type of cattle kept			
Improved dairy animals	10	32.3	
Local breeds	21	67.7	
Total	**31**	**100%**	
Reasons for keeping cattle in the area		**% of respondents**	**% of responses**
Milk	28	90.3	52
Manure source	16	51.6	30
Cash	10	32.3	19
Total	**54**		**100%**

(n=31)

Farming experience and farm land ownership

The number of years in production of the selected crop enterprises was used as a proxy for farmers' level of farming experience. The average number of farming years for the smallholder crop-livestock farmers applying cattle manure in cabbage and dodo vegetables were 13.3 years. Overall, a majority of the farmers interviewed had more than 10 years of farming (Table 4.4). Only 20% had an experience of less than 5 years. Land size ranged from 0.8 ha to 2 ha.

Table 4.4: Distribution of farmers according to experience with farming

Farming period	Number	Percentage
<5years	8	20.0
>5 years	13	32.5
>10 years	19	47.5

(n = 40)

System of rearing cattle in the area

The system of rearing cattle has a bearing on the availability and use of cattle manure. Table 4.5 presents the systems of rearing practiced in the area and lists the reasons for the choice of the system. The results show that 81% of the respondents practice zero grazing (a type of dairy farming in which the cattle are fed with cut grass), while 19% use semi-intensive systems (the semi-intensive group have access to grazing and supplemented with cut grass). Cattle are sometimes grazed or tethered during daytime, but are increasingly confined due to manure demand (45%) as the survey results showed insufficient manure in the area and limited space (90%). The indigenous cattle are kept in kraal. These are open structures built with local materials but exotic/cross breeds (improved dairy cattle) are more on intensive farms that are housed in improved/zero-grazing units. The zero grazing system is used because it allows use of local available materials in the area and flexibility (36%), as the temporary structures can be shifted from one location to another in the paddock. However, this requires capital, for it is labour intensive and involves indoor feeding. Plates 4.11 and 4.12 show the improved zero grazing unit and local kraal, respectively.

Table 4.5: System of rearing cattle and reasons for the choice of the rearing system in the area

Item	**Count**		**Percentage**
Indoor/zero grazing	25		81
Semi-intensive	6		19
Total	**31**		**100**
Reasons	**Count**	**% of respondents**	**% of responses**
Limited space	28	90	53
It is flexible and affordable	11	36	21
Need for manure	14	45	26
Total	**53**		**100**

(n=31)

Plate 4.11: Improved zero grazing unit

Plate 4.12: Cattle in Local Kraal, Namere site

Source and type of cattle manure used by smallholder farmers

The different sources of manure in the area are shown in Table 4.7. Most of the farmers collect manure from their own animals (55%), while 38% purchase cattle manure. Nine farmers (22%) obtain manure from the neighbours whereas 3 farmers (8%) purchase additional manure to supplement what is freely given. A few farmers (15%) were also purchasing manure in addition to using their own.

Table 4.6: Sources of cattle manure in the area

Source	No	% of respondents
Own source only	16	40
Own source and purchase	6	15
Both purchase and manure given free	3	8
Purchase only	6	15
Free from neighbours only	9	22
Total	**40**	**100**

(n = 40)

All farmers including even those who obtain free manure also reported that the cost of transport is extremely high especially during the rainy season due to poor roads; heightened by rising fuel prices. The study further found out that 45% of the farmers supplement cattle manure with poultry manure, while 32.5% also apply goat manure and 37.5% apply pig manure but in limited quantities because of the few animals kept. Rabbit manure accounted for 17.5%.

Table 4.7: Other types of animal manure

Type	No	% of respondents	% of responses
Poultry manure	18	45.0	34.0
Pig manure	15	37.5	28.3
Goat manure	13	32.5	24.5
Rabbit manure	7	17.5	13.2
Total	**53**		**100**

(n = 40)

As mentioned in section 4.3.2, all farmers applied cattle manure and only 5% applied inorganic fertiliser in addition to cattle manure. Table 4.8 gives the type of manure used in the area. Solid cattle manure (90%) was the predominant type of cattle manure applied by farmers in the area as it is easily transported to the garden and easily applied at planting, while 35% of farmers were applying liquid cattle manure. This is easy to apply particularly in vegetables. Manure tea (7.5%) was the least applied for it was reported that manure tea requires technical knowhow and large containers as shown in Plate 4.13; implying that capital is required.

Table 4.8: Type of cattle manure used by farmers to replenish soil fertility

Manure	Count	% of respondents	% of responses
Solid cattle manure	36	90	67.9
Liquid cattle manure (urine only)	14	35	26.4
Liquid manure (plant tea)	3	7.5	5.7
Total	**53**		**100**

(n = 40)

A summary of the nutrient contents of cattle manure used in the area is shown in Table 4.10. The concentrations of nutrients in cattle manure most used in the area are 0.51% N for the fresh manure and 0.44% N for uncovered fresh cattle manure.

Table 4.9: Nutrient contents of cattle manure used in the area on dry weight basis

Type of manure	N	P	K	Ca	Mg	Mn	Cu	Fe	Zn
	%	%	%	%	%	mg kg^{-1}			
Biogas slurry	0.60	0.22	0.52	0.23	0.09	32.3	1.12	62.6	0.96
Aged manure	0.52	0.28	0.45	0.22	012	24.2	2.14	52.5	0.84
Fresh Manure	0.51	0.18	0.51	0.19	0.10	28.6	1.51	58.4	0.75
Uncovered fresh	0.44	0.15	0.40	0.16	0.12	38.4	1.24	71.6	0.62

Source: Makerere University laboratory report 2010

Plate 4.13: A farmer preparing Tea Manure

Farmers reported that in order to optimise and maintain manure quality, young leaves of plants and crops are mixed with cow dung and water in the ratio of 1:2 in a drum and covered for 2 weeks. A dry stick is used to regularly stir the mix. However, good technical knowledge is required to get quality manure tea (slurry).

Cattle manure handling and application methods

Various methods of manure handling were noted; composting of manure was reported by 35% of the respondents, covering (27.5%), un-covered manure (55%), providing shade on heaped manure (15%) and direct application to crops (25%).

Table 4.10: Methods employed by farmers while handling cattle manure

Item	Count	% of respondents	% of response
Composting	14	35.0	22.2
Covered manure	11	27.5	17.5
Un-covered manure	22	55.0	34.9
Under shade	6	15.0	9.5
Apply directly	10	25.0	15.9
Total	**63**		**100.0**

(n = 40)

Farmers use different methods to apply manure to crops in the study area (Table 4.11). Thirteen (32.5%) farmers apply manure in trenches and cover with soil, while 57.5% broadcast to the soil surface and do not cover and 30% reported that they dig holes and apply the manure, cover and leave them for a while before planting, particularly cabbage. While 45% heap manure around the crop regardless of whether it is fresh manure or composted manure. Plate 4.14 shows cattle manure applied on soil surface.

Table 4.11: Methods used by farmers to apply cattle manure in the area

Method of cattle manure application	Count	% of respondents	% of responses
Heap around the crop	18	45.0	27.3
Apply in trenches and cover with soil	13	32.5	19.7
Broadcast to the soil surface and don’t cover	23	57.5	34.8
Apply in hole before planting cabbage	12	30.0	18.2
Total	**66**		**100**

(n = 40)

Plate 4.14: Cattle manure applied on surface

Practices employed by farmers to apply manure in the area

The practices employed by farmers to apply manure are summarised in Table 4.12. Cattle manure is either heaped temporarily outside the housing unit (Plates 4.9 and 4.10) or applied directly to the field without protection to minimise nutrient losses. It was noted that cattle manure application was concentrated on plots near the homestead (55%) regardless of whether the crops are deficient in nutrients or not. However, during the dry season, about 15% of the farmers reported applying cattle manure to plots further from the homestead for it is easier to transport than in the wet season. Fourteen farmers (35%) mix manure with crop residues, while 30% mix manure with animal beddings.

Table 4.12: Practices employed by farmers to apply cattle manure in the area

Practices	Count	% of respondents	% of responses
Fertilise the crops near homestead	22	55.0	25.9
Mix manure with crop residues	14	35.0	16.5
Apply anytime to get rid of the manure	7	17.5	8.2
Mix cattle manure with animal beddings	12	30.0	14.1
Blanket cover application	9	22.5	10.6
Mix cattle manure with ash	15	37.5	17.6
Apply further from homestead	6	15.0	7.1
Total	**85**		**100**

(n = 40)

A number of reasons were identified for the choice of the practice, including quickening of manure decomposition (37.5%), increasing manure volume (27.5%), and odour reduction (37.5%), while the 52.5% follow advice from technical personnel in the area as shown in Table 4.13. Plate 4.15 shows heaped cattle manure, one of the common storage methods in the area, while Plate 4.16 shows uncovered manure which famers apply direct to their gardens.

Table 4.13: Reasons advanced by farmers for the choice of the practice

Item	No	% of respondents	% of responses
Decomposes very fast	15	37.5	24.2
More manure is produced	11	27.5	17.7
Reduces odor	15	37.5	24.2
Recommended by technical staff	21	52.5	33.9
Total	**62**		**100**

(n = 40)

Plate 4.15: Heaped cattle manure as a method of storing manure in the area

Plate 4.16: Uncovered cattle manure outside a zero grazing unit to ready be applied direct to the garden

Cattle manure use

During the survey, 22 farmers (55%) reported that cattle manure was not adequate (Table 4.14) to fertilize the whole farm in a single cropping season due to the few animals kept because of limited land (small farm size) of 0.2 ha-0.8 ha and inadequate fodder as reported by 88% and 69%, respectively. As a result, farmers fertilise portions of the farm on a rotational basis according to perceived variability in fertility of the soil. In addition, gardens that are in close proximity to the homestead receive heavy applications of cattle manure. A few farmers were buying cattle manure to supplement their own. A number of challenges associated with cattle manure use were reported including weight and bulkiness of manure (75%), lack of labour (67.5%) and insufficient manure (55%). Other constraints include high transportation and application costs (37.5%), lack of storage facilities (32.5%) to maintain quality attributes of manure and the incidence of chaffer grubs and worms (27.5%) which are a nuisance during application, in addition to affecting crop growth.

Table 4.14: Farmers' response on the constraints associated with the use of cattle manure

Constraint	Count	% of respondents	% of responses
Bulky	30	75.0	25.4
Lack of labour	27	67.5	22.9
Insufficient manure	22	55.0	18.6
Transport costs	15	37.5	12.7
Lack of storage facilities	13	32.5	11.0
Chaffer grubs	11	27.5	9.3
Total	**118**		**100**

(n=40)

Economic benefits of cattle manure use by smallholder farmers

Farmers's response on the economic benefits associated with cattle manure use are presented in Table 4. 15. Farmers indicated that the major benefits obtained from cattle manure were increased yields (52.5%), disease reduction (30%) and low cost (37.5%). The least mentioned benefit was biogas as a source of energy that accounted for 7.5%. Although manure application to crop production was credited for its economic benefits, it was said that it enhances weed infestation as reported by 35% of the respondents. Other reported detriments with cattle manure application include poor hygienic conditions (32.5%), bad odour (25%); host various pests (22.5%) and scorching of plants (17.5%).

Table 4.15: Farmers' response on the economic benefits of cattle manure application by smallholder farmers

Benefits	**No**	**% of respondents**	**% of responses**
Increased yield	21	52.5	41.2
Manure cost is low	15	37.5	29.4
Reduces disease infestation	12	30	23.5
Biogas production	3	7.5	5.9
Total	**51**		**100**
Detriment			
Weed infestation	14	35.0	26.4
Poor hygienic conditions	13	32.5	24.5
Bad odour	10	25.0	18.9
Presence of pests	9	22.5	17.0
Scotches plants	7	17.5	13.2
Total	**53**	**132.5**	**100**

(n = 40)

The use and non-use of inorganic and organic fertiliser in the area

Only 5% of the respondents were using inorganic fertilisers in addition to cattle manure. The other 38 (95%) respondents as shown in Table 4.16 gave a number of reasons for the non-use of inorganic fertilisers. Overall, there was a negative attitude to inorganic fertiliser use despite farmers' acknowledgement that inorganic fertilisers increase yields (94%) and quickens crop growth (98%), although some farmers asserted this was on a short-term basis. Negative attributes of inorganic fertiliser use including pereceived health hazards (20%), increased soil acidity (25%), exhausts soil (45%) once applied and that fertilisers must continuously be used (42.5%) to sustain crop productivity. Other reasons include expense (90%) in terms of purchase and transportation, lack of knowledge of application rates and inaccessibility (30%), and lack of capital to purchase (67.5%).

Table 4.16: Reasons given by farmers for non-use of inorganic fertilisers

	Respondents		Responses
Item	**Count**	**%**	**%**
Expensive	36	90.0	28.1
Lack of capital	27	67.5	21.1
Exhaust soils when applied	18	45.0	14.1
Continuous application once used	17	42.5	13.3
Lack know how on application rates and inaccessible	12	30.0	9.4
Increase acidity	10	25.0	7.8
Affects health of human beings	8	20.0	6.3
Total	**128**		**100**

(n = 40)

Soil fertility status and management options in the area

Increased yields (52.5%), colour of the soil (37.5 %), health of the crop with no disease symptoms (60%) and crops surviving up to harvest time (25%), were the criteria farmers used to assess the increase in soil fertility. Soil fertility indicators reported by farmers included 55% of the respondents stating that fertility of their land was declining and very poor, while 37.5% reported that fertility of the land was increasing and therefore able to enhance crop-growth in the area. Farmers used appearance of the crop and the final crop yield as the most important indicators for soil fertility status. The major indicators used by farmers to assess the fertility decline of the soil in the area were stunted crop growth (45%), yellowing of crops and low yields (80%) and when soil is easily washed away by rainwater (easy erodability of the soil) (22.5%). Where cattle manure is properly applied, the crops were looking healthy as observed in Plates 4.7, 4.4.8 and 4.10; with yield increases reported in such gardens. Plates 4.17-4.18 show cabbages grown without any fertiliser application. The garden is bare where most of the top soil was washed away by rain.

Plate 4.17: Cabbage grown without any fertiliser

Plate 4.18: Dodo (Amaranthus *spp*) applied with inorganic fertiliser

Table 4.17: Farmer's response to the current level of soil fertility status on their farms

Soil status	Count	% of respondents	% of responses
Poor	19	47.5	34.5
Very poor	14	35.0	25.5
Average	13	32.5	23.6
Fertile	7	17.5	12.7
Very fertile	2	5.0	3.6
Total	**55**		**100**
Trend			
Decreasing (poor)	22	55.0	55.0
Increasing	15	37.5	37.5
Constant	3	7.5	7.5
Total	40		100
Indictors of increased soil fertility			
Health of crop	24	60.0	34.3
Increased yield	21	52.5	30.0
Colour	15	37.5	21.4
Crop survival up to harvesting	10	25.0	14.3
Total	**70**		**100**
Indictors of decreased soil fertility			
Stunted growth	18	45.0	30.5
Yellowing of crops & low yields	32	80.0	54.2
Easily eroded	9	22.5	15.3
Total	**59**		**100**

(n = 40)

Table 4.18 shows the practices used for management of soil fertility in the area as reported by the farmers. Mulching of crops was the main practice in the area, particularly in Wakiso, accounting for 85% of the respondents. However, other soil fertility management options included crop rotation (50%), legume cover crops (30%), crop residues (65%) (such as banana leaves and pseudo stems, potato vines, legume stalks of beans, maize stovers and trash from sugarcane bought from neighbouring sugarcane plantations and out grower farmers), and green manure (25%).

Of the farmers who were practicing green manuring and legume cover cropping, 90% of them were KULIKA charitable trust beneficiaries that promote organic farming. Overall, the major practices reported by farmers were mulching (67.5%), crop residues (55%) and crop rotation (42.5%). The least practiced included legume cover crops (22.5%) and green manure (17.5%).

Table 4.18: Soil fertility management options in the area as reported by famers

Practice	Area						Total	
	Wakiso			Kampala				
	Count	% of respondents	% of responses	Count	% of respondents	% of responses	Average % of respondents	Average % of responses
Crop rotation	10	50	19.6	7	35	22.6	42.5	20.7
Crop residue	13	65	25.5	9	45	29.0	55.0	26.8
Legumes	6	30	11.8	3	15	9.7	22.5	11.0
Mulching	17	85	33.3	10	50	32.3	67.5	32.9
Green manure	5	25	9.8	2	10	6.5	17.5	8.5
Total	**51**		**100**	**31**		**100**		**100**

(n=20 for Wakiso and Kampala each), overall n=40

Output and productivity of cabbage and dodo and costs of production

Table 4.19 presents the estimated mean output of cabbage and dodo crop enterprises of the surveyed farmers. The results of the two crop enterprises indicate that the average output for each enterprise was 25,200 kg ha^{-1} and 3,420 kg ha^{-1}, respectively. The results show outputs of both enterprises were lower under cattle manure application compared to inorganic fertiliser application.

Table 4.19: Mean outputs of selected crop enterprises from the survey study

Crop Enterprise	Output kg ha^{-1} Under CM application	Output kg ha^{-1} Under IF application
Dodo	3,420	4,160
Cabbage	25,200	27,980

Notes: CM is cattle manure and IF is inorganic fertiliser

The estimated cost of cabbage production under cattle manure and inorganic fertiliser are presented in Table 4.20. A gross margin analysis for the cabbage enterprise based on the survey data has been calculated. During the survey, it was reported that at times about 5% of the cabbage is consumed at home. However, shadow pricing has been used to calculate the revenue of the unsold cabbages.

The price of cabbage varied from area to area; however, an average selling price of 700 UGX per kg of cabbage was used to calculate the gross margin for the cabbage output. Farmers reiterated that cabbage under inorganic fertiliser application matures early and at times offered better prices.

Table 4.20: Average costs of cabbage production and revenue (UGX) ha^{-1}

Description	Mean output under cattle manure, in UGX 000s	Mean output under inorganic fertiliser, in UGX 000s
Yields kg ha-^{1}	25.2	27.98
Sales**	25.2	27.98
Total revenue	**17,640**	**19,586**
Expenses (UGX)	**Average cost under Cattle manure**	**Average cost under Inorganic fertiliser**
Transport	1,820	100
Cost of cattle manure	700	-
Cost of fertiliser	-	1,530
Seeds of cabbage	25	25
Sub total	**2,545**	**1,655**
Labour:		
Loading	500	10
Off loading	500	10
Manuring/fertilising	700	100
Composting	150	-
Weeding	1,200	700
Spraying chemicals	200	200
Harvesting	700	700
Sub total	**3,950**	**1,720**
Land cultivation	1,200	1,200
Chemicals & spraying equipments	1,300	900
Others containers, gunny bags	741	741
Sub total	**3,241**	**2,841**
Grand total	**9,736**	**6,216**
Gross margin (UGX)	7,904	13,370
Total	**17,640**	**19,586**
Equivalent US$	**8.82**	**9.79**

As per exchange rate of US$ =UGX 2000, January 2010

The results indicate that labour for weeding, fertilising/manuring, loading and offloading under cattle manure application was more costly than labour under inorganic fertiliser application. The costs for chemicals and spraying equipments under cattle manure were also high compared to those under inorganic fertiliser application.

4.3.2 Soil sampling

The dominant soil types in the sampled parishes of Kampala and Wakiso districts are dark red gravel loams or murram (small gravel stones mixed with soil) at Nangabo site, reddish brown sandy at Namere site, red clay loam and yellowish gravel at Kulika, Bikka and Kitegombwa sites. According to World classification, these soils are classified as Ferralic Nitisol (Krasnozems) (Stace 1968; Mckenzie et al. 2004) and most similar to Mesotrophic according to Australian Soil Classification Scheme (ASCS) (Isbell 1996) which are well drained and the surface condition is firm.

The soil analysis results are presented in Table 4.21. Soil texture varied significantly with 54.5-71% for sand, 8-22% for silt and 16-25% for clay. The pH ranged from 4.6 to 7, with Kulika having the highest pH 7.0 1:5 $CaCl_2$). The site with the lowest pH was Nangabo. The site with highest clay content (25%) was Kulika, which also had 62% sand. Namere site had the highest sand content of 71% characterised with low available N. While the EC varied from 11 to 45 mSm^{-1}. The Table with summary results of the soil analysis is in Appendix A4.

Table 4.21: Physical and chemical characteristics of the <2mm fraction of the top (0-10cm) in the study area

Parish	Al	EC	pH	pH	Sand	Silt	Clay	OrgC	N	K	P	P	P
	($CaCl_2$)	(1:5)	(H_2O)	($CaCl_2$)				(W/B)	(total)	(HCO_3)	(HCO_3)	PRI	(total)
	mg/kg	mS/m	(1:5)	(1:5)	%	%	%	%	%	mg/kg	mg/kg	mL/g	mg/kg
Luggungude	<1	11	6.5	6	65	14	21	1.46	0.123	240	67	16	580
Bikka	<1	13	7.4	6.8	70.5	12	17.5	1.42	0.125	430	86	14	620
Kulika	<1	17	7.3	7	61.5	13.5	25	1.7	0.168	430	26	33	430
Kitegombwa	<1	12	5.5	5	65	19	16	3.38	0.258	73	88	180	840
Nangabo	1	45	4.9	4.6	61	22	17	4.56	0.476	260	1100	-5.1	3800
Namere	<1	11	5.8	5.4	71	8.5	20.5	1.23	0.117	220	33	23	400

Chemistry Centre WA, Report 09A370/1-5

pH ($CaCl_2$) in 0.01 M $CaCl_2$ (Rayment and Higginson 1992a), Total N (Blakemore et al.1987; Rayment and Higginson 1992b; Searle 1984), Total P (Allen and Jeffery 1990; Murphy and Riley 1962), PRI (Allen and Jeffery 1990), Fe and Al extracted by 0.2M ammonium oxalate ($_{AmOx}$), Organic carbon (W/B)% by Walkley and Black (1934) (Rayment and Higginson 1992b), EC (1:5) at 25^{o}C (Rayment and Higginson 1992b). Sand, silt and clay 2.0 to 0.02 mm by method S07.

mS/m = milliSiemens per metre

mg/kg = milligrams per kilogram

mL/g = millilitres per gram

EC= Electrical conductivity

PRI=Phosphorus Retention Index.

4.3.3 Focus groups meetings

Four (14.8%) of the 27 farmers in attendance were not using cattle manure but had livestock and discussed manure use. The discussions were open and transparent. The responses regarding non-use of inorganic fertilisers were unanimous and or concurred with what individual famers had reported during face-to-face interviews. Table 4.22 presents a summary of the issues that emerged during the discussion.

Table 4.22: Issues emerged from group discussion

Issue	Farmer responses/reasons
Farmers' reluctance to use and or buy cattle manure	-Farmers use or operate on rented land
	-Manure may not be beneficial in one season
	-Manure smells
	-Manure use breeds pests and diseases
	-Affects human health and crops
High yields realised with manure application	-When incorporated in the soil or in trenches
Low manure production	-No supplementary feeds to animals
	-Insufficient fodder to feed animals
Men not willing to apply manure	-It takes long to realise effects of manure
Marketing and distribution of fertiliser	-Influenced by poverty and politicians
Socio economic factors influencing cattle use	-Off-farm income
	-Awareness of the benefits of fertilisers
	-Farm characteristics of land tenure
	-Location
	-Expectations to continue farming
	On rented land

From Table 4.22, it was noted that farmers were reluctant to buy cattle manure for use on rented land, as manure was not considered beneficial in one season. In addition, it was revealed that cattle manure smells and this is a nuisance to the neighbouring community members who are not using cattle manure and cattle manure application is a breeding ground for some pests and diseases.

Cattle manure production in the area

Farmers commented on low manure production in the area and reported that cattle are not given supplementary feeds and few animals are kept. This is heightened by lack of fodder due to limited land. Many men were reported as not willing to apply cattle manure, some because it takes too long to realise the results of manure application. However, a typical manure user (regardless of gender) perceived the practice as profitable and thought the practice would help improve soil fertility and ultimately crop yields. On the other hand, the four non-users of manure who participated in focus group discussions were off-farm income earners (salaried income earners in addition to farming). They planned to continue farming but did not perceive the practice to be profitable and believed the practice to be labour demanding. Similarly, the users of manure perceived the practice not to be expensive and to improve crop yields. Those who rented large land area were willing to apply more manure but reiterated that transport was a big issue in addition to temporary land ownership.

Reasons for non use of inorganic fertilisers

Farmers' reasons for non-use of inorganic fertilisers were its effects on the health of human beings and health of crops. Farmers mentioned that there are inconsistent crop responses to inorganic fertiliser; however, when farmers were reminded of nearby commercial farmers who use inorganic fertilisers in tea and sugar estates, farmers responded that these are crops whose products are processed and so fertilisers can not affect human health unlike vegetables that are eaten fresh. Farmers reported that they were advised to eat crops grown under inorganic fertiliser application four months after application, which may not be applicable to cabbage and dodo crop enterprises whose maturity period is 90-100 and 30 days, respectively.

Benefits of cattle manure and adoption of manure use in the area

Overall, farmers reported that there is increased yield with better management practices of manure application. Some comments on the impacts of using manure such as increasing yields and improving quantity and quality of crops were most common. Others discussed additional benefits of manure including improving the tillability of the land, which may suggest increased organic matter in the humus layer.

Other farmers noted the change in colour of their soil as an indicator of improved soil fertility. Among other issues raised was the issue of marketing and distribution of fertilisers, which was said to be influenced by poverty and politics.

Farmers' response about how much manure is applied to their gardens received mixed reactions. Farmers reiterated that most questions, though relevant, were hard to answer because they do not fit a cattle operation where cattle are out on the pasture all the time. 'I can't figure out how much manure is produced per day', one farmer commented. Another farmer simply stated 'the only manure on my farm is spread by natural means by cattle only; they run on pasture'. This emphasises the issue with farmers who keep cattle for milk production and apply manure to crops to get rid of it as it was listed as one strategy for applying cattle manure.

During the meetings, it emerged that Study Circles and Training and Visit methodologies have enhanced the adoption of cattle manure application in the area. Challenges affecting adoption and performance of the training methods include: work load in farming mainly borne by women, beliefs of pests and diseases inherent in manure application, gender stereotypes which greatly limit women's full participation and the kinds of enterprises selected by women. Other factors include: education level, off-farm income, awareness, expectation to continue farming, farm characteristics, land tenure, and perceived problems with weed seeds and uncertainty in manure application.

However, further comments suggested that farmers do use manure and find it valuable. Another farmer commented that they could not afford inorganic fertiliser and had been using cattle manure whenever they had it.

Several participants suggested that most farmers do their best to preserve land and properly manage cattle manure with comments such as:

> 'Farmers are good custodians of the land'
>
> 'I am proud of what I do for a living. I have worked hard to preserve the quality of our land....'
>
> 'Cattle manure has done wonders!!......right from food to clothe and education of my children'

During the discussion, farmers indicated that although some farmers are not concerned about manure handling and application, others acknowledged that it is a big problem in the area and wish to resolve it. In addition, there is difficulty in using the liquid compost and there are health risks associated with handling compost made from other animal manures such as pig manures which is also promoted in the area.

Farmers recognise the benefits of better manure handling and application methods but are constrained by costs in terms of labour and transportation. They all unanimously suggested that manure testing should be the way to go before application but noted that testing itself is complicated.

4.4 Discussion

This section discusses the results of the farmer survey, focus group meetings and field observations and soil analysis results conducted in Uganda. It specifically focuses on fertiliser use including application and handling methods of cattle manure and other soil fertility management options practised by smallholder crop-livestock farmers.

4.4.1 Cattle manure use in smallholder crop-livestock farming systems

The survey showed that farmers applied cattle manure to crops obtained from different sources including own source, purchase and free from neighbours. Regardless of the source, solid cattle manure (90%) was the predominant type of manure applied by farmers in the area; attributed to being easily transported to the garden and ease of application at planting. However, 35% of the farmers preferred applying liquid cattle manure because it is easy to apply; particularly in vegetables.

Farmers in the study area indicated that cattle manure was the major source of organic fertiliser and could be the main avenue to improve crop and soil productivity. Mugisa (2002) also reported similar observations in the peri-urban areas of Kampala and Wakiso. The farmers who were not using cattle manure on large scale for crop production, at the time of the survey, said they needed adequate capital to purchase more manure from neighbours.

Sixteen percent (16%) of respondents obtained their manure from other farmers' animals and the kind of manure used seemed to be related to the predominant animal farming in a particular district. For instance, Wakiso farmers were using more chicken manure than Kampala farmers because poultry is predominant in the area.

4.4.2 Application and handling methods of cattle manure employed by smallholder crop-livestock farmers

The most common application and handling method in the study area was broadcasting on the soil surface without covering (57.5%). Some farmers were heaping manure around the crop (45%) whereas others apply in trenches and cover with soil (32.5%). It was interesting to note that covering of manure is not a widely adopted practice by farmers in the study area despite being promoted by the Kulika charitable organisation trust, an NGO promoting organic farming in the area. Other researchers have recommended better management methods for the use of cattle manure to increase food production being a major organic fertiliser used by smallholder farmers in sub Saharan Africa (Snapp et al. 1998).

However, the effectiveness of the manure is often limited by poor quality (low nutrient content) and immobilisation of N, which occurs during early plant growth following application (Murwira and Kirchmann 1993; Nyamangara et al. 2003; Nyamangara et al. 2009).

Chemical analysis of the manure collected from the area showed low nutrient levels (Table 4.9); which is largely influenced by the diet of the animal and by the way the manure is collected, stored and handled before utilisation (Kirchmann 1985; Kemppainnen 1989; Mugwira and Murwira 1997; Chadwick et al. 2000). In order to optimise and maintain manure quality, knowledge is required for manure collection, storage and utilisation that would minimise nutrient loss and yet allow the nutrients to be readily available to the plants. For instance, knowledge of the nutrient contents of manure derived from different diets with different organic materials added and with storage in pits or heaps, covered or not covered would be useful to better determine application rates.

Low nutrient levels are expected given that the few animals kept due to limited land are not supplemented with feeds. Property sizes in peri-urban areas are increasingly becoming smaller (Atukunda et al. 2003; Ssembalirwa 2008). This coupled with lack of fodder heightens the situation. The non-provision of supplementary feeds is due to lack of capital and therefore less cow dung with low nutrient contents is expected. The poor management methods in the area means the quality of manure is low (0.5% N) and contributes to low crop yields. These low farm level yields per unit area for the smallholder crop-livestock farmers could be attributed to non-use of improved farming methods. However, the current efforts of the National Agricultural Advisory Services (NAADS) in the country, which aims to improve agricultural production and productivity through adoption of improved farming technologies including organic fertiliser use is likely to reverse the trend.

Uncovered manure was the most common storage method (55%), although some farmers were providing shade (15%) on heaped manure while others were applying it directly to crops (25%). In addition, a few farmers collect urine, whereas others used “manure tea”. These methods, however, dilute manure. In Uganda, farmers should be advised to compost their organic manures including cattle manure before application. This has a number of advantages which include reducing weeds and pathogens, results in healthy crops, improvement of soil structure hence making it easy for roots to penetrate and root development and movement is encouraged. Fourteen percent of the farmers mix manure with bedding materials. During application, cattle manure is normally uncovered with soil. As noted above, cattle manure is either heaped temporarily outside the housing unit without attempting to minimise nutrient losses or applied directly to the field. However, direct application would minise nutrient loss due to less voltalisation.

A common characteristic in the study area was to concentrate cattle manure application on plots near the homestead (55%). However, during the dry season, 15% of the farmers reported applying cattle manure to plots further from the homestead because it is then easier to transport. However, labour was a factor as well as capital to hire vehicles to transport the cattle manure. The labour resources associated with improved methods of farming are additional to those required by regular farm and non-farm activities. The study area is near Kampala capital city and most people (labourers) prefer to work in off-farm paying jobs, where payment is on daily basis.

Similar methods of application were being employed for all manure types. Some farmers apply cattle manure in planting sites inside the trenches/furrows made by hoes (32.5%) and cover with soil in an effort to aid the crops to access the needed nutrients. Further research should be conducted to establish whether this is the most feasible method of application.

4.4.3 Challenges associated with cattle manure application by smallholder farmers

A number of challenges associated with the use of cattle manure were reported including incidence of chaffer grubs and worms and high labour requirements for its transportation and application. The chaffer grubs particularly affect young vegetable crop seedlings, especially cabbages, compounded by bulkiness of cattle manure. The bulkiness and the associated difficulty in transporting manure to the point of application came out as the major problem hindering the use of manure by the farmers. Pali (2003) reported similar observations. Composting of cattle manure is recommended for it kills weeds and other pathogens. Organic fertilisers are also a difficult option as small farm size and insufficient labour availability often hinder their production (Lekasi et al. 2003; Pali 2003). Other challenges were labour demand because family labour was the most commonly employed in most agronomic activities including manure application; perceived by farmers to be cheap because it does not involve direct cash outlay. Opportunity costs for labour need to be calculated considering the fact that the study area was close to the capital city-Kampala.

Despite the above challenges, utilisation of cattle manure as a soil amendment is an integral part of the smallholder crop-livestock farming systems of Uganda. Manure produced in these systems is usually applied prior to planting field crops such as maize, beans and potatoes as well as vegetables such as kale, cabbages and tomatoes, and cash crops such as coffee.

Gender was relevant to manure, as many men were not willing to apply cattle manure, some commenting it takes too long to realise the results of manure application. Another reason noted by men was that most land is rented and so they didn’t see the point in applying manure, which may not bring immediate results but only benefit the owner of the land or the next farmer in the subsequent seasons. However, in the peri-urban areas, as in most of the country, gender roles and responsibilities are extremely differentiated. Men's work includes initial land clearance and primary cultivation. Planting, weeding, harvesting and processing are largely women's activities. As long as primary cultivation remains a male activity, then the women have to depend on the men for subsistence farming, which yields food both for family consumption and for sale to earn income. The most tiring and time consuming activities like water collection and gathering firewood are performed by women and children, mostly at the expense of their time for other care giving activities like childcare, food preparation and cleaning. The several obligatory roles and responsibilities of women including survival strategies and the rigid gender division of labour have influenced child bearing with the main purpose of getting children to help with domestic chores. Apart from primary tillage, men's work includes fishing, business related activities, and blacksmithing (Mulumba 2005). However due to limited land, blacksmithing is diminishing because land is put to food crop production. Men rarely perform women's work except in critical circumstances like taking a child to hospital (Mulumba 2008).

The growing and marketing of cash crops is exclusively men's activity;however, when it comes to cattle manure application, men want women to participate more than them. This implies that men are interested in activities that generate quick cash income and or revenue. Men say that the reason they had specialised in certain enterprises was that their enterprises are labour demanding, requiring more physical lifting as opposed to women's enterprises. However, selling of cash crops could be driven by the income motive. Men are largely involved in livestock keeping (mainly cattle) while women concentrate on poultry and ruminant management. Women own only 7% of the land.

The lower number of farmers under the age of 35 years (37.5%) and the high number of farmers over the age of 35 years (62.5%) implies fewer youth were interviewed. Reasons for this suggest that many youth do not own land or other assets like cattle and goats and youth who are energetic may be engaged in quick income generating activities in Kampala. This was expected, as youth are not interested in agricultural related activities (Nielsen and Chanhsomphou 2006).

4.4.4 Other soil fertility management practices employed by smallholder farmers

Mulching was reported to be the most adopted practice in the area to improve soil fertility, although more commonly in Wakiso (21%) than Kampala (12%). Mulch reduces the splash effect of the rain, decreases the velocity of runoff, and amount of soil loss (Lal 1993a; Kirchhof and Salako 2000; Onduru et al. 2002; Kirchhof and Odunze 2003; Adekalu et al.

2006; Salako et al. 2006; Junge et al. 2008; Barker 2010; Cantore 2011). Importantly, mulching promotes water infiltration, minimizes soil temperature fluctuations and enhances mineral nutrient availability and supply, improves soil faunal activity and soil structure in addition to suppressing soil pests and pathogens (Carsky et al. 1998) and retards weed growth (Morgan 1995; FAO 2005).

However, the supply of mulching materials were inadequate, for grass is used for fodder for confined (penned) animals. Farmers in the Kampala area have less land; an average of 0.8 ha compared with Wakiso at 1.5 ha and have difficulty harvesting enough mulching materials. A few farmers used coffee husks as mulch, however, lack of capital constrains the large-scale use of the material. However, Lal (1990) recommends different types of mulching materials including residues from the previous crop, brought-in mulch including grass, perennial shrubs, farmyard manure, compost, by products of agro-based industries, or inorganic materials and synthetic products.

Another option for managing soil fertility reported by the farmers was crop rotation; the growing of different crops in sequence, which varies in their nutrient demands, susceptibility to pest and diseases and ability to control erosion. It is imperative to note that good crop rotation facilitates the conservation and addition of humus, restoration of soil structure and fertility, control of erosion and reduction of pests and diseases. Studies have demonstrated 10 to 17% greater yield for corn grown in rotation with other crops than when grown in monoculture (Mannering and Griffith 1981; Riedell et al. 2009). Crop rotations that included legumes increased soil N levels (Peterson and Varvel 1989a 1989b; Raimbault and Vyn 1991; Bullock 1992).

A few farmers had adopted the use of legumes (particularly cover crops) to improve soil fertility status, though on a small scale. Legume cover crops require labour, capital to purchase inputs and knowledge for their appropriate use in a farming system. This may explain their low relative use. Legume cover crops improve soil productivity through increased soil organic matter content, improved soil physical and microbial properties, suppression of weeds and pests, and erosion control (Palm et al. 1997; Sullivan 2003). Legume cover crops could be considered the backbone of any annual cropping system that seeks to be sustainable (Sullivan 2003) due to associated advantages of providing nutrients. Elsewhere, an improved fallow system using N fixing legumes such as pigeon peas (*Cajanus cajan*) and Leucaena (*Leucaena leucocephala*) has been recommended due to their capacity to raise soil organic content (SOC) (Lal 2000; Bationo et al. 2000; Abunyewa and Karbo 2005). According to Manley et al. (2004) and (Sanginga and Woomer 2009), the rate of SOC increase or reduction depends on several factors including climate, cropping system, N content, N fertility and fertility management strategy.

As mentioned earlier, 90% of the farmers who were practicing green manuring and legume cover cropping, were Kulika charitable trust beneficiaries that promote organic farming. However, there is scanty information in literature for their extensive use despite being promoted by both Kulika charitable trust organisation and National Organic Agriculture Movement of Uganda (NOGAMU) NGOs.

The sampled manure in the area varied in nutrient contents, but nutrients were very low, especially N. This could be attributed to the fact that most livestock kraals (Plate 4.6) are not roofed and have no bedding to absorb urine. Manure and urine are thus exposed to the intense sunlight, high temperatures throughout the year and intensive rainfall in part of the year (Kwakye 1980; Lekasi et al. 2003; Abunyewa et al. 2007). High variability of manure N content has been reported in the savannah areas of West Africa (Harris 2002; Tarawali et al. 2004; Abunyewa et al. 2007) and in east Africa (Onduru et al. 2008). Likewise, the climatic and handling effect on manure, quality and quantity of fodder to livestock could affect the proportion of N in manure (Powell et al. 1994; Romney et al. 1994). Therefore, improving manure collection and storage may increase the manure quality.

Manure tea was being promoted in the area for use as a fertiliser. In its preparation, farmers use a dry stick to stir the mix of manure and water regularly. However, good technical knowledge is required to get quality manure. Manure tea production requires water, which is expensive in the area, particularly in the Kampala peri-urban area. The study did not analyse the manure tea to ascertain whether the farmers' methodology controls quality. Further research is needed to come up with suitable guidelines and recommendations for manure tea use in the area.

During the survey, it was also established that a number farmers were using different types and or sources of manure including goat (32.5%), pig (37.5%), chicken (45%), and rabbit (17.5%). Rabbit and chicken manure were credited to be handy and not involve high labour requirement. This may explain why some farmers give away their cattle manure freely to neighbours in the name of high labour requirements. However, there is need to establish whether the manure from other animals is enough given that there are small plots of crop production.

4.4.5 The use of inorganic fertilisers as another soil fertility management option by smallholder crop-livestock farmers

Of the farmers using cattle manure, only 5% were applying inorganic fertilisers to their crops. This is low when poor soil fertility is one major cause of low yields in SSA including Uganda (Kanonge et al. 2009). During the survey, a number of reasons were given for the non-use of inorganic fertilisers as outlined in Table (4.16) including health hazards, increasing acidity to soils, exhausting soil once applied and that fertilisers must continuously be used to sustain crop productivity. The small number of farmers applying inorganic fertiliser could be attributed to NGOs in the area advocating organic fertiliser. However, this requires further studies in other areas of the country to ascertain this trend.

Much of Africa's soils are old and poor, situated on very old continental plates. This coupled with low fertiliser use estimated at 1 kg ha^{-1} in the country has aggravated the situation. Only a few places have soils that have substantial nutrient stocks, such as those derived from young volcanic material and metamorphic rocks (IITA 2010). The use of inorganic fertilisers and other soil amendments should be intensified if crop production and productivity is to be increased (Olson 1987; Agbenin and Goladi 1997; Iwuafor et al. 2002; Rufino et al. 2006; Panda 2008). Uganda lags behind most of the SSA countries in mineral fertiliser use, applying below 1,000 tons per annum (Jayne et al. 2003). However, Omiat and Diiro (2005) quoted a 2005 FAOstat data base where fertiliser use increased from 192 t in 1990 to 9,305 t in 2002. It has been argued that such limited adoption of fertiliser use is due to lack of subsidies (Ellis 1992; IFDC 2003), poor market infrastructure (Crawford et al. 2003), or management- related constraints (Ellis 1992; Howard et al. 2000) in SSA.

The judicious use of mineral fertiliser that is moderate in quantity, applied at the right time and in the right way, and combined with locally available organic matter improves crop production (Panda 2008). The combination of fertilisers and organic matter provides much needed additional nutrients that are used efficiently by crops. The organic matter helps to retain mineral fertilisers applied in the top soil and reduces losses from leaching (Panda 2008). It also improves the soil physical properties, which help plants to thrive as the roots are better able to take up nutrients.

Powell and Ikpe (1992) noted that the recycling of natural vegetation and crop residues by animals via excreta that fertilise the soil is an important linkage between livestock and soil productivity, especially under smallholder crop-livestock production systems. By passing through the ruminant stomach, plant material is broken down quicker than through the natural decay process, thus speeding up the nutrient recycling process. McIntyre et al. (1992) observed that wherever cropping is possible, crop-livestock interactions permit optimal use of local natural resources and represent the most efficient form of production in terms of nutritional returns per unit area. Thus, integration of livestock and crops raises human support capacity, which is measured in terms of the number of people that can be supported by a unit area of land; however, coupled with insufficient fodder due to limited land to increase manure production and limited knowledge on the appropriate use of cattle manure, has meant crop productivity has not improved.

The non-use of inorganic fertilisers is attributed to high cost as the major factor as reported by 90% of the respondents and negative attitudes in the area. Negative attitudes towards inorganic fertilisers were high as noted during the focus group meetings. Such negative sentiments to inorganic fertiliser use prompted the researcher to ask the source of agricultural information. Ministry of Agriculture Animal Industry and Fisheries (MAAIF) through NAADS, NGOs, fellow farmers, researchers and research institutes and student interns at Kulika were mentioned as the source of agricultural knowledge in the area. However, Kulika and NOGAMU NGOs are the main source of information in the study area. It was established that the latter NGO discourages farmers from using inorganic fertilisers as it promotes organic farming to supply European markets. This seemed to be the driving factor behind the negative attitudes towards inorganic fertilisers. Further research should be conducted to assess the impact of organic farming on the livelihood of smallholder farmers participating in these interventions.

4.4.6 The soil status and trend of soil fertility in smallholder farming systems

The study investigated the soil status and how farmers perceive the trend of the soil fertility in the area. Physical and chemical soil analyses were conducted and details of analysis are described in Chapter 5. Results indicate varying nutrient deficiencies for example acidity, changing pH levels that ranged from 4.6 to 7, the highest being at Kulika. However, there is need for research in this area as this study focused on N.

Compared to other nutrients, most of the soils were low in N (Table 4.21). However, N occurs in several forms, only some of which are available to plants as much of total N is held in organic matter and is not immediately available to plants. It has to be mineralised to available forms (NH_4^+,NO_3^- and NO_2^-). Hazelton and Murphy (2010) report that estimating critical values for N requires local knowledge of soils and climatic conditions. Accordingly, they further show the ratings by weight for N as <0.05% very low, 0.05-0.15 low, 0.15%-0.25% medium, 0.25%-0.50% high and > 0.5% very high. Therefore, the study results indicate that Luggungudde, Bikka and Namere sites had low levels of N, while Kitegombwa and Nangabo sites had high N levels. This suggests that in the former sites, there is nutrient mining as harvested produce is sold to Kampala city and other trading centres without recycling back the nutrients.

It should thus be noted that unless nutrients are brought into a farm from which products are exported, the net balance of all management practices on that farm, no matter how biologically appropriate, will be negative. This is true because all products, animal or vegetables that are sold off the farm contain nutrients that must be replaced from one source or another.

Fifty-five percent of the farmers reported insufficient quantities of cattle manure available for application to replenish the removed nutrients. This is compounded by its low nutrient content as a result of poor quality feed or insufficient pasture, and a lack of supplementary feeds to the animals. The soil fertility decline reported by farmers and resultant poor crops observed during field visits is attributed to continuous cultivation, non-use of improved methods of farming, lack of fallow periods (which previously were the major practice in the area) and non-use of adequate fertilisers. As noted earlier, land availability is increasingly constraining the productivity and the small land area available is often used to its maximum (Atukunda et al. 2003). The farmers are not able to let the land be in fallow and this eventually results in soil degradation. This has been aggravated by land fragmentation due to population increase and negative attitudes towards the use inorganic fertiliser. The fact that the output for these enterprises was low (25.2 t ha^{-1} of cabbage 3.4 t ha^{-1} of dodo) compared to yields obtained from research stations of about 29.3 t ha^{-1} of cabbage and 4.5 t ha^{-1} of dodo confirms the decline in productivity. The increase in population in Uganda is expected to exert pressure on land resources and environment. This will affect the ability of Ugandan soils to continue to provide the food needed for her increased population (34.5 million) (UNFPA 2011).

Uganda, in particular the central region, is not able to keep pace with the expanding population growth and the ever-increasing demand on diminishing natural resources. This leads to continued decline in its already low food production per capita. Most of Uganda's soils, like the rest of the African countries, are formed from weathered rocks that are low in N and P (Zake et al. 1999). Not only are the soils poor, but the climate is also extreme, rainfall being irregular and erratic or too high and intense in SSA (Breman 1990) as cited by Breman and Debrah (2003). The soils are also characterised by low organic matter content, which contributes to the lack of nutrient storage capacity. This is worsened by the fact that Ugandan soils are prone to erosion (Zake et al. 1999; Olson and Berry 2003).

4.4.7 Potential of cattle manure in crop-livestock farming systems

Farmers highlighted a number of economic benefits of cattle manure use, which have the potential to change their lives. Most of the respondents indicated that increased crop yields, disease reduction and low cost were the major benefits obtained from cattle manure. Wabudeya (1996) found similar benefits among zero grazing farmers in Mbale milk shed in eastern Uganda. This is in agreement with research conducted by Mureithi et al. (1996) who reported that manuring increased maize grain and stover dry matter yields. In effect, animal manure is an asset for transferring plant nutrients from feeding to crop areas, keeping land fertile (de Wit et al. 1997).

The potential of cattle manure has been confirmed in various studies which indicated that organic manure is applied by farmers to meet N, P and K requirements (Ngambeki and Rubaihayo 1993). When supplemented with a dose of inorganic fertilisers, four cows can produce sufficient manure to fertilise one hectare, usually applied once every two years (Singh 1978). In Uganda, the current Government's policy on Plan for Modernisation of Agriculture (PMA), has earmarked strategies in a number of areas to diversify the economy. The funds from the National Agricultural Advisory Services (NAADs) and Local Government Development Project (LGDP) received in the study area have been allocated towards promoting non traditional export crops and transfer of extension services to farmers including appropriate use of fertilisers and if achieved farming could turn into a business (MFPED 2002).

From the study results, it can be inferred that a Ugandan smallholder cattle manure user (farmer) selling cabbage at UGX 700 a kg in the peri-urban areas of Wakiso and Kampala can expect a gross margin of UGX 7,904,270 (US$ 3,952) ha^{-1} $season^{-1}$, while a smallholder farmer in the same area using inorganic fertiliser can earn a 69% increase in gross margin of UGX 13,370,270 (US$6,685) at an exchange rate of UGX 2,000 to a US dollar.

Despite the aforementioned economic benefits of cattle manure; bad odour and scorching of plants were found to be negatives by 25% and 17.5%, of the farmers, respectively. A similar observation was made by Lekasi et al. (1998) but this was attributed to poor storage and handling techniques of cattle manure. In addition, a similar proportion (32.5%) of respondents reported poor hygienic conditions. This coupled with limited space could explain why some farmers have not adopted cattle manure in peri-urban farming. Generally, respondents reported that the smell of manure bothers neighbours more than themselves. This perhaps is because neighbours who do not have animals are bothered by the smell more than livestock farmers themselves are.

Although, high returns could be obtained from inorganic fertiliser use, 68%, 45% and 43% of the respondents mentioned lack of capital, soil exhaustion and need for continuous application as limiting factors to inorganic fertiliser use, respectively.

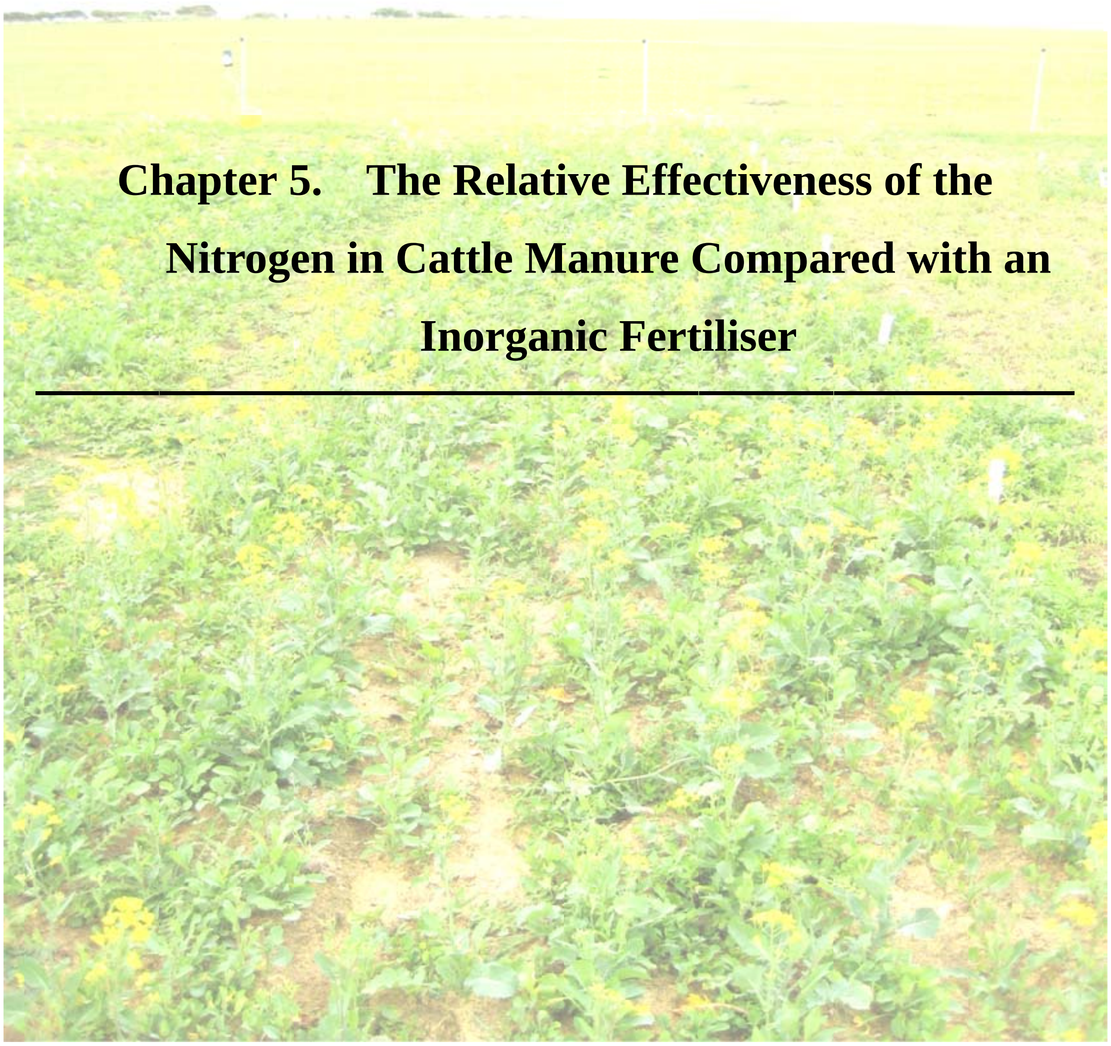
The results further indicate that labour for weeding, fertilising/manuring, loading and offloading under cattle manure application was more costly than labour under inorganic fertiliser application. The costs for chemicals and spraying equipments under cattle manure were also high compared to those under inorganic fertiliser application. This could be attributed to the fact that manure is bulky and requires more man hours. The manure also carries along with weed seeds implying more weed growth under cattle manure application compared inorganic fertiliser application.

4.5 Conclusions

- Smallholder farmers were aware of the benefits of fertiliser use (inorganic and organic) and reiterated that cattle manure is a valuable source of nutrients in smallholder crop-livestock production systems. However, the rates of cattle manure used needs to be investigated and manure should be tested to ascertain its nutrient levels for effective food production. This is because test results of cattle manure showed different concentrations of N and other nutrient levels.
- In order to address soil fertility depletion and low productivity in the central districts of Wakiso and Kampala, there is need to investigate soil fertility management options, such as the use of external inputs including inorganic fertilisers, and to popularise low-external input technologies that add nutrients using locally available materials, such as cattle manure, compost, mulch, growing leguminous cover crops and trees.
- Farmers should be encouraged to use crop residues as a source of fertiliser because it covers the land and thus reduces soil erosion. This underscores the need to discourage farmers from harvesting crop residues since this practice leaves the soil bare and more prone to erosion.
- Although only 5% of households were applying inorganic fertilisers, the study results show that farmers who used inorganic fertiliser yielded positive economic returns, compared to cattle manure. However, other low input approaches are necessary to address soil fertility problems, since some farmers may not have the capacity to afford inorganic fertilisers. For mineral fertilisers to be used effectively there is need to strengthen farmers' knowledge about their correct use, potential benefits and limitations in the context of smallholder Ugandan farms. In addition, the organic manures applied by farmers were considered less expensive than were inorganic fertilisers.
- Farmers were aware of the potential benefits of other soil fertility management options including containing manure. However, there were concerns regarding the potential costs of producing high quality compost, the difficulty in using the liquid compost and the health risks associated with handling compost made from other animal manures such as pig manures as evidenced from focus group meetings.
- There is a need to explore the viability of community-based manure collection initiatives at the farm level, where manure transportation costs are shared and minimal. It is necessary to improve manure collection and storage to keep its quality attributes. The difficulty in obtaining large quantities of manure coupled with transportation and application challenge in the area could be disincentives for increased manure use in the vegetable production.

- Although farmers have largely adopted cattle manure application, the results indicate that the N contents of cattle manure used in the area are low compared to the literature norms; 0.51% N for the fresh manure and reducing to 0.44% N for uncovered fresh cattle manure; the latter being the most commonly used cattle manure. This is expected given that animals are not provided with supplementary feeds and not enough fodder is available due to limited land and much N is leached whilst manure is stockpiled.
- There is need to design effective manure handling and storage systems that reduce loss of nutrients after excretion as low quality manure may immobilise N.
- Improving the manure quality should be intensified to enhance crop performance.
- Though the farmers received limited education on manure application from family members and extension agents, they did not consider it adequate and suggested the need to provide more education. The information on processing of organic manure, timing of application, placement of the manure, and the proper amount of manure to be applied should be intensified to help farmers increase/maximise crop yield. The Ugandan government and the local administration units should therefore make efforts where manure is applied at optimum rates to intensify education among farmers. This would help farmers to maximise yield and eventually boost the economies of scale of the farmers. However, the availability of the nutrients in the manure should be understood to apply the right rates and this forms the basis of the following chapter.

Chapter 5. The Relative Effectiveness of the Nitrogen in Cattle Manure Compared with an Inorganic Fertiliser



5.1 Introduction

Average fertiliser use rates for countries in Sub-Saharan Africa (SSA) are low and ineffective for sustaining crop and soil fertility maintenance (Gruhn et al. 2000). In addition, the reduction in soil productivity that accompanies most systems of continuous cultivation in the tropics has resulted in low productivity of crops, particularly cereals and vegetables that dominate the crop-livestock production systems. Under smallholder systems, maintenance of soil fertility is poor. Globally, fertiliser prices have tripled in recent years (IFDC 2008; Holt-Giménez 2008; Marquer 2010) and coupled with unavailability, their use is limited (Chefurka 2008; Hergert 2009). Nitrogenous commercial fertiliser prices doubled between 2000 and 2007 and rose again by 62% between December 2007 and September 2008 (U.S. Bureau of Labour Statistics 2009), whereas phosphate commercial fertiliser prices increased by 115 % between 2000 and 2007, and by 177 % between December 2007, and September 2008 (MacDonald et al. 2009). The significant price changes and likelihood of high future prices have kindled greater interest in naturally occurring fertilisers including animal manures from goat, sheep, chicken, rabbit and cattle. In Uganda, there are opportunities for widespread use of manure from the latter manure with the increasing number of cattle at 7.5 million, comprised of 1.3 million (or 17.3%) exotic/cross cattle and 6.2 million (or 82.7%) indigenous cattle (UBOS 2006). However, there is limited knowledge on soil nutrient deficiencies and farmers may not know the precise combination of nutrients needed for specific crops and fields when using cattle manure.

Cattle manure is used widely as a crop fertiliser and as a soil amendment (Lekasi et al. 2003; Panda 2008); a key resource to sustain productivity of the majority of smallholder farming systems in Africa (Giller et al. 2002; Rufino et al. 2006; Rufino et al. 2007). It contains nutrients such as nitrogen (N), phosphorus (P), and potassium (K) that facilitate plant growth, and can improve soil quality by decreasing compaction, increasing organic matter and water holding capacity (Sutton et al.1986; Randall et al. 2000; Eghball 2002; Butler and Muir 2006; Panda 2008). Manure also provides other trace nutrients for crops and maintains soil organic matter both vital to guarantee efficient use of fertiliser N (Rufino et al. 2006). The relative effectiveness of cattle manure compared to commercial fertiliser on crop yield and growth is dependent on the type of manure applied (Sutton et al. 1986; Randall et al 2000; Griffin et al. 2002). Crop availability of N in manure is lower than N from inorganic fertilisers, because of the slow release of organically bound N and the volatilization of ammonia (NH_3) from surface-applied manure (Beauchamp 1983; Jokela 1992). Cattle manure can be deposited on cropland by grazing animals, but is commonly transported from animal confinement and manure storage facilities and spread on the ground or injected into it.

The application of inorganic fertilisers has achieved a considerable level of success by increasing crop production compared to past yields by providing nutrients that are readily available to crops. However, its application has also faced important limitations due to high costs, highly variable nature of soils and inherent low nutrient conversion efficiency (AGRA 2007). Soils in Africa are typically highly variable in fertility and in their response to inputs (AGRA 2007; Omotayo and Chukwuka 2009). Most soils in Africa exhibit low nutrient levels with a high propensity towards nutrient loss due to their fragile nature (Lal 1993a).

The use of cattle manure, balanced with chemical fertilisers, offers an opportunity to improve long-term sustainability in crop production systems. Balanced fertiliser use through synchronized supply of essential nutrients to growing crops as well as increased soil organic matter content over the long term are major gains realized through application of organic resources (Omotayo and Chukwuka 2009). At present, there is no guidance about the best specific combinations of chemical fertilisers and cattle manure for farmers. This investigation aims to compare the relative effectiveness (RE) of N from cattle manure with an inorganic source of fertiliser N (urea) for plant growth and N uptake. The results will enable an economic modelling package be developed to determine the most feasible rates of manure and inorganic fertilisers for the Ugandan environment; also relevant to other developing countries with similar farming systems and provide a benchmark for sustainable productive crop-livestock farming systems.

5.2 Materials and methods

5.2.1 Trial layout and design

The design of the field experiment was a systematic arrangement following several researchers who used used organic residues; hence considered appropriate for manure (Cleaver, et al. 1970; Greenwood, et al. 1980a; 1980 b; Smith and Hadley 1988; Smith and Bellet-Travers 2001; Smith et al. 2002b; Morris et al. 2003; Rigby, 2008). Treatment levels were arranged in a systematic gradient design to prevent edge effects that may result from a high rate plot adjacent to a low rate plot. The elimination of wide guard rows increased the ratio of harvested to non-harvested area and reduced the potential threats from experimental error. Smaller plots with less guard rows facilitate more rates of fertiliser. Plots measuring 2m x 2m were systematically arranged in three blocks in replicate treatments with the direction of fertility gradient randomized to reduce variation that may be caused by natural fertility trends (Figure 5.1, Plate 5.1). Randomisation helps to detect the variation that may be due to natural fertility trends. Originally, the design included P experiment but was discontinued because the soils of the Ugandan central districts surveyed in chapter 4 were not P deficient. Plates 5.1 and 5.2 present the field trial establishment showing the systematic gradient design and application of basal treatments uniformly to the soil, respectively. While plates 5.3 and 5.4 show an established canola crop and its sampling during the 2009 season, respectively.

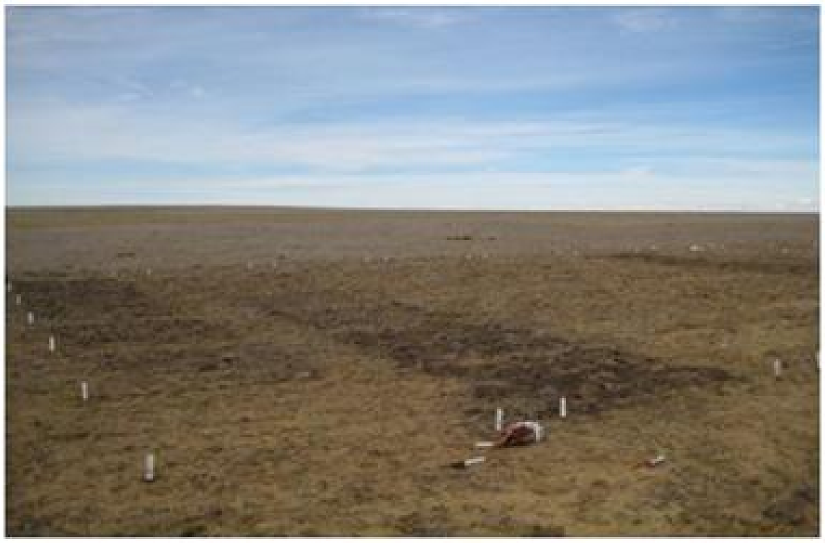


Plate 5.1: Field trial establishment showing the systematic gradient design

Plate 5.2: Applying basal treatments uniformly to the soil surface, 2009

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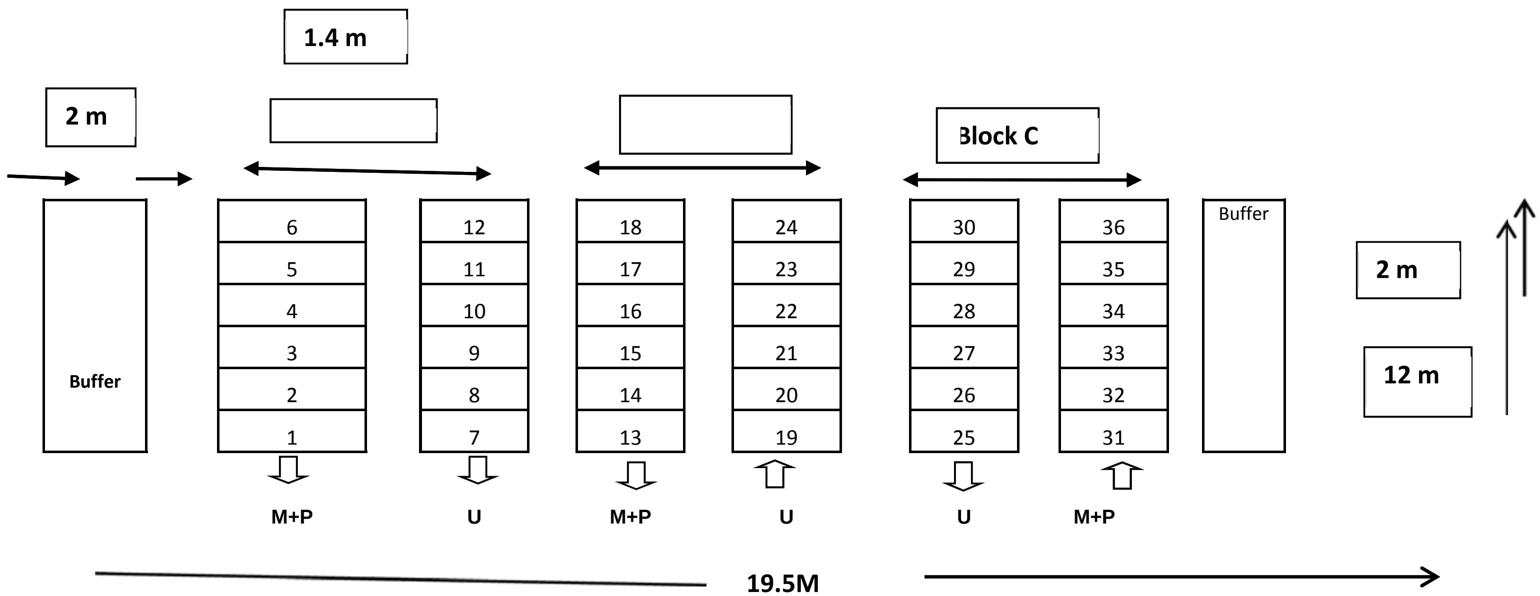


UCARTY COLLINS FARM

Key;

M+P= Cattle manure

U=Urea

↑ Gradient

5.2.2 Description of the study site

The field experiment was established at Ucarty, located 120 km east of Perth, Western Australia (31.19159^{o}S, 116.57083^{o}E) on acidic dark yellowish-brown sand**.** The region is characterised by a dry temperate climate with cool, wet winters and hot, dry summers, and average rainfall of 302 mm over the growing season (April-October).

5.2.3 Soil type

Soil samples were collected from the surface layer (0-10cm) of the site before application of treatments. Four random cores were taken from the site with a 5 cm diameter tube auger and bulked and then dried at 40^{0}C for 72 h in a forced air oven. All soil samples were stored at room temperature until required for chemical analysis. Table 5.1 shows the characteristics of the soil. The site was chosen to be low in N to enable a nutrient response to be determined. The ChemCentre, Perth, which is accredited by the National Association of Testing Authorities (NATA), performed all analyses.

5.2.4 Treatments

The experiment comprised 12 treatments; 6 rates of cattle manure and 6 rates of inorganic N fertiliser. The treatment rates were calculated from the N composition of cattle manure (Table 5.3) calculated to provide the same total N per hectare as in inorganic fertilisers. The following rates of cattle manure were applied; 12,500 kg ha^{-1}, 26,750 kg ha^{-1}, 40,000 kg ha^{-1}, 53,250 kg ha^{-1}, and 66,750 kg ha^{-1} and urea were 87 kg, 174 kg 261 kg 348 kg and 435 kg ha^{-1} to provide the respective equal N rates as shown in Table 5.2.

Table 5.1: Selected physical and chemical characteristics of the <2mm fraction of the top soil (0-10cm) at Ucarty

Parameter	Value
EC (1:5) (mS/m)	6.0
pH (0.01 M $CaCl_2$; 1:5)	5.0
Sand (%)	95.5
Silt (%)	2.0
Clay (%)	2.5
Organic C (W/B) (%)	0.74
Total N %	0.065
Total P (mg/kg)	74
P (HCO_3) (mg/kg)	7
PRI (mL/g)	0.2
K (HCO_3) (mg/kg)	45
Al ($CaCl_2$) (mg/kg)	<1

Chemistry Centre WA, Report 08A7/1-5

pH ($CaCl_2$) in 0.01 M $CaCl_2$ (Rayment and Higginson 1992a), Total N (Blakemore et al. 1987; Rayment and Higginson 1992b; Searle 1984), nitrate-N and ammonium-N extracted by 1 M KCl (Rayment and Higginson 1992b) p53, Total P (Allen and Jeffery 1990; Murphy and Riley 1962), Bicarbonate extractable P extracted by 0.5 M $NaHCO_3$ (1:100) (Colwell 1963; Rayment and Higginson 1992b), PRI (Allen and Jeffery 1990), Al extracted by 0.2M ammonium oxalate ($_{AmOx}$), pH 3.25 (Rayment and Higginson 1992a), Organic carbon (W/B)% by Walkley and Black (1934) (Rayment and Higginson 1992b), EC (1:5) at 25^{o}C (Rayment and Higginson 1992a).
(mS/m = milliSiemens per metre, mg/kg = milligrams per kilogram, mL/g = millilitres per gram). EC = electrical conductivity and PRI = P retention index

Table 5.2: Rates of cattle manure and inorganic N applied

Treatment	Rate kg ha^{-1}					
Cattle manure-N	0	40	86	128	170	214
Inorganic-N	0	40	80	120	160	200

Application of basal nutrients

For optimum crop growth and to ensure all mineral requirements were adequate, basal nutrients other than N were applied as super phosphate 100 kg ha^{-1}, muriate of potash (588.2 kg ha^{-1}), copper sulphate (6.7 kg ha^{-1}), zinc sulphate (13.3 kg ha^{-1}), gypsum (12.5 kg ha^{-1}) and manganese sulphate (120 kg ha^{-1}). All inorganic fertiliser treatments were broadcast at planting by hand and then well incorporated into the respective treatments by disc plough (Plate 5.2).

Application of cattle manure

Air-dried and stockpiled cattle manure (90% dry matter, 0.32% N and 0.11% P) (Table 5.3) were used for the experiment. Cattle manure was weighed into buckets using an electronic weighing scale for each plot and then broadcast evenly by hand and incorporated into the soil during seeding by discs.

Table 5.3: Dry matter content and total, mineral and organic concentration of nitrogen and other analytes in cattle manure applied in 2009 field experiment

Analysis	**Value**
pH (0.01*M* $CaCl_2$;1:5)	7.0
Org C (W/B) (%)	6.7
Total N (%)	0.32
NH_4-N (mg kg^{-1})	0.01
NO_3-N(mg kg^{-1})	0.04
P (HCO_3)(mg kg^{-1})	730
K (HCO_3)(mg kg^{-1})	0.21
Total P (mg kg^{-1})	0.11

Method: Total N by combustion; nitrate-N and ammonium-N by SFA; total P and K by ICP-AES; pH by $CaCl_2$ and organic carbon W/B. Cattle manure oven dried and reported as percent dry basis, mg/kg= milligrams per kilogram

Nitrogen experiment

Urea was used as the source of N at 46% N. Two applications of N were top dressed to all N treatments at seeding and later applied at 8 weeks after planting.

Seeding

Canola (*Brassica napus*) was sown at the start of growing season on 28 May 2009, at a rate of 9 kg ha^{-1} top dressed by hand and incorporated to a maximum depth of 3-4 cm by disc. Canola was used as it is efficient at capturing high amounts of plant available N, similar to cabbage, a commonly grown vegetable in Uganda and it was deemed suitable for comparison purposes for this study as it can do well under climatic conditions of Western Australia.

5.2.5 Site Management

Weeds were removed by spraying with glyphosphate at a rate of 2 L ha^{-1} before planting and Amor for grass control at 150 mL ha^{-1} five weeks (July) after planting and a few hand weeded on sampling days. An electric fence was erected to prevent both grazing cattle and field rabbits from damaging the crop. Remote data loggers were used to continuously collect soil temperature (Tiny Tag Transit Temperature range H TG-0050, Omni Instruments); the temperature logger positioned at a depth of 10 cm in a randomly chosen plot included maximum, minimum and average temeperture was recorded on a daily basis. Weather data (maximum, minimum and average) was recorded by an automated weather station. Soil moisture was determined by drying 200 g of wet soil in the oven at 105°C for 24 h and then subtracted the dry weight from the fresh weight over the mass of fresh weight x100.

5.2.6 Plant sampling and harvests

At 32 days after sowing (DAS), plant establishment counts were made from two, randomly located, 0.25 m^2 quadrants per plot. Samples of canola were obtained by collecting whole plant (above ground) biomass on two, 0.25m quadrants from each plot at 63 and 93 DAS. Fresh weights were measured and plant tissue was dried to a constant mass at 70^0C for 48 h in a forced-air oven to determine dry matter (DM) weight. The average plant density for each plot was used to determine DM g m^{-2}. Twenty fresh plants from all plots were oven dried at 63 DAS. The plant biomass (DM) was only done at 63 DAS in order to get enough plant samples at the end of the experiment, although this may raise the possibility of the extra error. Yield component was determined at harvest on every plot.

5.2.7 Plant tissue nutrient analysis and N uptake

Whole dried plant samples collected from the determination of DM were used to determine shoot concentration of N. The plant samples were ground to pass through a 1.0 mm sieve and analysed for total N by combustion in a Leco FP-428 analyser. Samples were combusted in pure oxygen at 850°C whereby nitrogen oxides were converted to N with the removal of water, oxygen and carbon dioxide, and N measured by thermal conductivity by method PCM P03 (CCWA 2000).

Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) was used to determine other plant (macro and micro) nutrients concentrations. ICP-AES measures precision of macro-nutrients to 0.01% and trace elements to 1 µg/g (McQuaker et al. 1979; CCWA 2000) providing results for K, Ca, Mg, Na, S, Fe, Mn, Zn, and Cu. The organic material was digested by heating to 250°C with nitric and perchloric acids, followed by evaporation of nitric acid and addition of water. Nitrogen uptake by the canola crop was determined by multiplying the DM yields with the N concentration in the DM of shoots. The regression coefficients of plant N uptake measurements in DM yields on the manure treatments were compared with coefficients of N uptake on the inorganic-N treatments to calculate the fertiliser equivalent value of the mineralised organic N (Figure 5.3).

5.2.8 Data analysis

Statistical analysis of data was carried out using standard analysis of variance (ANOVA) (GenStat Procedure Library Release PL20.1) (Payne et al. 2011). The significance of the treatment effect was determined using the F -test and the difference between the means of the six treatments; least significant differences (LSD) were estimated at the 5% probability level. The aim of the use of ANOVA was to determine whether cattle manure had a significant effect on crop growth and yield compared with inorganic fertiliser.

Fresh and dry weight yields and N uptake in relation to organic N from cattle manure were statistically analysed by linear regression analysis and compared to respective yields from mineral N calibration plots. Linear models of the form $y = a + bx$ were fitted to the data where y is the yield (kg ha^{-1} fresh or DM or N uptake). Where the linear regression was significant according to ANOVA analysis, the slopes of the regression equations for N from cattle manure were compared to the slope obtained for mineral N to obtain N equivalency value. A similar approach was employed by different researchers including Kiemec et al. (1987); Huang and Lin (2001); Smith et al. (2001; 2002b); Morris et al. (2003); Rigby, (2008). Yield response to manure N is considered to be linear between applications of 0-300 kg N ha^{-1} (Whitehead 1995). This is within the range of standard rates of application of fertiliser N. Mean N equivalent values were calculated from each of the indicators of crop response to N (fresh yield, dry yield and N uptake) to each treatment. The linear method calculated relative values for the overall response to organic N from cattle manure compared to mineral N.

5.2.9 Soil analysis

The parameters of the characteristics of the soil (Tables 5.1) were analysed as follows;

pH

The pH was measured by pH meter using a glass electrode on a 1:5 extract of soil and deionised water (Rayment and Higginson 1992a).

EC

Electrical conductivity (1:5) was measured by conductivity meter at 25°C on a 1:5 extract of soil and deionised water (Rayment and Higginson 1992b).

Organic Carbon

Organic carbon was determined, on soil ground to less than 0.15 mm, by Metson's colorimetric modification of the Walkley and Black method (Metson 1956; Walkley 1947). The procedure is based on oxidation of soil organic matter by dichromate in the presence of sulphuric acid. The heat for the reaction is supplied by the heat of dilution of the sulphuric acid with the aqueous dichromate.

Total Nitrogen

Total nitrogen was measured by Kjeldahl digestion of soil (Copper sulphate-potassium sulphate catalyst) and measured as ammonium-N by automated colorimetry by the nitroprusside.dichloro-*S*-triazine modification (Blakemore et al. 1987) of the Berthelot indophenol reaction reviewed by Searle (1984) and Rayment and Higginson (1992b).

Ammonium and Nitrate

Ammonium and nitrate were extracted from soil by 1M KCl solution and measured by automated colorimetry: ammonium by salicylate - chlorine (Reardon et al. 1966) and nitrate by reduction, diazotisation and coupling with N-1-naphthylethylenediamine dihydrochloride (Best 1976).

BIC-P (Plant Available)

Samples of soil were extracted in 0.5 M sodium bicarbonate solution (pH 8.5) for 16 h on an end-over-end shaker. Inorganic P in the centrifuged extract was measured using automated colorimetry. Orthophosphate in the extract reacts with a reagent containing ammonium molybdate, potassium antimony titrate, ascorbic acid as reductant and sulphuric acid to form a blue complex ion (Murphy and Riley 1962; Rayment and Higginson 1992b).

BIC-K (Plant Available)

Plant available potassium was measured by displacing K from soil 0.5 M sodium bicarbonate (pH 8.5) (soil: solution ratio 5:100, 16 h extraction, 23^{o}C. This procedure is modification of the standard test for bicarbonate-extractable K (soil to solution ratio 1:100). The greater soil to solution ratio used in this procedure provides improved accuracy and precision for sandy soils containing relatively low concentrations of extractable K (<100 g kg^{-1} soil) (Jeffery 1982).

Total Phosphorus

Total Phosphorus was measured by colorimetry on the Kjeldahl digest for total N using a modification of the Murphy and Riley (1962) molybdenum blue procedure.

Phosphorus Retention Index (PRI)

PRI was determined by the method of Allen and Jeffery (1990) and published in Allen et al. (2001).

Mehlich-3 Extractable Elements

Soil was extracted with the Mehlich 3 extraction (2.5 g + 25 mL) for 5 min, then analysed for extractable P, K, Ca, Mg, Na, S, B, Cd, Co, Cu, Fe, Mn, Mo, Ni and Zn by ICP-AES (Varian Vista axial spectrometer) (Mehlich 1984).

Al and Fe Extracted in Ammonium Oxalate

Three (3) g of soil was shaken for 2 h at 23^{o}C with 100 mL of ammonium oxalate solution. Floating organic matter was removed from the extract and centrifuged at 3,500 rpm for 10 min. The concentrations of Fe, Al and Mn were measured by both flame AAS or ICP-AES against the standards in ammonium oxalate solution following Blakemore et al. (1987).

5.3 Results

5.3.1 Weather conditions

The experimental site received 246.2 mm of rainfall during the growing season (May to October). This was relatively low compared to the long-term average of 302 mm. The trial was sown on 28 May 2009 following 30 mm rainfall for the month, which increased gradually during the growing season with an intermittent dry spell over September - October. July recorded the highest rainfall of 74 mm. There was vigorous vegetative growth in the first 3 months but dry September conditions that registered 19.6 mm of rainfall, affected the flowering and setting of the seeds. October was the warmest month with minimum of 2.5°C and maximum of 36.4°C. The lowest minimum and lowest maximum temperatures during the crop growth of 0.5°C and 20.6°C, respectively, were recorded in July (Figure 5.2).

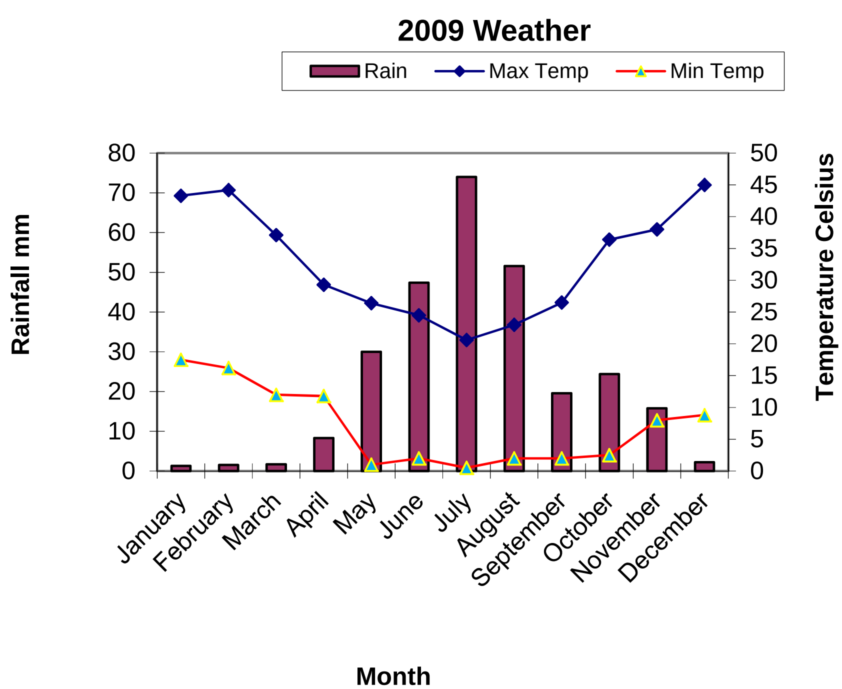


Figure 5.2: Total monthly rainfall, mean monthly, maximum and minimum temperature at Ucarty, Western Australia in 2009.
Rainfall is the cumulative for each month while temperature is the mean for each month

5.3.2 Plant establishment and development

The mean canola establishment was 151 plants m^{-2}, which was not significant between treatments. The mean plant density in each plot was used to calculate the dry matter of canola shoots. The growth of shoots in manure-N treatments was poor compared to inorganic-N treatment plots where good growth was observed as at 32 DAS at its highest rates of application. High plant numbers were observed in the highest rates of inorganic-N treated plots compared to highest rates of manure-N plots although not significant. Plant growth improved as N loadings increased in both cattle manure-N and inorganic-N treatments with the highest growth rate observed in inorganic-N than manure-N.

Plate 5.3: An established canola crop under cattle manure application

Plate 5.4: Sampling of the field trial during 2009

5.3.3 The effect of nitrogen on canola yield

Dry matter yield increased with increasing rates of inorganic-N at all sampling dates (Figures 5.2 and 5.3). Inorganic-N treated plots reached a maximum yield of 743 kg DM ha^{-1} at 200 kg N ha^{-1}. At all N rates and sampling dates the application of inorganic-N resulted in higher yields compared to cattle manure-N at almost equal rates of application. There were significant differences (P≤0.001) at 63 and 93 DAS between inorganic-N and cattle manure-N (see Table A5 in appendix). Large differences in yield for inorganic-N were observed between the rates of 40 kg N and 80 kg N ha^{-1}.

All DM yields of canola shoots for the first and second harvests are presented in appendix, Table A5; the highest yield obtained during the 2nd harvest. This was consistent with the results of the N equivalent values Tables 5.6, which indicate that the highest N equivalent value was obtained in the second harvest. Increased plant biomass and yield were observed in the highest rates of manure treatments.

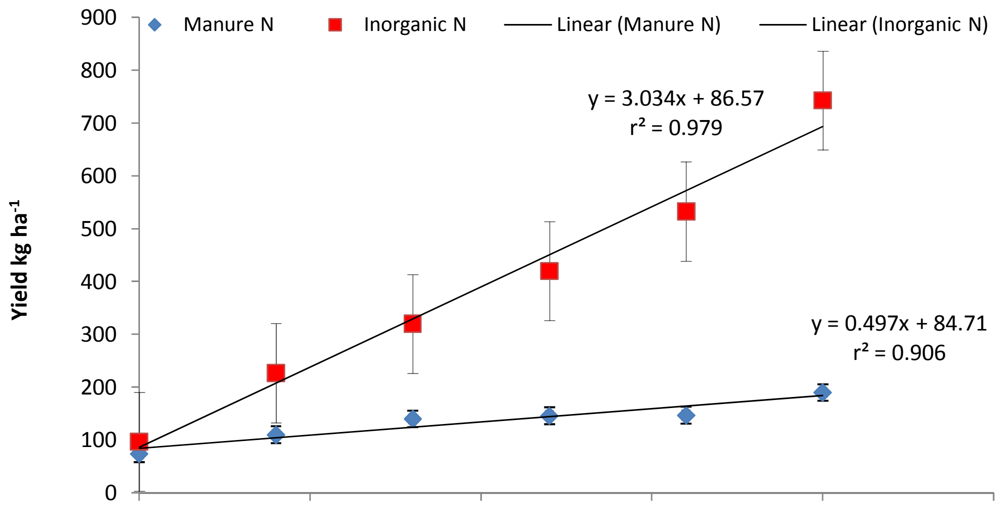


Figure 5.3: **Effect of nitrogen in cattle manure and urea on DM yield (kg ha^{-1}) of canola at 63 DAS**

Values are the means of three replicates. Line plotted using Microsoft Excel. Vertical bars denote LSD (P = 0.05) for data from all treatment means.

At the maximum rate of manure-N, the yield was 3.9 times less than the highest rate of inorganic-N (631.2 kg ha-1) at 63 DAS and 4.1 times less at 93 DAS (2,582 kg ha-1). This was a linear relationship. The maximum yield was approached at the top rate of inorganic-N at 200 kg ha-1, and while maximum yield for cattle manure-N varied at both sampling dates (Table A5); the mean fresh weight was 534.3 kg ha-1 and 1,738.4 kg ha-1 for manure -N and inorganic-N, respectively, at 63 DAS and increased to 3,412 kg ha-1and 14,976 kg ha-1at 93 DAS for the respective inputs. However, the fresh weight is lower even at 40 kg N ha-1in the inorganic-N treatment of the current study. Therefore increasing the level of inorganic-N up to 120 kg ha-1significantly increased crop fresh weight but decreased when the rate was increased to 160 kg ha-1. This was not consistent as yield increased again at 200 kg ha-1.

The crop response did not approach a curvilinear at the top rates of application to necessitate the use of quadratic equations but even then when quadratic equations of the form (y = a + bx + cx^2) were fitted to the data, the quadratic term (X^2) in the crop response model was not significant at P<0.05, and the yield pattern was therefore approximated to a linear function of N applications.

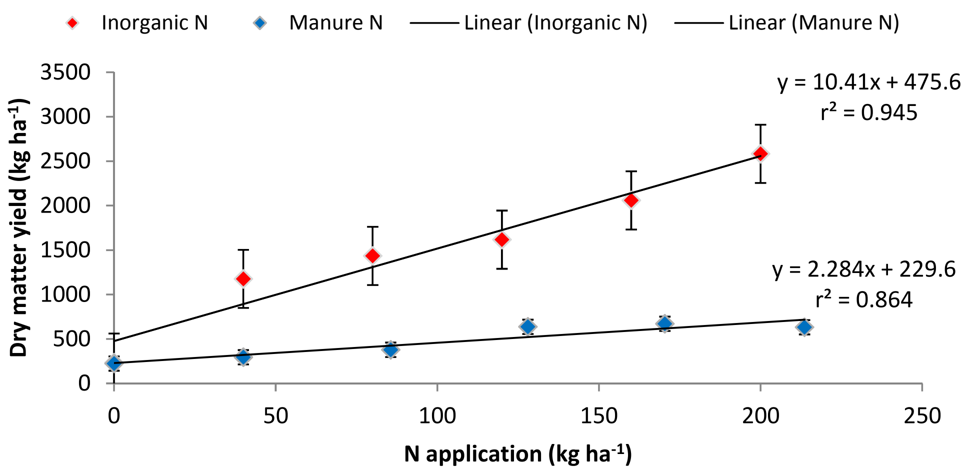


Figure 5.4: **Effect of nitrogen in cattle manure and urea on DM yield (kg ha^{-1}) of canola at 93 DAS**

Values are the means of three replicates. Line plotted using Microsoft Excel. Vertical bars denote LSD (P = 0.05) for data from all treatment means.

5.3.4 Shoot nitrogen concentration and uptake

The concentration of N in the DM of whole shoots of canola showed a positive response to increasing levels of N. Over the duration of the growing season, N concentrations declined with overall means as follows; 3.2% (lsd=1.08) and 2.8% (lsd=0.83) for 63 and 93 DAS, respectively. At all sampling dates and for all rates, the concentrations of N were below the critical concentration required for maximum yield based on equivalent growth stages (Reuter and Robinson 1997). Mean total N uptake by canola shoots increased with increasing rates of either inorganic N or cattle manure N at all sampling dates (Figures 4.5 and 4.6). There were significant differences ($P<0.001$) in N uptake at 63 and 93 DAS between inorganic N and cattle manure at comparable N loadings. At 93 DAS, the highest rate of inorganic N (200 kg N ha^{-1}) displayed high N uptake relative to the highest rate of cattle manure N ($P <0.001$). Nitrogen uptake in both treatments at the highest rate of inorganic N and manure N had not reached a plateau.

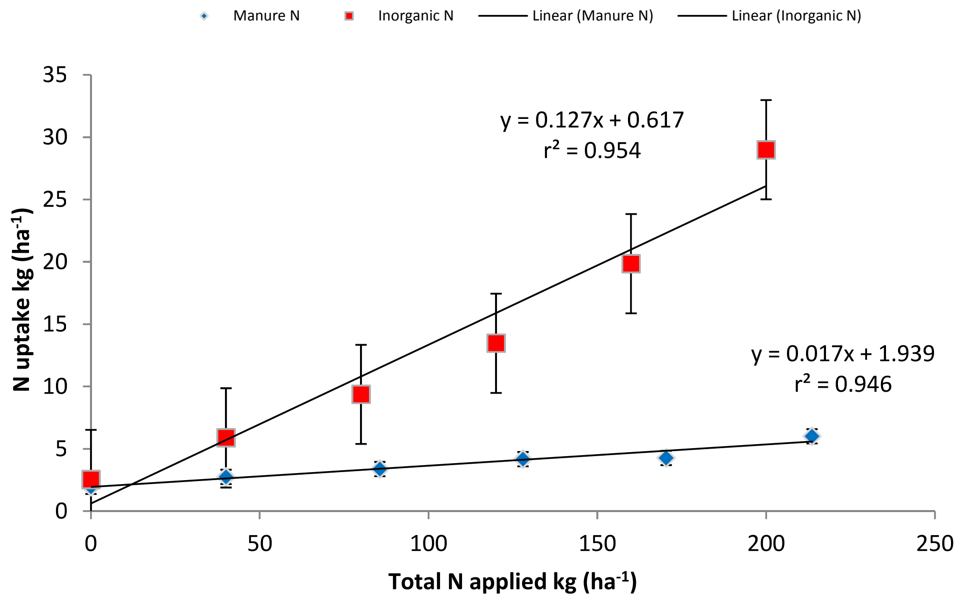


Figure 5.5: Relationship between total N uptake (kg ha^{-1}) in canola shoots and the level of N applied in inorganic and cattle manure at 63 DAS

Values are the means of three replicates. Line plotted using Microsoft Excel. Vertical bars denote LSD (P = 0.05) for data from all treatment means.

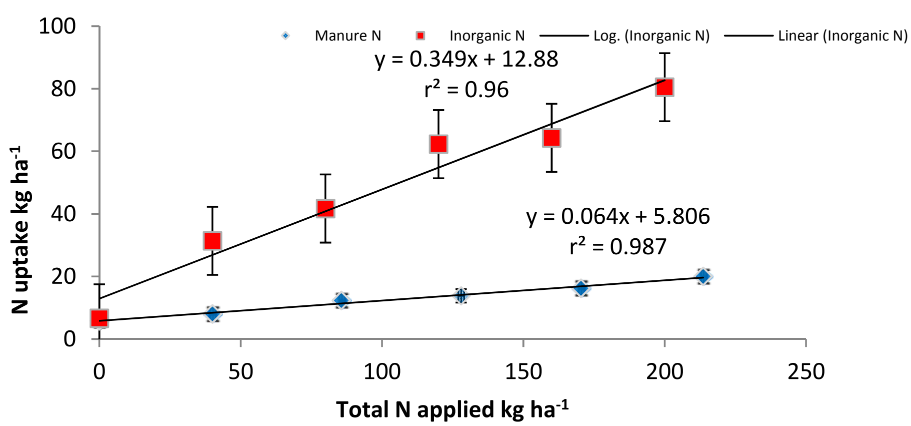


Figure 5.6: Relationship between total N uptake (kg ha^{-1}) in canola shoots and the level of N applied in inorganic and cattle manure at 93 DAS

Values are the means of three replicates. Line plotted using Microsoft Excel. Vertical bars denote LSD (P = 0.05) for data from all treatment means.

5.3.5 Relative effectiveness of cattle manure-N compared with inorganic-N during the growing season

Nitrogen equivalency values of cattle manure for each measure of crop response (fresh, dry and N uptake) yield based on linear regression coefficients with inorganic-N followed a Mitscherlich equation (Tables 5.4-5.5). Nitrogen equivalency value calculated for cattle manure treatment demonstrated a significant relationship between rates of N application and crop response (P=0.05), by comparing linear regression coefficients with inorganic-N. The RE value was determined using the three measures of crop response, N uptake, dry yield and fresh yield. The N equivalency value was summarised by expressing N as a mean of the three measures of crop response. The relative effectiveness for cattle manure-N compared with inorganic-N was 15 % for fresh yield, 16% for DM and 13% for N uptake at 63 DAS (Table 5.6). The N equivalent value with cattle manure-N at 93 DAS was 21%, 22% and 18% for the fresh weight, DM yields and N uptake, respectively. There was little difference for the effectiveness of cattle manure-N over the season as N value only ranged from 16% to 22% for DM and 13% to 18% for N uptake.

Table 5.4: Linear regression coefficients and r^2 values for cattle manure-N and Inorganic-N fertilisers at 63 DAS

Source	Fresh weight		Dry weight		N Uptake	
	Slope	r^2	Slope	r^2	Slope	r^2
Manure N	0.9283	0.57	0.4974	0.72	0.017	0.52
Inorganic N	6.0137	0.83	3.0357	0.89	0.1274	0.85

Table 5.5: Summary table of linear regression coefficients and r^2 values for cattle manure and inorganic N fertilisers at final harvest (93DAS)

Source	Fresh weight		Dry weight		N Uptake	
	Slope	r^2	Slope	r^2	Slope	r^2
Manure N	11.6700	0.82	2.2847	0.71	0.0617	0.69
Inorganic N	50.9970	0.86	10.411	0.88	0.3495	0.86

The mean N equivalent values for cattle manure at all sampling dates calculated from the crop response for each measure (fresh weight, N uptake and dry yield) over the season were 14.6% and 21% at 63 and 93 DAS, respectively.

Table 5.6: N equivalent values of cattle manure for each measure of response (fresh and dry yield) on comparison of linear regression coefficient with inorganic N fertiliser during the season

Source	**Days after sowing (DAS)**	**Yield/parameters**			
Cattle manure N		Fresh	Dry	N uptake	Mean
	63	0.15	0.16	0.13	0.146
	93	0.23	0.22	0.18	0.210

5.4 Discussion

5.4.1 Crop response to nitrogen fertiliser application

Plant establishment and development

There was slow growth observed on all cattle manure treatment plots during the growing season. This is attributed to the fact that for cattle manure treatment, which was a significant source of mineral N, the nutrient contents were low (see Table 5.3) implying that the majority of N was already mineralised before application as the manure was aged and or the nutrients were quickly utilised by the plant or there could have been slow mineralisation of N over the season. However, this supported the findings of (Morris et al. 2003) and (Rigby 2008) who found that there was little response to cattle manure slurry applied at normal agronomic rates. In the case of the inorganic fertiliser, the vigorous and high plant numbers observed in the highest rates of inorganic-N treated plots compared to highest rates of manure-N plots demonstrates that N was readily available for the crop uptake. It should be noted that not all the nutrients present in manure are immediately available for plant uptake with 80-100% of K present in soluble inorganic form (Sutton et al. 1999; Laboski et al. 2006; Laboski et al. 2008; Baxter et al. 2006 ; Mikkelsen 2007), while 70-100% of P is bioavailable depending on soil reactions (Eghball et al. 2002; Nelson and Janke 2007). A proportion of N in the cattle manure is in organic form (Gale et al. 2006; Rigby 2008; Endelman 2009). Nitrogen is the least bioavailable ranging from 10-50% of total N in solid manure for plant uptake within the season of application, this fraction tending to decrease with the extent of decomposition (Gale et al. 2006). The partial bioavailability of manure is major concern but elsewhere researchers suggest manure should be applied at a rate where the estimated bioavailable N meets the N fertiliser recommendation (Baldwin 2006; Gaskell et al. 2006; Andrews and Foster 2007). It is not surprising that there were low DM yields in the current study.

The observed differences in plant biomass and better health of the crop (and subsequent greater R^2 value) for the inorganic fertilisers over the manure-N amended treatments was expected. Although N was below the critical range for crop growth. This critical range is the nutrient concentration in the plant below which a yield response to added nutrients occur (Havlin et al. 1999). Further research is required to determine what higher application rate of cattle manure exceeds the critical range for N and results in luxury consumption where the added nutrient will not increase yield but can increase nutrient concentration in the plant.

5.4.2 Crop yield response to N fertiliser application

The small increase in yields over the two successive harvests which was consistent with the N equivalent values, (Table 5.6) of the second harvest are attributed to increased levels of manure N following mineralisation of organic forms of N with time or leaching of inorganic N beyond root zone. At all N application rates (loading rates) and sampling dates, the application of inorganic-N resulted in higher yields compared to cattle manure-N at almost equal rates of application. There was significance difference ($P \leq 0.001$) at 63 and 93 DAS between inorganic-N and cattle manure-N indicating a difference in N availability (≤P0.001). The observed low yield response from cattle manure-N compared to inorganic-N could be attributed to infertile soil. Rigby (2008) made a similar observation following an addition of unstabilised livestock waste in 2 sites in the UK which had availabilities of 2.5 and 6.2 % total N, respectively. This demonstrated that mineralisation of N is less rapid in infertile soil implying that there is a lag phase in less fertile soil compared to fertile soil. The lag phase is due to a delayed response to manure amendment in the soil with the less active microbial population, or simply a longer period required to turn over the added organic matter. Results indicate that up to 1.29 t ha^{-1} and 0.4 t ha^{-1} for inorganic-N and manure-N were produced, respectively. This is on the lower side for manure N compared to inorganic N. This confirms the notion that canola yield responds to fertiliser application, especially available N (Ramsey and Callinan 1994; Hocking et al. 1997; Rathke et al. 2005; Kazemeini et al. 2010). In the present study, manure application rates were very low compared to other studies such as those of Lekasi et al. (2003); Morris et al. (2003) and Onduru et al. (2008) therefore the low levels of nutrients contained in manure coupled with low rainfall received during the season can explain the low yields.

The seasonal fresh and DM yield increases may be due to an improvement in the soil conditions by the supply of additional C and other nutrients from cattle manure. A more likely explanation is that the high soil pH maintained by the cattle manure may have contributed to the yield effect, possibly together with the water use efficiency attributed to cattle manure (Weil and Magdoff 2004). These two factors may have interacted with plant growth. Elsewhere, cattle manure rapidly increased soil pH, and concentrations of exchangeable K, Ca and Mg and extractable P were also greatly (Naramabuye and Haynes 2006; Rigby 2008; Naramabuye et al. 2008; Gana 2009). Other identified benefits of manure application are the biological influences such as organic-matter mediated disease suppression that are active on long time scales (Stone et al. 2004).

The amount of DM yield was the highest at 170 kg ha-^{1} manure-N. Elsewhere, application of 175 kg N ha^{-1} cattle manure resulted in corn DM yields of no less than 90% of the maximum yield (Zebarth et al. 1996). This is closer to the 5th rate which is the second highest application rate of N kg ha-^{1} in cattle manure in this study. Application of liquid dairy cattle manure at 45 t ha^{-1} yr^{-1} (dry weight basis) for 3 yr produced excellent yields of coastal Bermuda grass (*Cynodon dactylon* L.). Maximum sudan grass (*Sorghum sudanese* L.) and barley (*Hordeum vulgare* L.) yields at 21 t ha-^{1} yr-^{1} (dry weight basis) liquid feedlot manure was observed on a 4 yr application (Lund et al. 1975; Pratt 1982; Mooleki et al. 2004). N, P and K uptake by corn plants was increased with increasing rate of liquid dairy cattle manure, applied for more than 2 year, at levels similar to the inorganic N, P, and K Fertilisation (Culley et al. 1981; Motavalli et al. 1989). Similar observations were made by Quansah (2010).

5.4.3 Effect of nitrogen transformation in cattle manure on canola yield

There was slow response to manure-N on canola N uptake, DM and fresh yield (appendix Table A5). Mean output of 631 kg ha^{-1} and 2582 kg ha^{-1}for manure-N and inorganic-N were produced, respectively, at 93 DAS. The low response to manure-N could be attributed to its transformation process that occurs over time. Some short-term studies have reported that little of the organic N becomes available in the year of application (Paul and Beauchamp 1994; Helgason et al. 2007). However, longer-term applications of cattle manure may eventually release a sufficient supply of N each year to meet crop nutrient requirements without the addition of inorganic fertilisers(DeLuca and DeLuca 1997; Helgason et al. 2007).

A similar result was found by (Eghball 2002) who suggests that unlike in inorganic-N salts that are immediately available for uptake by plants when applied to soils, N release from organic fertilisers is dependent on the degrading action of proteolytic microorganisms in the soil. For instance, N mineralisation from 107 individual dairy manure samples after 8 weeks of incubation showed on average 13% of the organic N was mineralized, but overall N net mineralisation ranged from 0-55 % (Van Kessel and Reeves 2002). This can account for the varying canola yields in manure treated plots.

Elsewhere, studies indicate that the use of manure increases the soil inorganic N pool and increases the seasonal soil N mineralisation available to the crops (Murwira and Kirchmann 1993; Ma et al. 1999a; 1999 b). Huang and Lin (2001) and Yang et al (2006)Huang and Lin, (2001) established that combined chemicals and organic inputs in a plot had the best ability to build up soil N, and produced the highest crop yield. Smith and Hadley (1988) suggested that the mode of N release from organic N sources may explain the increased response, and that plant roots at 32 DAS were not sufficiently developed to absorb the large pool of available N from inorganic fertiliser sources immediately after sowing.

Other research studies have reported that the use of organic manure results in qualitative and quantitative differences in the transformation of nutrients in the soil. This directly affects nutrient availability to crops by contributing to the nutrient pool and or indirectly influences the soil chemical and physical environment (Egrinya et al. 2001). Therefore, the forms of N present in manure affect N availability to plants; manure with higher content of immediately available ammonium offers greater short-term crop response. The N value of manure from the present study is within range of other studies. However, substantial differences between the rates of manure mineralisation have been reported elsewhere ranging from 2% to 39 % (Moral et al. 2009). Mineralisation is dependent on the rate of carbon decomposition, which is also related to the C: N ratio and structure of the organic matter (Seneviratne 2000; Nicolardot, 2001; Pansu et al., 2003; Burgos 2006). Emphasis should therefore be put on management and handling of the cattle manure for better results such as good storage and proper working on manure (Holmes 2007; Gooch and Wedel 2010) for handling can affect the fertiliser value of manure, particularly its N content. The ammonium form can be lost to the air and the nitrates leached by rainfall. However, ammonium losses can be minimized by not stockpiling manure while it is moist, minimizing its handling, and working it under immediately after spreading. It is reported that ammonia can be lost to the air each time manure is moved or hauled (Stowell and Bickert 1995). Much of the loss is from hydrolysis of the NH_2 groups (enzymatic) and then volatilization of N_20 and NH_3. This loss can be very high when spreading manure, especially during warm, dry weather. However, the release of available N from the complete organic compounds during manure decomposition is very gradual. This slow release of N extends N availability and reduces leaching of particular importance in sandy soils (http://www.ecochem.com/t_manure_fert.html).

In this study, up to 21% of N was available to the crop which is consistent with other studies where various methods including difference methods and fertiliser equivalent approach to measure nutrient availability were from 12 to 63% of dairy manure N has been estimated to be taken up by grain crops during the first growing season after application (Motavalli et al. 1989; Klausner et al. 1994; Munoz et al. 2004)**.** Nitrogen in cattle manure is mainly in the organic fraction with a low percentage in the inorganic fraction (Eghball et al. 2002; Larney et al. 2006; Adhikari and Chen 2011). Thus, the results obtained in the current study could be attributed to the type of manure applied as it was very dry with low levels of nutrients (Table 5.3). Total N content is reported to be high in fresh manure than any other type of cattle manure (Eghball et al. 1997; Larney et al. 2006), available N (Larney et al. 2006), and soil mineralisation of N is generally greater for fresh beef cattle manure (Paul and Beauchamp 1994; Eghball et al. 2002). It should however be noted that although there was low response of manure N to canola yield, inorganic N was applied two times (split application) as opposed to cattle manure which was applied once at/before sowing. This could contribute to yield difference between the two treatments. However, the low N uptake could be attributed to a number of factors including soil physical conditions, N losses from the soil, insect attack, plant disease; although this could not be ascertained as no pest or diseases were spotted during the season.

At Ucarty, in this present study, the low rainfall may have affected the amount of N mineralised for the crop uptake and this is possible one explanation for not seeing a difference in yield response between cattle manure-N at 63 DAS.

5.4.4 Relative effectiveness of cattle manure-N compared with inorganic- N during the growing season

The yield response of canola to N in cattle manure was lower than the response to inorganic-N. The relative N efficiency of cattle manure-N for canola was 0.16 for DM and 0.13 for N uptake at 63 DAS, while that for the second harvest was 0.22 for DM and 0.18 for N uptake (Table 5.6). The data indicate that the value of N in cattle manure was only about 15% that of inorganic fertiliser. However, as the season progressed, the N-value of cattle manure increased gradually to 0.18 and 0.22 for N uptake and DM, respectively, at 93 DAS. Overall, relative effectiveness of cattle manure-N compared to inorganic fertiliser-N ranged from 17% to 23% on fresh matter basis and 16% to 22% for DM and 13% to 18% for N uptake. The increased relative effectiveness of cattle manure N over the growing season could be attributed to increased levels of manure N availability following mineralisation of organic forms of N with time. This is attributed to cattle manure inclusively, improves physical and chemical properties of soil Blaise et al. 2005; Fening et al. 2010; 2011).

Nitrogen efficiency of cattle manure as a source was lower than inorganic-N indicating that N was not rapidly mineralised at the start of the season, or due to age it was already mineralised, or because of slow release of N from manure, it did not benefit the crop. However, the N efficiency slightly increased from 15% to 21% as the season progressed for each measure of crop response, implying that N from cattle manure continued to be mineralised over the season. Linear responses to application of cattle manure and inorganic N over the range 0 to 200 kg N ha^{-1}, equivalent to an additional 3.0 and 12.9 kg DM biomass per one kilogram added manure N and inorganic N, respectively were measured. Other researchers have found greater N equivalent values and higher yields from similar and or different types of cattle manure in comparison to inorganic-N fertiliser. A field study in Taiwan found that cattle manure application to rice had a 34% N value of the chemical fertiliser and a 25% N value in cabbage production. In another season, a 27% N value was found for cabbage while spring rice and summer rice gave N values of 23% and 29%, respectively (Huang and Lin 2001; Nicolardot 2001; Pansu et al. 2003; Carbrera et al. 2005). Rigby (2008) found N equivalent values ranging from 40-73 % in cattle slurry. Zhang et al.(1998) found that 2 kg of manure-N were equivalent to 1 kg of urea-N in terms of plant uptake and yield response in the first year of manure application for an irrigated corn production.

Elsewhere, application of cattle manure to soil is reported to have increased the soil available macronutrients N, P and K (Sutton et al. 1986; Lithourgidis et al. 2007). However, according to Beauchamp et al. (1982) almost 24% to 33% of the ammoniacal N of the liquid cattle manure was lost by volatilisation as NH_3 during a week after manure application to soil in early May. Beauchamp (1983) found that availability of liquid cattle manure-N to corn (*Zea mays. L*) ranged from 33 to 60% of that of inorganic fertiliser N and that injection of the manure increased its efficiency. Improved efficiency was attributed to reduced NH_3 volatilisation (Beauchamp 1983). While, Chantigny et al (2009)., reported that the proportion of applied total ammoniacal N (TAN) lost as NH_3 was 22% lower with treated than untreated liquid swine manure.

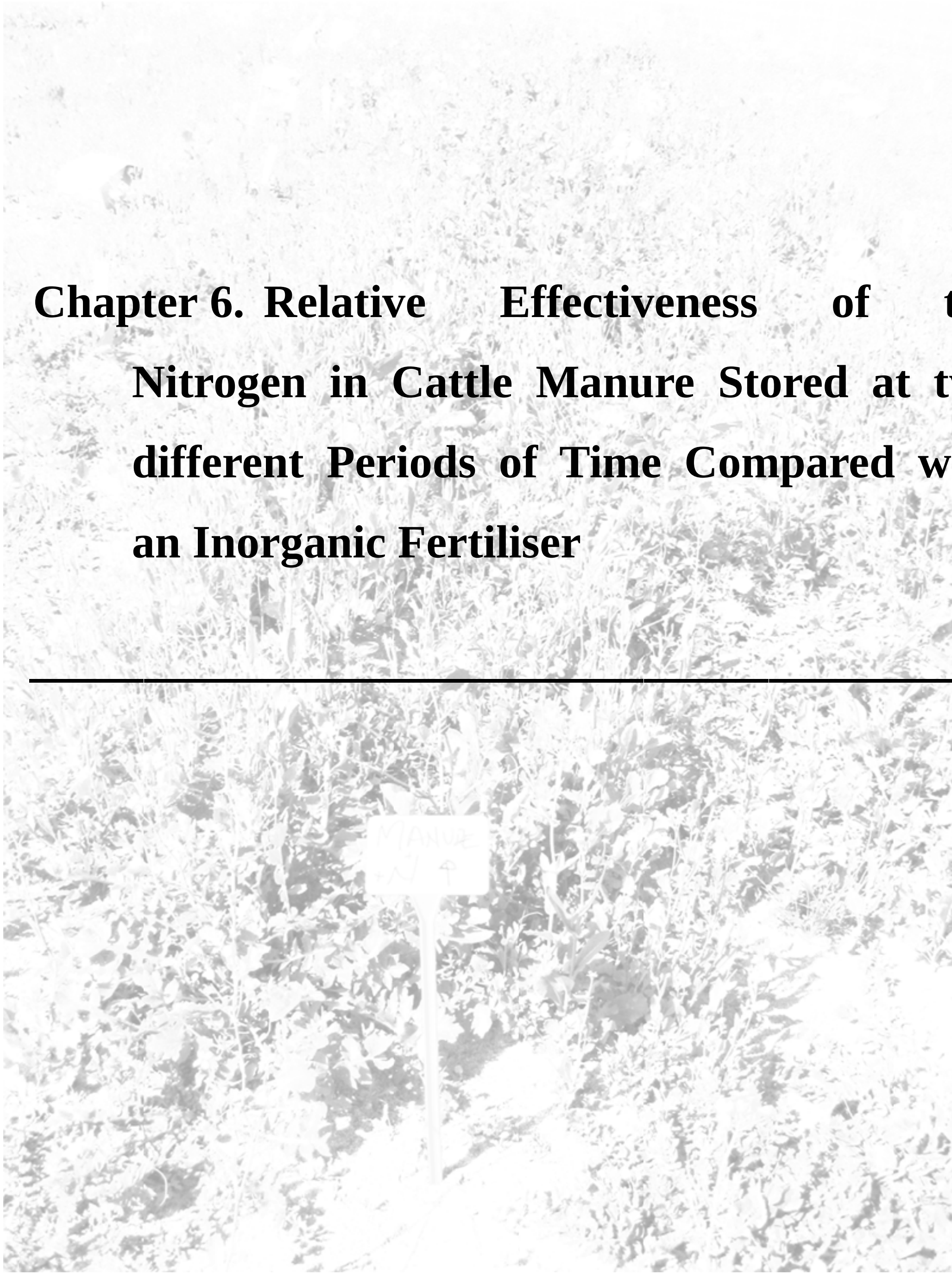
In the UK, 3.4 % organic N at Brices Field and 9.1 % organic N at North Sidelands were calculated as mineralisable N in farm yard manure (FYM) that included cattle slurry (Rigby 2008). The UK fertiliser recommendations suggest that approximately 10% of the organic N fraction is available (MAFF 2000). Laboratory incubation studies have found mineralisable N values of 6-13 % organic N from cow manure (Chae and Tabatai 1986; Chadwick et al. 2000). In other studies, N recoveries by corn ranged from 19 to 25% for dairy cattle manure (Ma et al. 1999; Cusick et al. 2006; N'Dayegamiye 2009).

A comparison of linear regression coefficients to response to mineral fertiliser N, rather than individual yield values, provides an approximation of the N equivalency across the whole response curve (Kiemnec et al. 1987; Smith and Bellett-Travers 2001; Smith et al., 2002b; Morris et al., 2003; Morris et al. 2007). This may be inaccurate if there were fewer rates of application; however, the systematic design in this study had six rates of application. Therefore, in this case, it is a more reliable estimate of average N availability over these rates of application. The linear regression curve was a good fit to the data, and may be considered more accurate to use.

5.5 Conclusions

- The field trial marked a significance step to compare the relative effectiveness of cattle manure to inorganic fertiliser as a source of N. The results indicated that aged cattle manure-N used in this experiment was 21% effective as top dressed inorganic-N (urea), and therefore approximately five times more total N equivalent in cattle manure is required to obtain comparative N uptake to urea, where all other nutrients are not limiting.
- The canola crop was able to take up more N over the season; with RE for N uptake increasing from 13% to 18% and 16% to 22% for DM production. Although, the current RE values seem to be low compared to other studies, the second field experiment will explore the effectiveness of cattle manure at two different storage periods to develop better recommendations for the Ugandan farmers especially cabbage growers, hence forming the a basis for the following chapter.

Chapter 6. Relative Effectiveness of the Nitrogen in Cattle Manure Stored at two different Periods of Time Compared with an Inorganic Fertiliser



6.1 Introduction

Soil fertility depletion in Uganda is a widespread problem, with evidence of declining soil fertility cited by farmers throughout the country (Sserunkuuma et al. 2001; Pender et al. 2004; Esilaba et al. 2005; Nkonya et al. 2005) as it is in the rest of SSA. Soil productivity can be improved using inorganic fertilisers (Bationo et al. 1998; Gruhn et al. 2000; Jen-Hshuan Chen 2008; Misiko et al. 2011) but it is an expensive venture for most smallholder farmers (Woomer and Muchena 1996; Nkonya et al. 2002; Mundus et al. 2008; U.S. Marquer 2010). Consequently, smallholder farmers use less than 1 kg ha^{-1} of inorganic fertilisers on average (Nkonya et al. 2002; FAO 2007). Invariably crop production is low due to low levels of soil productivity (FAO 2001). Smallholder farmers in SSA have resorted to cattle manure to improve soil fertility (Pingali et al. 1987; Powell et al. 1993; Mapfumo and Giller 2001; Eghball 2002 ; Kanonge et al. 2009; Nyiraneza et al. 2009); because of perceived benefits to soil health and the environment (Hulugalle et al. 2009) to replace N,P and K essential for crop growth (Sommerfeldt and Chang 1985; Chang et al. 1991; Benbi et al. 1998; Lekasi et al. 2001; 2003; Ashiono et al. 2006; GRDC 2010; Joghan et al. 2010).

Cattle manure could be directly applied to gardens, but it is common for farmers in SSA to store it in piles for periods of between 2 to 6 months prior to application in order to bulk up adequate manure for the crop. However, the effect of different storage times has not been investigated despite the fact that it is applied to crops at varying times. It is envisaged that the productivity of small-holder farming could further be enhanced if manure produced by daily cattle reared in the peri-urban areas of Wakiso and Kampala could be recycled back into the soil (Mugisa 2002). There is not enough scientific data available on the relative effectiveness of cattle manure on crop growth and yield in vegetable production particularly cabbage (*Brassica spp*) and Amaranthus *spp* in Uganda.

In recent years, with increasing cost of inorganic fertilisers, scientific interest has focused on the quality and methods of application of organic materials (Campbell et al. 1995; GRDC 2009; 2010). Some studies have examined the residual effects of cattle manure on soil properties and crop yield (Gana 2009). However, the current study examined the effect of storage and storage methods of manure on N availability required for crop production. The aim of the experiment was to determine the relative effectiveness of N in cattle manure stored for two different periods compared with inorganic fertiliser N. This was necessary for developing economically viable practices that can maximize and sustain the productivity of smallholder agriculture.

6.2 Materials and methods

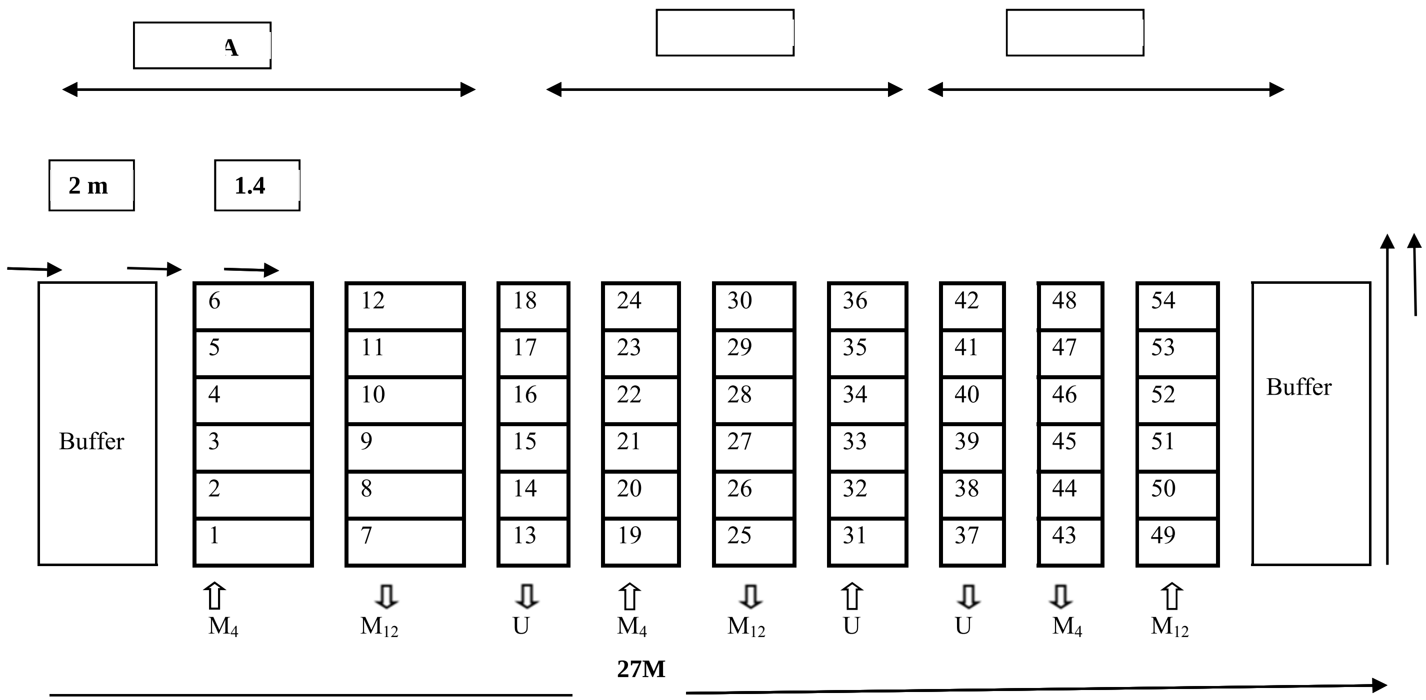
6.2.1 Experimental design

A systematic design (Cleaver et al. 1970; Greenwood et al., 1980a; 1980b; Smith and Hadley, 1988; Smith and Bellet-Travers 2001; Smith et al. 2002b; Morris et al. 2003; Rigby 2008) as described in 5.3.1 was used with three treatments arranged as three replicate blocks to give a total of 54 plots. Each plot measured 2 m wide x 12 m in length with a buffer control plot placed at each end of the site. A diagram of the 2010 experiment is given in Figure 6.1; the main plots were divided into 6 subplots, each $4m^2$.

6.2.2 Site history, climate and soil type

Details of the site location is given in Section 5.3.2. Weather data, including rainfall and air temperature were collected at the sites daily as described in section 4.3.5. The experiment was located adjacent to the 2009 site at Goomalling, Western Australia. This was purposely to compare the crop response of treatments by cattle manure stored for two different periods of time and inorganic-N (Urea) application in similar soil and climatic conditions. The soil properties of the site are described in Section 5.2.3.

Figure 6.1: Treatment allocation of the field trial, 2010



Ucarty Collins Farm

Key;

Treatments

M_4 = Cattle manure stored for 4 months ; M_{12} = Cattle manure stored for 12 months; U = Urea; and

= Gradient

6.2.3 Treatments

The field experiment comprised three treatments; cattle manure stored in the open for a period of four months and twelve months and an inorganic fertiliser source; applied at six rates each. Cattle manure was classified as M_4 and M_{12} for manure stored for a period of 4 months and 12 months, respectively, and urea as inorganic-N fertiliser. The N content of the cattle manure measured 1.31% N and 1.18% N for M_4 and M_{12}, respectively, while urea was 46% N. Six treatment rates were derived for cattle manure based on the N requirement to provide equal total N (kg ha^{-1})as in inorganic fertiliser. The amount of cattle manure as a source of N that would give a maximum rate of 200 kg N ha^{-1} was calculated on 90% DM (Table 6.1).The % indicated in Table 6.2 refer to the specific amount of N that was applied as different treatments in kg ha^{-1}. All treatments were applied at N rates of 40, 80, 120, 160 and 200 kg ha$^{-1.}$ The contents of the cattle manure were determined by drying overnight at 105^{o}C in a forced air oven. To ensure a response to N on this site, basal amounts of all nutrients were applied.

Table 6.1: Treatment allocation for rates of nitrogen supplied by cattle manure and urea in 2010

	Source		
Rate N ha^{-1}	**M_4**	**M_{12}**	**Urea**
0	0	0	0
40	3000	3400	87
80	6100	6800	174
120	9200	10200	261
160	12200	13600	348
200	15300	16950	435

Manure samples were collected from manure heaps at a depth of 45 cm from the surface of the heap (Lekasi et al. 2001) and were analysed for total N accordingly by ChemCentre, Bentley.

6.2.4 Fertiliser application

Cattle manure

Air dried and stock-piled aged cattle manure (M_{12}) and four month stored cattle manure (M_4) were selected to be typical of the manure applied by smallholder farmers in Uganda (Table 6.1).

Care was taken to collect samples which were representative of the manure properties, for example when the manure was solid, which was stored in a pile; the sample was taken from below the top layer and from several locations. Both manure samples were collected on the day of application. Analytical properties of the M_4 and M_{12} subsamples are given in Table 6.2.

Table 6.2: Dry matter content, total, and mineral concentration of nitrogen in cattle manure applied in the 2010 field experiment

Analysis	**Amount**		
		Type of cattle manure	
Dry matter content (90 %)		**M_4**	**M_{12}**
Total N (%)	-	1.31	1.18
NH_4-N (mg kg^{-1})	-	0.01	0.01
NO_3-N(mg kg^{-1})	-	0.01	0.03

ChemCentre report # 09A0508: Total N by combustion; nitrate-N and ammonium-N by SFA. Cattle manure oven dried and reported as percent dry basis, mg kg^{-1}.

Application of basal nutrients

To ensure nutrients besides N were adequate for plant growth, basal nutrients were applied prior to seeding as follows: double superphosphate (588.2 kg ha^{-1}), copper sulphate (6.7 kg ha^{-1}), zinc sulphate (13.3 kg ha^{-1}), gypsum (12.5 kg ha^{-1}) and manganese sulphate (120 kg ha^{-1}). All basal nutrients were mixed together and incorporated using a disc plough working across plots.

Inorganic nitrogen application

Inorganic-N calibration plots were established, using urea applied at rates described in 6.2.3. Inorganic N was broadcasted and incoroporated in the soil using a disc. The inorganic-N fertiliser control was included, so that N equivalency values could be calculated, using the statistical methods described in Section 5.2.8.

6.2.5 Seeding

Canola (*Brassica napus*) was top-dressed by hand sown at rate of 6 kg ha^{-1} at the start of growing season on 26 May 2010 and incorporated to a maximum depth of 3-4 cm by disc plough. Canola was selected as an indicator crop for this experiment, as being in the Brassica *genus*; it is similar to cabbage, which is a widely grown vegetable in Uganda. It is suitable for the climate in addition to its efficiency at capturing high amounts of plant available N like leafy vegetable crops including cabbage. Canola was also used in the N experiment at Goomalling (Chapter 5) so this allowed direct comparisons to be drawn between years. The choice of an indicator crop permitted an absolute N equivalency value to be determined from which the fertiliser value of the material under different application regimes can be predicted. Field trials are a good measure as they depict the real life situation of the farmers, thus, the trial should be replicated in Uganda.

6.2.6 Site management

Similar management practices as described in 5.2.5 were carried out. However, during the 2010 experiment, Amor chemical was applied seven weeks after planting for grass control at 150 mL ha-^{1} and a few plants hand weeded as they emerged. To allow canola to establish, care was taken not to disrupt the root system while hand picking. There was little weed competition during the season. As in the previous experiment of 2009, an electric fence was erected to exclude rabbits and grazing animals.

6.2.7 Plant density and shoot dry matter

At 30 DAS, plant establishment counts were made from four, randomly located, 0.25 m^2 quadrants per plot. Samples of canola were obtained as described in 5.2.6. Shoot DM was determined at 70 and 100 DAS. Fresh weights were measured and then plant tissue was dried to a constant mass at 70^{0}C for 48 h in a forced-air oven. Similarly, the average plant density for each plot was used to determine DM g m^{-2}. Yield components were determined at harvest on every plot.

6.2.8 Plant tissue nutrient analysis and N uptake

The plant samples were ground to pass through a 1.0 mm sieve and analysed for total N as described in section 5.2.7. Similarly, N uptake by the canola crop was determined by multiplying the DM yields with the N concentration in the DM shoots as explained in Chapter 5, with the regression coefficients of plant N uptake measurements in the former yields on both manure N treatments compared with coefficients of N uptake on the inorganic-N treatments to calculate the fertiliser equivalent values of the mineralised organic N from the manure under two storage times (Figures 6.3).

6.2.9 Data analysis

Means were compared with the Bonferroni multiple comparison t tests for fertiliser treatments. Data were analysed with an analysis of variance (ANOVA) (GenStat Procedure Library Release PL21.1) (Payne et al. 2011)with single degree of freedom contrasts to determine treatment differences. Treatment means found to be significantly different from each other were separated by Least Significant Differences (LSD) at $P < 0.05$; i.e. the significance of the treatment effect was determined using the F -test and the difference between the means of the three treatments; least significant differences (LSD) were estimated at the 5% probability level. The aim of the ANOVA was to determine whether N type (whether 4 or 12 month stored cattle manure) had significant effects on crop growth and yield compared with inorganic fertiliser. Post-hoc tests were performed to further examine the effects of cattle manure on yield using the Bonferroni adjustment testing procedures. Fresh and dry weight yields of canola and N uptake in relation to N from both stored cattle manures were statistically analysed by linear regression analysis and compared with yields from inorganic N calibration plots. All ANOVA tests were carried out as described in 4.3.8. Similarly, linear regression coefficients for the cattle manure treatments were expressed as a proportion of the regression coefficient for inorganic N to obtain RE values for the two types of cattle manure, which were then repeated for DM yield and N uptake measurements.

Nitrogen availability in manures may be expressed as Plant Available Nitrogen (PAN) or as a percentage of total N applied (Gilmour et al. 2003; Gale et al. 2006; Sullivan 2008) Evanylo 2010). Alternatively, N availability may be expressed in relation to the amount of inorganic N available in inorganic fertiliser N reference treatment (Kiemnec et al. 1987; Jackson et al. 1997; Nicholson et al. 1999; Mutuo et al. 1999; Smith and Bellett-Travers 2001; Smith et al. 2002b; Morris et al. 2003). This relative N fertiliser value is referred to as an N equivalency value or Nitrogen Fertiliser Replacement Value (NFRV) (Schröder et al. 2007; Lalor et al. 2011).

Calculation for the corresponding N fertiliser equivalent for an organic material was obtained from the linear equation ($y = a + bx$) exhibited by the N response curves following a Mitcherlich equation; where y is the yield or N uptake (kg ha^{-1} fresh or dry matter or kg N ha^{-1}).

The response of canola to application of urea, M_4 and M_{12}, measured as fresh and dry shoot yield and N uptake is shown in Figures 5.3-5.6. The crop response was plotted against rate of total N application in the manure (M_4 and M_{12}) and urea, where crop response was plotted against rate of application (DS kg N ha^{-1}). Where a significant linear relationship between rate of application of N (M_4, M_{12} and urea) and crop response was found, r^2 and P-values from an ANOVA test of significance are graphed. A summary of r^2 values and regression coefficients for the measures of crop response for each treatment is given in Table 6.4. Nitrogen equivalency values for the M_4 and M_{12} relative to urea fertiliser control are shown in Tables 6.6. Canola was harvested at 100 DAS, one week longer, than the 2009 season, which was at 93 DAS before maturity as the focus of the experiment was on vegetative growth to compare with cabbage.

6.3 Results

6.3.1 Weather conditions

The growing season (May-October) followed a six-month dry spell, with 237 mm rainfall recorded for the year. This was lower than the 2009 season. The trial was sown into dry conditions on 26 May 2010. After two days, this was followed by 33 mm of rain with a further 24 mm of rain recorded for the month of June. Although the amount of rainfall received was lower and remained in the same range over the season, it aided crop establishment during the early emergency of the crop. Rainfall continued to be below average for the region, with September and October being the driest on record with only 6 mm and 2.4 mm of rainfall recorded, respectively. July recorded the highest rainfall of 46.5 mm. Vegetative growth was not vigorous over the season and dry September conditions subsequently affected the growth and performance of the crop. The lowest minimum and lowest maximum temperatures during the crop growth of -1°C and 22°C, respectively, were recorded in July. The total monthly rainfall highlighted the dry conditions, and mean monthly temperatures are shown in Figure 6.2.

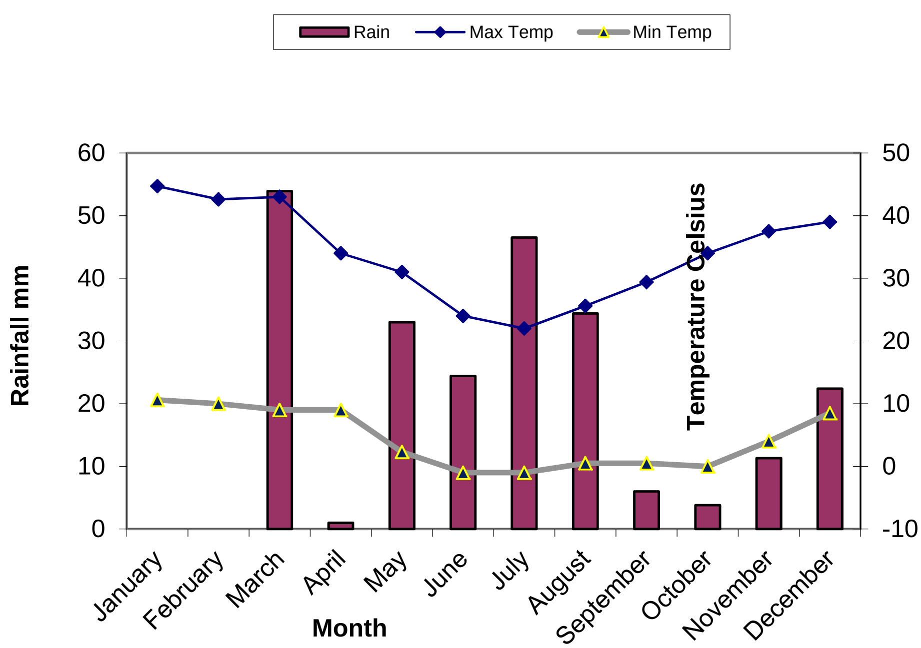


Figure 6.2: **Total monthly rainfall, mean monthly, maximum and minimum temperature at Ucarty, Western Australia in 2010.**
Rainfall is the cumulative for each month while temperature is the mean for each month

6.3.2 Plant establishment and development

Crop establishment figures were based on plant counts taken 30 DAS. Treatments had no significant effect on plant establishment (P=0.79) with mean canola establishment of 42 plants m^{-2}. The mean plant density was used to calculate the DM of canola shoots. Poor growth and development were observed (Plate A-1) where no N was applied compared with the highest rates of N (Plate A2). Plant development was variable in all manure treatments compared to urea treatments, consistent with uneven mixing of manure into the soil. However, random sampling of plants ensured that representative plants were collected for analysis.

The growth of shoots in M_4 treatments was not as vigorous as those of urea treatment plots, where good growth was observed at 30 DAS at its highest rates of application. There were high plant numbers that were vigorous and healthy in the highest rates of urea treated plots compared to similar rates of M_4 treated plots. Despite the dry conditions, there was general improvement of plant growth in both treatments particularly in high N loadings of M_4 and urea with remarkable growth rates observed in top dressed urea compared to M_4 treatments.

Crop response to twelve month stored cattle manure showed a linear relationship with increasing rate of application. Plant growth improved as N loadings increased in the highest rates but not as much as in both inorganic-N (urea) and cattle manure (M_4) treated plots that showed a greater response ($P \leq 0.001$) than M_{12} as a source of N.

6.3.3 Dry matter accumulation

The seasonal DM of canola shoots showed a positive response to increasing rates of both cattle manure (M_4 and M_{12}) and inorganic N (urea). Plant growth improved as N loadings increased, irrespective of the N source, with top dressed urea showing a greater rate of response than cattle manure treatments (Figures 6.3 and 6.4). Detail results are in Appendices A6 and A7.

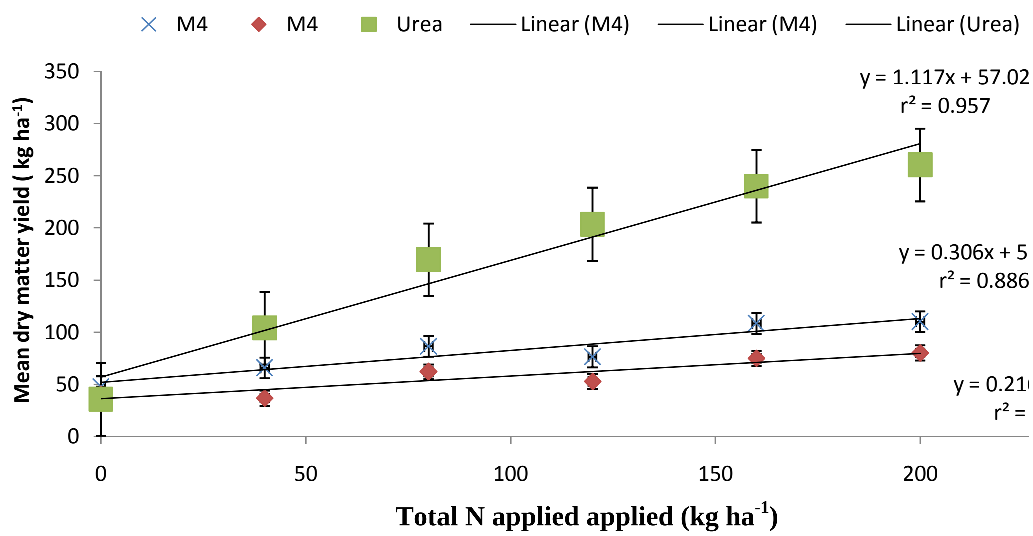


Figure 6.3: Mean dry matter yield (kg ha^{-1}) in relation to rate of total N application in inorganic-N (urea), cattle manure-N at 4 months (M4) and 12 months (M_{12}) with regression equation and standard errors at 70 DAS.

Values are the means of three replicates. Line plotted using Microsoft Excel. Vertical bars denote LSD (P = 0.05) for data from all treatment means.

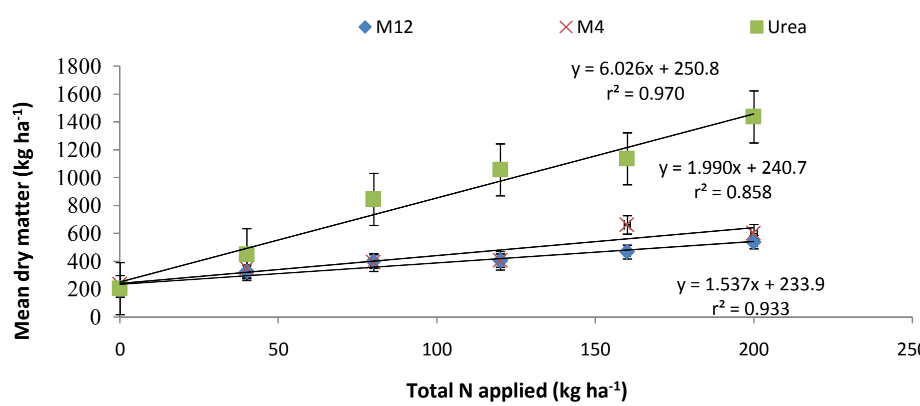


Figure 6.4: Mean dry matter yield (kg ha^{-1}) in relation to rate of total N application in inorganic-N (urea), cattle manure-N at 4 months (M_4) and 12 months (M_{12}) at 100 DAS with regression equation and standard error bars.

Values are the means of three replicates. Line plotted using Microsoft Excel. Vertical bars denote LSD (P = 0.05) for data from all treatment means.

DM yield of canola production from M_4 and M_{12} treatments were below that of the urea control but increased over the two successive harvests during the season. However, the results indicate that 160 kg N ha^{-1} of M_4 produced 108 kg ha^{-1} DM whereas 40 kg N (urea) yielded 104 kg ha^{-1} DM. Significant differences in DM were measured between the M_4, M_{12} and urea treatments ($P<0.001$) for any of the two consecutive harvests. The production started increasing at the third rate of M_4 and but did not become as high as that of the urea where yields increased when N reached 200 kg N ha^{-1}at both sampling dates.

Similarly, there was a significant difference among blocks and the treatments ($P<0.001$). Combined effects of block and treatment were also significant ($P=0.012$). According to the results of Duncan's multiple range test (DMRT), all M_4 treatments produced much less than urea when dosage was less than 160 kg N ha^{-1}at 70 DAS (Appendix A6). DM production at 120 kg N ha^{-1} showed no difference from urea control treatment ($P=0.05$); however, it became significantly ($P<0.001$) higher in urea than M_4 treatments when rates reached 160 kg N ha^{-1} and 200 kg N ha^{-1}. As expected, the results show that the production of canola had better response to the increase in urea dosage than both the M_4 and M_{12} as sources of N.

There was a less response to M_{12} as at 70 DAS compared to the urea but not significantly different to M_4. At 70 DAS increasing the rate of M_{12} from 0 kg ha-^{1} to 40 kg ha-^{1} resulted in low DM yield; 36.7 kg ha^{-1} compared to 40.5 kg ha^{-1} in the nil N rates and almost equal to the non treated plot of urea gradient. However, the DM yield for M_{12} plots at final harvests was significantly ($P<0.001$) increased. In comparison to urea, the recorded maximum DM yields were 80 kg ha^{-1} and 537 kg ha^{-1} for M_{12} and 260 kg ha^{-1} and 1436 kg ha^{-1} for inorganic-N (urea) at 70 and 100 DAS, respectively. Overall, the results show that there was a positive relationship between total N applied and DM yield by canola regardless of the source of N.

6.3.4 Nitrogen uptake

The concentration of N in the DM of whole shoots of canola showed a positive response to increasing levels of N. During the season, mean concentrations of N in shoot DM declined with overall means as follows; 3.42% (lsd=0.805) and 2.6% (lsd=0.942) for 70 and 100 DAS, respectively. The N concentrations were below the critical concentration required for maximum yield based on equivalent growth stages (Reuter and Robinson 1997). The mean total N uptake by canola shoots increased with increasing rates of all treatments (inorganic N, M_4 and or M_{12}) at all sampling dates (Figures 6.5 and 6.6). There were significant differences in N uptake at 70 ($P<0.001$) (lsd = 2.679) and 100 ($P<0.001$) (lsd =7.924) DAS between inorganic N, and cattle manure N (M_4 and M_{12}) at comparable N loadings. N uptake were greatest from inorganic N plots (54.5 N kg ha^{-1}), followed by M_4 (18.7 N kg ha^{-1}) and least from M_{12} cattle manure (15.9kg N ha^{-1}) at 100 DAS. However, nitrogen uptake in either of the treatments at the highest rate of inorganic N and cattle manure N (M_4 and M_{12}) did not plateau. Inorganic N treatment displayed high N uptake compared to the latter at the highest rates ($P < 0.001$).

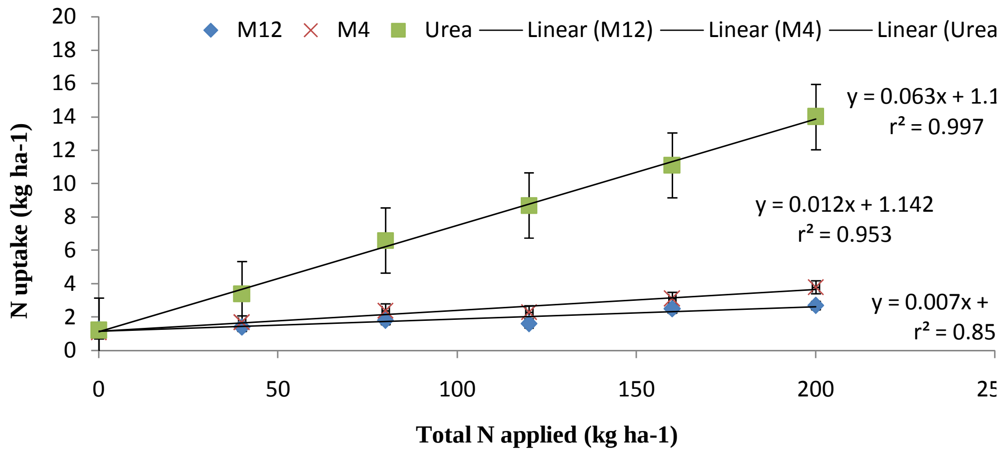


Figure 6.5: Relationship between total N uptake in canola shoots and the level of N applied in inorganic and cattle manure at 70 DAS

Values are the means of three replicates. Line plotted using Microsoft Excel. Vertical bars denote LSD (P = 0.05) for data from all treatment means.

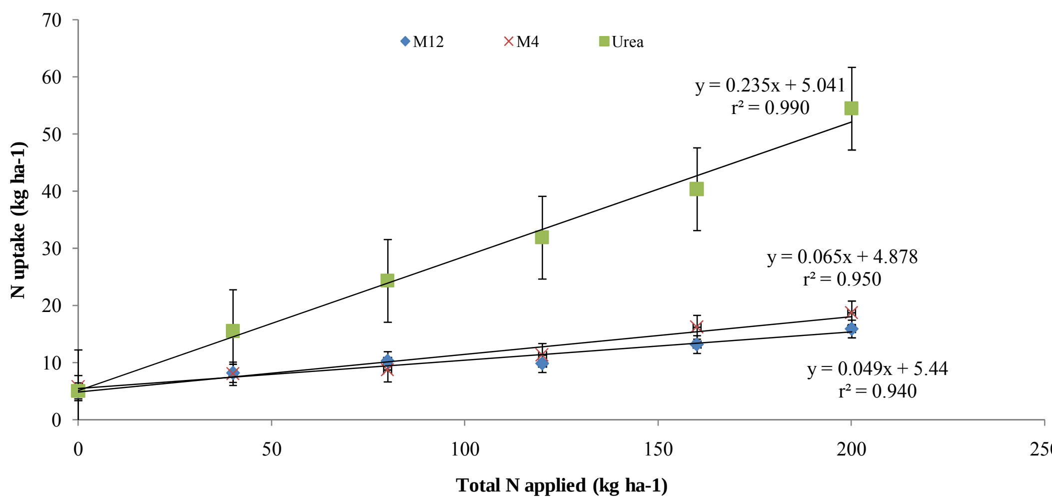


Figure 6.6: Relationship between total N uptake in canola shoots and the level of N applied in inorganic and cattle manure at 100 DAS

Values are the means of three replicates. Line plotted using Microsoft Excel. Vertical bars denote LSD (P = 0.05) for data from all treatment means.

6.3.5 Relative effectiveness of cattle manure-N compared with inorganic-N during the growing season

The values for Mitscherlich coefficients for fresh, DM production and N uptake over the two sampling dates are presented in Tables 6.4 and 6.5, and were used to calculate the N equivalency values. The manure fertiliser equivalent values were derived from a comparison of crop yields on the manure treatments with inorganic fertiliser N response curves as described in section 5.2.8. The modelled values accounted for 64%, 49% and 74 % of the variance in the experimentally derived results, with the slopes of the fitted linear regressions being 0.3065, 0.2161 and 1.1174 at 70 DAS and 63 %, 71% and 89% with slopes of 1.9925, 1.5388, and 6.0245 at 100 DAS. Significant responses to manure storage times (M_4 and M_{12}) were in the 2010 final harvests, resulting in N equivalency values of 0.33 and 0.26 for DM and 0.28 and 0.21 for N uptake, for M_4 and M_{12}, respectively.

The coefficients for urea demonstrated that N application contributed to the crop response despite the dry weather. The coefficients for urea were greater than for M_4 and M_{12} for all three measures of crop response. Nitrogen equivalent values for the two manures at 70 DAS and 100 DAS are given in Table 6.5. Nitrogen equivalency value calculated for M_4 treatment demonstrated a significant relationship ($P<0.05$) between rates of N application and crop response obtained by comparing linear regression coefficients with urea as described in section 5.2.8 and 5.4.4.

Table 6.3: Linear regression coefficients and r^2 values for cattle manure-N (M_4 and M_{12}) and inorganic-N (urea) fertiliser at 70 DAS

	Fresh weight		**Dry weight**		**N uptake**	
	Slope	**r^2**	**Slope**	**r^2**	**Slope**	**r^2**
M_4	4.4883	0.73	0.3065	0.64	0.0125	0.69
M_{12}	3.22	0.62	0.2161	0.49	0.0072	0.45
Urea	17.776	0.77	1.1174	0.74	0.0635	0.81

Table 6.4: Linear regression coefficients and r^2 values for cattle manure-N (M_4 and M_{12}) and inorganic-N (urea) fertiliser at 100 DAS

	Fresh weight		**Dry weight**		**N uptake**	
	Slope	**r^2**	**Slope**	**r^2**	**Slope**	**r^2**
M_4	13.409	0.70	1.9925	0.63	0.0659	0.68
M_{12}	10.900	0.65	1.5388	0.71	0.0496	0.64
Urea	45.383	0.92	6.0245	0.89	0.2354	0.88

The RE for cattle manure-N stored for (M_4) compared with inorganic-N (urea) was 25% for fresh shoot weight, 27% for DM yield and 20% for N uptake at 70 DAS and 30% for fresh shoot weight, 33% for DM yield and 28% for N uptake at 100 DAS. The relative N values were 18% for fresh shoot, 19% for DM yield and 11% for N uptake at 70 DAS and 27% for fresh shoot, 26% for DM yield and 21% N uptake at 100 DAS for M_{12}. Nitrogen from cattle manure M_{12} became more available as the season progressed. However, the results indicate that the values were lower than four month stored cattle manure (M_4). Overall, the effectiveness of cattle manure-N compared to inorganic N (urea) increased as the season progressed to achieve values of 33% and 26% in M_4 and values of 28% and 21% for M_{12} for D harvests and N uptake at 100 DAS, respectively. Urea was more effective as a source of N than comparable N loadings for either M_4 or M_{12} as indicated by RE for fresh weight, DM and N uptake (Tables 6.4-6.5).

Table 6.5: N equivalent values of cattle manure for each measure of response (fresh yield, dry yield and N uptake) on comparison of linear regression coefficient with inorganic N fertiliser during the season.

Source	Days after sowing (DAS)				
	Yield/parameters				
	DAS	**Fresh**	**Dry**	**N uptake**	**Mean**
M_4	**70**	0.25	0.27	0.20	0.24
M_{12}		0.18	0.19	0.11	0.16
M_4	**100**	0.30	0.33	0.28	0.30
M_{12}		0.24	0.26	0.21	0.23

6.4 Discussion

6.4.1 Effect of cattle manure-N on plant shoot growth and development

Canola was satisfactorily established on the plots in May 2010 with the germination rate observed from 5 to 10 DAS, showing no significant difference between cattle manure (4 month and 12 month stored cattle manure) and urea N treatments as sources of N (P=0.79). The overall germination rate was not as high as expected (60%); attributed to early low rainfall, and didn't change over time (30 DAS). Growth of canola was more responsive to urea than manure treatments.

The lower growth rates in M_4, and M_{12} treatments compared to urea at similar rates of total N could be attributed to slow release of N in manure. Cattle manure releases N slowly and in response to environmental factors, such as soil moisture and temperature, and in response to the effects of these factors on microbial activity in the soil, unlike chemical fertilisers that release nutrients rapidly with less dependence on environmental factors other than water supply and perhaps temperature (Langmeier et al. 2002; Stewart et al. 2005; Barker, 2010; Mallory et al. 2010). Inadequate supply of available N frequently results in plants that have slow growth, depressed protein levels, poor yield of low quality produce, and inefficient water use (Mikkelsen and Hartztter 2008). Growth vigour affects other parameters such as DM production and yield (Amudalat et al. 2006). The direct effect on vegetative growth as observed in this study had been reported for vegetable crops such as Amaranthus spp (Olufolaji and Tayo 1980; Amudalat et al. 2006).

With crops that are grown for their vegetation such as spinach, cabbage, Amaranthus *spp*, lettuce and celery, the promotion of vegetative growth by N is a favourable response. Therefore N should be available to crops for efficient and profitable crop production (Mikkelsen and Hartztter 2008). Haynes et al.(1991), Dick (1992) and Edmeades (2003) report that application of manures contains significant amounts of organic N and more efficiently increase soil N (N'dayegamiye and Côté 1989; Smith et al. 2003; Lekasi et al. 2003; N'Dayegamiye 2009; Nyiraneza et al. 2009), which results in more fixation of applied N in soils. However, they noted that the extremely low available P content in soil may greatly inhibit crop growth, which in turn reduces crop-based N uptake and thereby organic N input into the soil. However, basal nutrients including P were applied to the experiment. These are important for sustained maintenance of soil fertility and plant growth.

6.4.2 Relative effectiveness of nitrogen from stored cattle manure compared to inorganic N during the season

The rates of N applied ensured that an N response was achieved. At 100 DAS, RE of M_4 and M_{12} compared with urea increased as the season progressed, as shown by seasonal fresh weight, DM yields and N uptake (Figures 6.3 and 6.6). The RE of M_4 and M_{12} compared with top-dressed urea ranged from 25%-30% for fresh weight, 27%-33% for DM yield and 20% -28% N uptake at 70 DAS and 18%-27% for fresh weight, 19%-26% for DM yield and 11%-21% for N uptake at 100 DAS, respectively, over the season.

The progressive increases in RE in stored cattle manures may be due to a number of factors including N in cattle manure becoming more available with time, the manure N being accessed more effectively by larger plant roots , increased soil moisture and or higher rates of N responding to lower levels of soil N (Table 5.1). However, there was no evidence to suggest that lower soil N contributed to improvement in percentage RE during the season since soil tests were not conducted after the conclusion of the experiment.

Barker (2010) report that if a single application of cattle manure is made, about 50% of N would be available during the current crop year, with about 8% being available in the first following year, 5% and 4 to 8% (Powell et al. 2005) in the following year, 2% in the third following year, and 1% in the fourth subsequent year. However the actual composition and release rates in the cattle manure will vary according to weather and climate, the specific origin of the manure, and how the manure is handled, processed and stored (Havlin et al., 2005; Gichangi et al. 2006; Barker and Pilbeam, 2007; Barker 2010; GRDC 2010) and the diet of the animal (Kemppainnen 1989; Mugwira and Murwira 1997).

Contrasting the two field experiments; Figures 5.5 and 6.6 indicate that the N uptake efficiency at 40kg/ha of urea was about 50% this is about average for crops in WA as measured by Fillery and Maclines (1992) during the 2009 experiment.However, there was considerable less uptake efficiency in 2010 experiment (about 25%), presumably due to the low rainfall; this is further evidence that low rainfall was probably not a factor in 2009.

The best handling for conservation of nutrients in manures is to apply freshly excreted manures to fields and to incorporate the manures into the soil immediately after application Eghball et al. (2002); Lekasi et al. (2003); Gichangi et al.(2006); Reijs et al. (2007); Gachimbi et al. (2009) and Baker (2010) recommend that manure from piles should be handled as fresh manure and turned under as soon as it is spread to avoid further N losses. However, these practices are not feasible for labour may not be available particularly for smallholder farmers. Time between application and incorporation also affects the relative value of cattle manure N on increasing yields of crops at rates of 100%, 85%, 75%, 70%, 55% and to less than 50% level from 0, 6, 24, 48, 96 and 336 (2 weeks) hours being the time that manures lie on surface until they are incorporated to soil (Barker 2010). In addition, cattle manure is reported to have N effectiveness index of 80 %, 55% and 50 % when piled for 2 days, 14 days and 30 days, respectively (Gunnerson and Stuckey 1986). As cattle manure (M_{12}) in this study had been piled or stored for a longer period (12 months), most of the readily decomposable components such as sugars, starches, and proteins (Brady and Weil, 2002) are expected to have been lost through volatilization and leaching (Dewes 1995). In addition, the samples collected for the trial potentially had a smaller pool of mineralisable N consistent with Rigby (2008) and Barker (2010). This suggests that storage influences the ability of cattle manure to release N and so the varying N equivalent values.

In the manure-based system, it is reported that there are temporal patterns of N availability that are more synchronous with early season crop needs than in the fertiliser based system and mineralisation continues even after harvest (Mallory et al. 2010). Therefore, more manure N was expected to be mineralised if the trial reached maturity suggesting that manure is an effective source of N. Different N values from field and laboratory studies have been documented and listed in Table 6.6 for comparison purposes.

Table 6.6: First-year N availability/N effectiveness index for different cattle manures

Manure type	Crop	RE %	Reference
Dairy manure		24	Hart 1963
Fresh manure		3	Idnani and Varadaraj an 1974
Cattle solid		30-50	Rajabapaia et al. 1979
Fresh manure		40	Hashimoto and Chen 1981a
	Corn	25	Klausner and Bouldin 1983
Dairy manure		30-50	Vetter and Steffens 1988
		31- 63	Motavalli et al. 1989; Klausner et al 1994
	Incubat	35	Klausner 1997; Van Kessel and Reeves 2002
	Barley	25-37	Glendining et al. 1997
Spring Slurry	Cereals	24-58	Chambers et al. 1999
Autumn Slurry	Cereals	3-30	Chambers et al. 1999
Solid FYM	Silage	4-32	Chambers et al. 1999
Dairy solids		0-20	Bary et al. 2000
Un-composted yard trimmings		10-30	Sullivan et al. 1998
Dairy sludge/slurry		20-30	Harter et al. 2002
Dairy lagoon water	Corn	40-50	Harter et al. 2002
Dairy mechanical screen solids	Corn	10-20	Van Kessel and Reeves 2002
Aerobically composted cattle (finished or mature)	Corn silage	0-10	Harter et al. 2002; Van Kessel and Reeves 2002
		55	Van Kessel and Reeves 2002
	Corn	25	Leikam and Lamond 2003
Dairy solids	Corn	9	Gale 2005
Diary lagoon slurry		40-70	Gale et al. 2006 ; Andrews and Foster 2007
Dairy solids	Corn simulation	39%	Gale at al. 2005
	Corn	21	Powell et al. 2005
	Grass	25	Ketterings et al. 2005
Solid manure	Silage	35	Ferguson et al. 2005
Composted	Silage	25	Ferguson 2005
	Corn	25	Ketterings et al. 2005

Note:

RE: Relative efectiveness

Table 6.6 cont

Manure type	Crop	RE %	Reference
Solid manure		10-50	Gale et al. 2006
	Corn	25	Laboski et al. 2006
Table 6.6 cont			
	Vegetable	25	Laboski et al. 2006
Dairy mechanical screen solids	Corn silage	10-20	Sullivan 2008; Heinrich 2009; Pettygrove et al. 2009
Aerobically composted cattle manure	Corn silage	0-10	Sullivan 2008; Heinrich et al .2009; Pettygrove et al. 2009
Dairy lagoon water	Corn	40-50	Pettygrove et al.2009
	Corn	13	Mikkelsen and Hartz 2008
	Wheat	13-25	Powell and Russelle 2009
	Corn	8–11	Mallory et al. 2010
Solid manure	Barley & potato	46 -59	Mallory et al. 2010

Other studies suggest higher RE values of cattle manure N than obtained in the present study: from 40% to 70% as effective as inorganic sources of N especially cattle manure slurry (Table 6.6).Throughout the two years of this study, the soil remained dry for extended periods. The dry conditions were due to low opening rains and below average rainfall. Thus, climatic differences need to be taken into account when comparing data from elsewhere that may cite higher RE values. The region is characterised by a dry temperate climate as described in section 5.3.2. In addition, uneven distribution of rainfall would be experienced in the field.

Elsewhere, variability of manure N mineralisation has been reported by Pettygrove et al. (2009) which may explain varying RE values. The actual rate of mineralisation is determined by several factors including animal diet, age of manure, and soil temperature and moisture content. Mineralisation is more rapid in warm, moist soils and slower in soils that are cold or dry. Even under uniform soil and environmental conditions, manures from the same animal species can display a wide range of N mineralisation rates. In an 8-week laboratory study of 107 solid and liquid dairy manure samples, N mineralisation for most samples fell between 10 and 20% of initial organic N. However, mineralisation for some samples exceeded 50% of organic N while for others was less than zero, indicating N immobilization (Van Kessel and Reeves 2002).

With varying weather conditions between Uganda and WA, the former may experience greater mineralisation rate than the latter. This needs to be considered when calibrating the SYN model in addition to the information required for its adaptation as highlighted in section 3.4.7. For instance, in comparison to the two countries , the actual mean temperatures in the growing season in Uganda are 25^{0}C and 15^{0}C in WA.

Other researchers (Gale et al. 2006; Heinrich 2009) have found that manures and other organic materials can be grouped into categories displaying similar N mineralisation rates based on how the materials were produced, treated, and stored. In laboratory incubation studies, Heinrich (2009) observed some consistency in N mineralisation rate within types of dairy manure (fresh manure, corral manure, separated solids, windrow compost, lagoon water, and lagoon sludge). These values are in approximate agreement with Oregon State University manure N Mineralisation guidelines (Harter et al. 2002; Sullivan 2008).

6.4.3 Canola response to cattle manure application compared to other crops

The rate of N had a significant effect on DM yield at 70 and 100 DAS ($P<0.001$). Significant differences occurred between the N treatments and the nil rates. The response of dry matter production was not as pronounced as in earlier studies on canola and Indian mustard by Hocking et al. (1997) and Hocking and Stapper (2001). This could be attributed to stress on the crops due to lack of moisture.

Canola DM yields were between 537, 670 and 1436 kg DM ha^{-1} for M_{12}, M_4, and urea, respectively, at equivalent rate of 200 kg N ha^{-1}. Total canola DM production was significantly ($P<0.001$) higher in plots amended with M_{12} and M_4 manure receiving rates of 160 kg N ha^{-1} but lower than inorganic (urea) fertilised plots. These results corroborate those of other researchers who have reported varying yields in various crops after manure application compared to sole inorganic application. For example, Kanonge et al. (2009) reported 3.6 and 3.87 t ha^{-1} for cowpea and soybean yields, while Mugendi et al. (2010) obtained 4.1 t ha^{-1} of maize following cattle manure application. Others include Zingore (2011) 1.8 t ha^{-1} of maze, Negassa et al. (2005), 5.9 t ha^{-1} of maze, Edmeades (2003) 6 t ha^{-1} of maize, 5.6 t ha^{-1} wheat and 12.2 t ha^{-1} of pasture, Mucheru-Muna et al. 2007 obtained 4.5 t ha^{-1} of maize and Glendining et al. 1997 recorded 7.1 t ha^{-1} of barley.

6.4.4 Options for fertiliser nitrogen application

Rising fertiliser prices and a desire to improve soil health have increased grower interest in the use of alternative inputs for crop production (GRDC 2010). In Uganda, as transporting fertilisers from the nearest seaport involves considerable expense, the use of mineral fertilisers is extremely low (1 kg h^{-1}) (Nkonya et al. 2002). However, organic recycling practices such as mulching, composting and manuring are well known in Sub-Saharan Africa (Yamoah and Grosz 1988; Pali et al. 2003; 2005; Gichangi et al. 2006; Zake et al. 2005; Gichangi et al. 2006). Organic residues are mostly used as mulch to cash crops, such as coffee and beer bananas, or as fodder. In this way, 1.5-3 t ha^{-1} of farmyard manure could be annually produced under optimistic conditions (up to 2000 m hedgerows and 2-3 stall kept goats or one cow) and 20-30% can afford one or more cows (Ford 1990). Barker (2010) report that cattle weighing 454 kg body weight can produce 26 kg of faeces and 4.5 kg of urine totalling 30.5 kg of manure per day, with a total annual with bedding of 16,000-18,000 kg of manure.

An application of 49, 421 kg of good quality manure ha^{-1} supplies about 224.9 kg of N, 112.2 kg P, and 227.3 kg K. From this application, about 45.4 kg N, 22.7 kg P and 92 kg K are potentially available (Barker 2010). This application of 49,421 kg ha^{-1} is often referred to as the agronomic rate of application. However, N application should be based on the amount required by crops. The amount of N removed is a function of the amount of DM that a crop produces and of the N concentration in the DM. Well-nourished plants have from 1-4% N or more in the forage, with variation occurring among species and with plant age (Mills and Jones 1996; Reuter and Robinson 1997; Epstein and Bloom 2005 Barker 2010. Application of N from fertilisers may be 50-100% greater than the amount that is removed by a crop to compensate for losses and failures of plants to recover N that is applied (Panda 2008; Barker 2010).

However, in Uganda, adoption of fertiliser is associated with much higher yields of maize and coffee production (Nkonya et al. 2002; Zake et al. 2005), which are crops that require vast pieces of land that do not exist in the central districts of Kampala and Wakiso because they are peri-urban areas.

Therefore, there is need for appropriate quantities of cattle manure based on soil N requirements for crop growth. Gunnerson and Stucky (1986) estimate that at 50% mineralisation, the quantities of manures or fertilisers needed to supply 1 kg N to any given area of cropland are 690kg for cattle dung (fresh), 266 kg for cattle dung (dried to 20% of fresh weight), 1350 kg for an aerobically digested cattle dung sludge (wet), and 160 kg for aerobically digested cattle dung sludge (dried at 10% of weight) have been reported including urea (100%) can supply the N needed by crops.

However, animal manure may be disadvantageous due to weed seeds common in some animal manure that may enter the animal with its feed and then pass through the digestive tract, still viable, or they may have come with the litter, or they may have simply blown into the feed yard (Ecochem 2011). A number of options that are employed by smallholder farmers to improve soil fertility for crop production have been discussed in section 4.3.1.

6.5 Conclusions

- Overall, DM yields and subsequent N uptake were similar between M_4 and M_{12} treated plots; however, the high rates of cattle manure (M_4) application added significantly more DM yields and more N uptake than the high rates of aged cattle manure (M_{12}). Although, cattle manure can provide alternatives to inorganic fertilisers, a chemical analysis of the manure and or all organic manures is essential in determining the key nutrients available calculating application rates.

- The application and management of organic N sources to provide sufficient N at the time of maximum crop growth requires knowledge of N availability and uptake to the crop particularly when cattle manure is utilised as a nutrient source. Manure has the potential under favourable climatic conditions where soil moisture and temperatures are high particularly in Ugandan tropical conditions, which may quicken mineralisation of nutrients from manure that are required by crops. Effects of storage affect nutrient availability and warrant further investigation.

- N uptakes of mineralised organic N were greatest on M_4 than M_{12} manure treatments with 18.74 kg ha^{-1} and 15.91 kg ha^{-1} taken up, respectively. On the M_4 and $M_{12,}$ cattle manure treatments; this suggests that there was no net mineralisation between the 1^{st} and 2^{nd} sampling dates as at 100 DAS. This study showed that N applications of M_4 and M_{12} have increased fresh weight, DM yields and N uptake.

- Modelling of organic N inputs for crop production and soil fertility maintenance requires a better understanding of the dynamics of plant nutrient uptake and crop requirements. Owing to the slow release of nutrients and their low concentration in manure, large volumes of manure must be applied to satisfy the nutrient recommendations compared to inorganic fertiliser. Therefore, application rates of cattle manure in applications of a few tonnes per hectare are required in comparison to a few kg of commercial fertiliser. Applications of cattle manure could be supplemented with N fertiliser at reduced rates to complete crop N nutrition. There is need therefore for further studies to determine and or examine the effects of cattle manure combined with reduced mineral fertiliser on crop yields and on soil properties for the Ugandan conditions and other countries with similar farming systems.

- Manure stored for 4 months (M_4) and 12 months (M_{12}) were 33% and 26% as effective as inorganic fertiliser for final yield, respectively, for DM yield. The results indicated that aged cattle manure-N and four month stored manure were 21% and 28% effective as top dressed inorganic-N (urea), respectively for N uptake, and therefore approximately five and three and half times more total N equivalent in cattle manure is required to obtain comparative N uptake to urea, where all other nutrients are not limiting. The canola crop was better able to take up N over the season, with RE for N uptake increasing from 11% to 21% and 20% to 28% for M_{12} and M_4 for DM production, respectively.

- The results of the present experiment have provided sufficient data needed for N modelling; however, there is need to examine the growth characteristics of canola compared to the growth of cabbage under controlled conditions, which is the basis for the following chapter.

Chapter 7. Comparative growth response of cabbage (*Brassica oleracea*) and canola (*Brassica napus*) under controlled conditions

7.1 Introduction

Cabbage (*Brassica oleracear*) has a high biomass yield and is used traditionally in tropical regions for consumption by people and animals (Tisdale et al. 1993; Amudalat et al. 2006). Cabbage is a leafy vegetable which is a heavy user of N, P and K, particularly N. Inadequate supply of available N frequently results in plants that have slow growth, depressed protein levels, poor yield of low quality produce and inefficient water use (Mikkelsen and Hartztter 2008). Nitrogen stressed plants often have greater disease susceptibility compared with properly nourished plants. The best practice to successfully grow these vegetables, as is traditional practice elsewhere, is to use inorganic fertilisers (mainly urea) as a source of N but the price of urea in Uganda is expensive in recent years (Omiat and Diiro 2005; Van Hiep and Preston 2006; Makinde et al. 2007; IFDC 2008; Nziguheba et al. 2010).

The nutrient requirement for the effective growth and productivity of cabbage and Amaranthus *spp* in Uganda, require that sustainable and easily available sources of N be sought to ease the twin problem of scarcity and cost associated with inorganic fertilisers. The results from the two field experiments (Chapters 5 and 6) showed that N had a significant role to play in canola (*Brassica napus*) production. For example, in the 2009 field trial, there was response to N application at 200 kg N ha^{-1} for canola crop. There is a need to examine the effects of growth between Brasssica (cabbage and canola) yield under ideal conditions to enable results under field conditions to be compared with the Ugandan situation. The research is part of an overall study designed to provide information for cabbage and Amaranthus crop growth model. To improve crop production, it is necessary to study the effect of plant development, N accumulation, and DM production over time to enable growth characteristics of the different Brassica *spp* to be compared. The information is required to aid in the development of an economic model for manure application to improve fertiliser use (predominantly cattle manure) in Uganda.

Diversification of agricultural production to improve human nutrition and contribute towards the millennium development goals (MDG) by halving the percentage of people suffering from hunger; an indicator of the percentage of the population below the minimum dietary energy intake is needed. Vegetables particularly leafy vegetables such as cabbage and Amaranthus *spp* as well as cereals including maize would be ideal if their yields are improved (Palma et al. 2009) hence the basis of the study.

The objective of the experiment was to compare the growth and yield of three *Brassica* crops. The field trial used canola; hence, there was a need for comparison to assess whether canola is a suitable proxy indicator for DM production and growth in cabbage that could then be used in the modelling as discussed in chapters 8 and 9. The results from the Australian field trial (canola) were used as a benchmark for predicting the response to cabbage in Uganda. This therefore, forms the basis for the following chapter.

7.2 Materials and methods

7.2.1 Trial layout and design

The experiment consisted of three crop species of Brassicas; two cabbage varieties namely Gloire Enkhuisen (White cabbage) and Tronchuda (which does not form a head/heart) and canola (Cobbler) as test crops. Cabbage is commonly grown in the Ugandan central districts. The crop enterprise is less labour intensive and has a readily available market. In addition, it could be grown all the year around hence the basis of selection. The three treatments were replicated three times in a completely randomised design. The plants were grown one plant per pot, for a period of 110 days at Muresk research glasshouse, Western Australia.

7.2.2 Soil type

Soil samples from the top 0-10 cm were collected from the experimental site of field trials conducted in 2009 and 2010 seasons; at Ucarty located 120 km east of Perth, Western Australia (31.19159^{o}S, 116.57083^{o}E), with full details given as per experiment 1 (see 5.3.2). The soil was randomly collected to represent the experimental area, air dried, and sieved with the <2 mm soil fraction mixed well and stored in 100 kg plastic bins until required. Characteristics of the soil are listed in Table 5.1 and described in section 5.2.3.

7.2.3 Pot size and basal nutrients

Plastic pots (Springdale) measuring 15 cm deep by 15 cm diameter were lined with plastic bags measuring 40 x 50 cm to prevent free drainage and subsequent leaching of nutrients and two (2) kilograms of air dried soil was added. The depth of soil in the pots was 10 cm. The pots were treated with basal fertiliser containing ammonium nitrate as a source of N at 280 mg N kg^{-1} of soil following the response of field experiment 1 and soil nutrient status as well as the critical nutrient requirement for the *Brassicas* as described by Reuter and Robinson (1997). Two subsequent N applications brought the total N applied to 320 kg N ha^{-1} deemed adequate for the crops.

This is because canola field trial of 2009 season at 200 kg N ha^{-1} still had a positive response and advanced seedlings were used. No leaching of the nutrients was expected. Balint and Rengel (2008) applied 400 mg N/kg soil to plants grown to grain maturity.

Basal amounts of P, Cu, K, Ca, Mo, B, Mn and Zn were applied per kg soil as follows: 80 mg P (mono-calcium phosphate (MCP), Ca $(H_2PO_4)_2 \cdot H2O$, i.e. 24.6%), 80 mg K_2S_4O, 1.25 mg $CuSO_4.5H_2O$, 1.0 mg Zn as $ZnSO_4.7H_2O$, 0.24 mg B as H_3BO_3 and 0.05 mg as $Na_2Mo_4.2H_2O$. 150 mg Ca as $CaSO_4.2H_2O$; 106 mg manganese sulphate. This was followed by air-drying thorough mixing and filling into all prepared plastic pots following Osborne and Rengel (2002b) and Balint et al. (2008). Ca and P were weighed out as fine dry powders and applied to each bag as per treatment specifications and mixed thoroughly into the soil. These were allowed to dry after application for 24 h prior to mixing in the bag to incorporate through the soils. The basal nutrients were applied to ensure that all mineral requirements were adequate for optimum growth of the crops.

7.2.4 Sowing and transplanting

Cabbage and canola seeds were sown in cavity trays (33cm x 29 cm) containing 72 individual cells (5 cm deep by 3.5 cm wide) in the greenhouse on 23 June 2010. Ninety eight percent of the seeds germinated and the seedlings were raised in a peat-vermiculture containing commercial rates of fertiliser. Forty-one (41) days after sowing (DAS); plants were lifted from the cavity trays and immediately transplanted in the prepared pots. Prior to transplanting, gravimetric soil water content (GSWC) was determined as the amount of water remaining after 24 h in the top 5 cm of soil in a 50 cm high free draining soil column covered with plastic wrap to prevent evaporation following the procedure of Jenkinson and Powlson (1976); Hillel (1982); Geering (1995). The GSWC sub-samples of soil (10 g) were dried overnight at 105°C in a forced air oven to determine the gravimetric water content by loss in mass of the soil. Samples were placed in desiccators to cool before weighing to prevent absorption of atmospheric moisture. The gravimetric moisture content was calculated as: Gravimetric moisture content (%) = [(mass of fresh soil – mass of oven dry soil) /mass of fresh soil] x100.

Soils were watered to GSWC of 14.5% using deionised water and then allowed to incubate in the glasshouse for 7 d prior to transplanting. Incubation and transplanting were done on 28 July and 3August 2010, respectively. Pots were made up to GSWC at least every second day and the pots re-randomised. Data collection on the development of transplanted crops was on a 10 d interval. There were neither insect pests nor diseases observed.

7.2.5 Location

The experiment was conducted at the Muresk research glasshouse, Curtin. The temperature was maintained at $25^{o}C+-3^{o}C$ by an air conditioning system and the relative humidity ranged from 50 to 90%. Pot soil temperatures during the day were constant from $22^{o}C$ to $23^{o}C$.

7.2.6 Plant measurements and harvest

Germination of plants was observed daily for 5-10 days. Plant height (from the ground surface) and leaf length of each plant species were measured at each sampling date. Measurements included number of expanded true leaves (leaves with clearly visible petiole), leaf area (using leaf area metre), model LI-3100, LI-COR, Lincoln, Nebraska, root and shoot (fresh and dry) mass were recorded from each of the plant samples. Plant roots were measured using a meter ruler.

At each sampling date, plants were harvested at random. Plants were removed at random from each pot at all harvests, except at 110 DAS when all remaining plants were harvested. This was by assigning a number to each plant and all numbers mixed in a container and 10 picked randomly. The first samples of the crops were harvested at 70 DAS; 29 days after transplanting (DAT) to match with the field trial. Second, third and fourth sampling were at 80, 90 and 100 DAS, respectively. Final samples were taken on 13 October 2010, at 110 DAS. At each harvest, 10 plants of each species were harvested, washed, and weighed and the plants separated into shoots and roots and then dried at $70^{o}C$ for 48 h in a forced draught oven for DM content. Five plant harvests were taken during the experiment, with measurements taken for fresh, DM and N uptake. The different activities conducted during the experiment are described in plates 7.1-7.6.

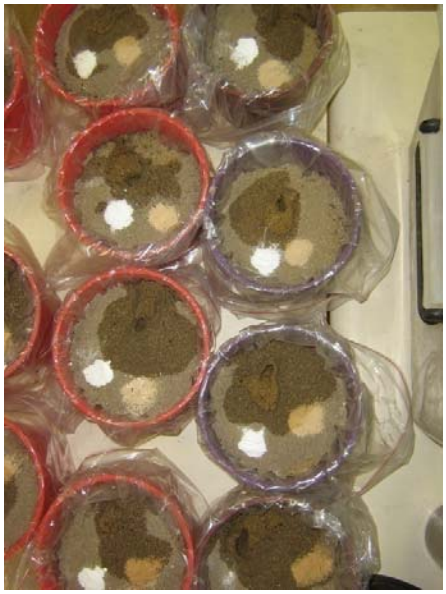


Plate 7.1: Prepared pots with soil, basal and N ready to be mixed

Plate 7.2: Newly transplanted cabbage spp

Plate 7.3: Arranging the transplants into random blocks of cabbage and canola, June 2010

Plate 7.4: Canola and cabbage at 100 DAS

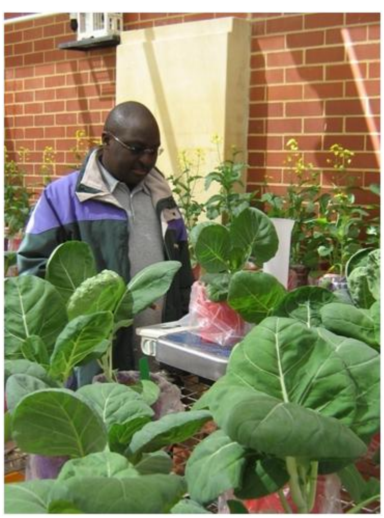


Plate 7.5: Weighing to water to GWSC in the glasshouse at Muresk

Plate 7.6: Sampling of Brassica species at 80 DAS

7.2.7 Plant nutrient analysis

Whole dried plant shoots were weighed, finely ground using a herb-grinder and then analysed for the concentration of N using a Leco FP-428 analyser. Samples were combusted in pure oxygen at 850°C whereby nitrogen oxides were converted to N with removal of water, oxygen and carbon dioxide. After digestion with sulphuric acid and hydrogen peroxide, N was measured by thermal conductivity by method PCM P03 (CCWA 2000) as described in 5.2.8. Replications were bulked together where DM was less than 800 mg of final sample. Shoot nutrient concentrations were compared with critical nutrient concentration levels in Reuter and Robinson (1997) for *Brassica spp* for whole shoots at the closest comparable growth stage. Total N was determined by multiplying final DM by percentage of N concentration of shoot tissue.

The elemental analysis of plant material from sampling dates was conducted to investigate the nutrient status of the canola, compared with the two cabbage varieties. Mean tissue content of concentration of N is presented in (Table 7.1). Typical nutrient concentrations in canola (Reuter and Robinson 1997) are shown in Appendix (Table A8). Other nutrient concentrations including P, K and S were examined to determine whether these nutrient elements in the *Brassica spp* might have been limiting growth at the applied rate when the response became uniform for all spp at 100 DAS and curvilinear for the cabbage varieties.

7.2.8 Soil analysis

The soil used for the experiment was analysed for N, pH, EC, Al ($CaCl_2$), organic carbon, total N, ammonium and nitrate, BIC-P (Plant Available), BIC-K (Plant Available), total phosphorus, phosphorus retention index (PRI) and Mehlich-3 Extractable Elements as per description in section 5.2.9.

7.2.9 Statistical analysis

The data were analysed using standard analysis of variance (ANOVA) (GenStat Procedure Library Release PL20.1) (Payne et al. 2011) as described in section 5.2.8.

7.3 Results

7.3.1 Plant growth and development

The growth and development of the three Brassica *spp* was compared between shoots and roots, which was monitored for 110 DAS and showed no significant difference between species. Canola, like cabbage plants has a tap root system. The root system continued to develop with secondary roots growing outward and downward from the taproot. Root development was relatively constant averaging nearly 0.7 cm, 1.5 cm and 0.8cm per day for tronchuda, canola and white cabbage, respectively (Table 7.3). There was uniform and vigorous growth of the plant species with increases in height and number of leaves at every sampling date, with canola continuing to develop multiple stems and branches. There were increases in length of leaves at each sampling date relative to first harvest at 70 DAS. The increments were: 121.6%, 40.4%, 37.4% and 4.5% for canola, 25.4%, 31.6%, 6.0% and 10.7% for white cabbage and 37.9%, 12.8%, 0.2% and 8.7% for tronchuda cabbage and increases in height of plants were 23.3%, 25.8%, 3.1% and 5.7% for canola , 14.5%, 35.4%, 0.9% and 1.4% for white cabbage and 23.7%, 30.3%, 0.1% and 6.7% for tronchuda cabbage at each sampling date (Table 7.2). There was a tendency for plant height to be increased every 10 days, with the effect being more apparent for canola ($P < 0.001$).

Plants of canola, tronchuda and white cabbage measured at 70 DAS averaged 3.7, 4.0 and 5.0 leaves, respectively. At 80 DAS, plants were green with a mean of six leaves and four tillers and multiple stems specifically in canola.

7.3.2 Dry matter production

Dry matter production was slow up to 80 DAS with an increase in production between 80 and 90 DAS and then increased the most between 90 and 110 DAS peaking at 100 DAS, which was the fourth harvest. However, the percentage increase was on a declining trend. Increases in the shoot DM were primarily the result of increased leaf and tiller number. In addition, there was a positive relationship between the sowing (DAS) and DM production of the Brassica shoots over the five consecutive harvests. No differences in DM were measured between the different crops at 70, 100 and 110 DAS ($P=0.05$). At 70 DAS, the lowest DM was measured canola (1.71 g pot^{-1}) and was highest white cabbage (2.19 pot^{-1}). Significant differences between species for DM production occurred at 80 and 90 DAS sampling dates ($P < 0.05$). The results for DM production and other yield components are presented in Figure 7.1 and Table 7.1, respectively.

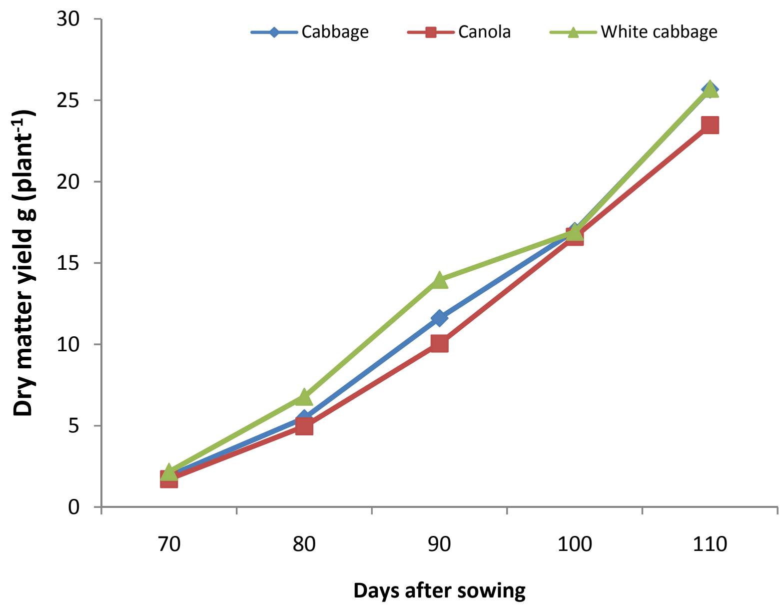


Figure 7.1: Dry matter yield of white cabbage, canola and tronchuda cabbage from 70-110 days after sowing

Figures 7.1 presents growth characteristics of canola, cabbage and white cabbage showing DM yield of 5 sampling dates. While, Figures 7.2 and 7.3 show DM versus fresh weight of the first and final harvest of white cabbage, canola and tronchuda cabbage, respectively. They show the rative DM and trend lines for biomass yield. At 70 DAS, all the three crop species had similar moisture content (7%) but at 110 DAS, the species had a moisture content of 7%, 15% and 16% for tronchuda cabbage, white cabbage and canola respectively.

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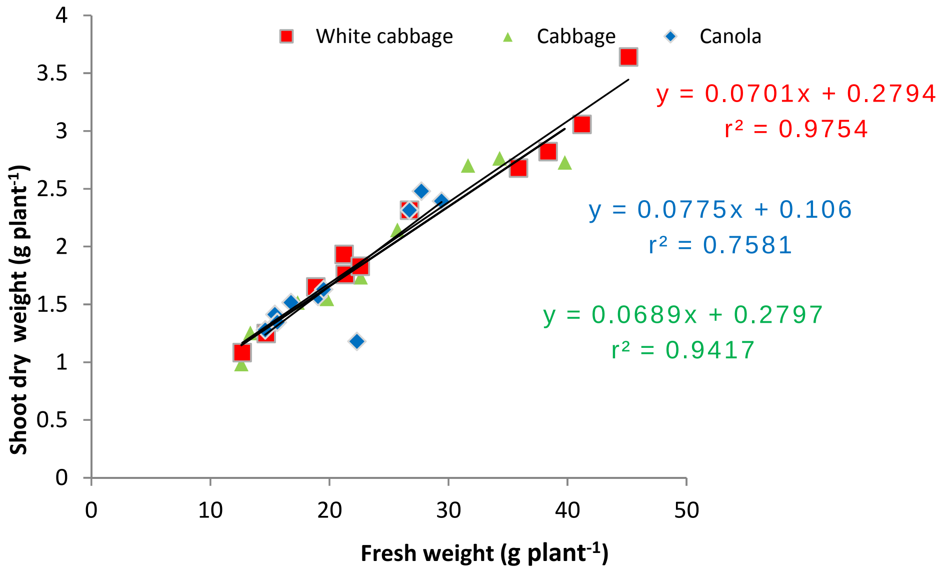


Figure 7.2: Dry matter versus fresh weight of the frist harvest of white cabbage, canola and tronchuda cabbage at 70 DAS

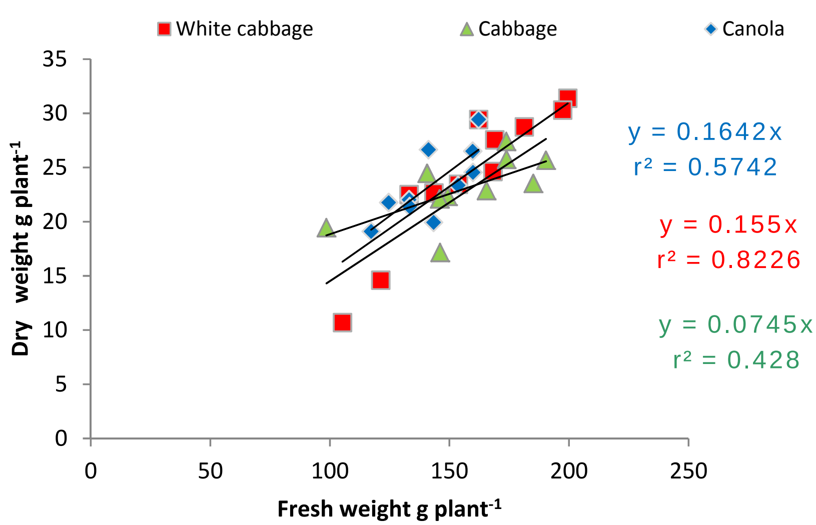


Figure 7.3: Dry matter versus fresh weight of the final harvest of white cabbage, canola and tronchuda cabbage at 110 DAS

7.3.3 Comparison of yield of field grown canola with canola raised under controlled environment (Glasshouse)

The DM results of field-grown canola and canola in the glasshouse are presented in Figure 7.4. Only data at 70 DAS and 100 DAS for field and glasshouse experiments were compared. Results show that higher DM yields were obtained in the glasshouse in a shorter period.

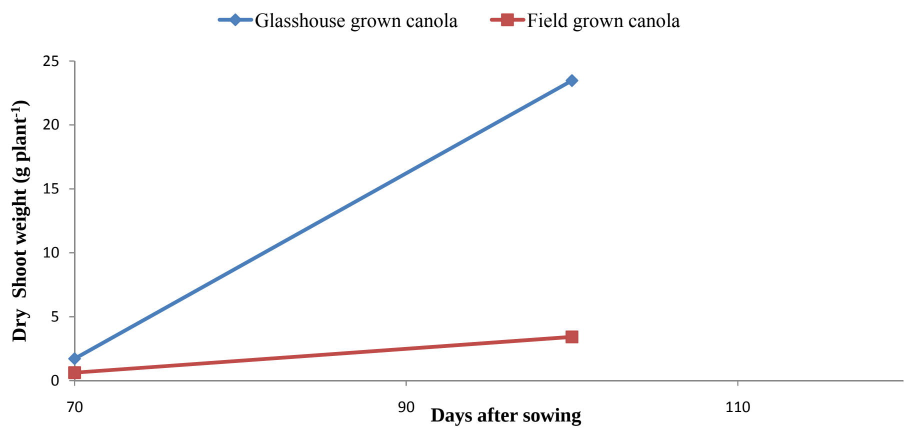


Figure 7.4: A graph showing dry matter yield of differences of canola grown in either the field or Glasshouse at 70 and 100 DAS

7.3.4 Shoot nitrogen concentrations and uptake

The shoot N concentrations results for the three Brassica crops indicate that the concentration of N in canola shoot DM decreased from 7.4% at 70 DAS to 2.7% at 110 DAS with increasing number of days (over the growth period). For white cabbage, the N concentration was higher than canola decreasing from 7.7% to 2.3%. While, for the tronchuda cabbage, the concentration decreased from 8.0% to 1.9%. There were no differences in concentrations of N in shoots between 70 DAS and 110 DAS ($P = 0.05$) between species. Total nutrient uptake, however, continued to increase through bloom.

A positive linear relationship existed for shoot N uptake and days after sowing, with N uptake increasing for each crop but on a declining rate over the season (Figure 7.5). There were also no differences in shoot N uptake between 70 DAS and 110 DAS between the crop *spp* ($P = 0.05$). Nitrogen uptake at 70 DAS was 0.13 g N pot^{-1}, 0.17 g N pot^{-1} and 0.15 g N pot^{-1} and increased to 0.63g N pot^{-1}, 0.59 g N pot^{-1} and 0.49 g N pot^{-1} at 110 DAS for canola, white cabbage and tronchuda cabbage variety, respectively.

Overall, this is equivalent to 53.2 kg N ha^{-1} to 266.2 kg N ha^{-1}, 70.2 kg N ha^{-1} to 248.4 kg N ha^{-1} and 64.2 to 204.86 kg N ha^{-1} for canola, white cabbage and tronchuda cabbage crops at 70 and 110 DAS, respectively.

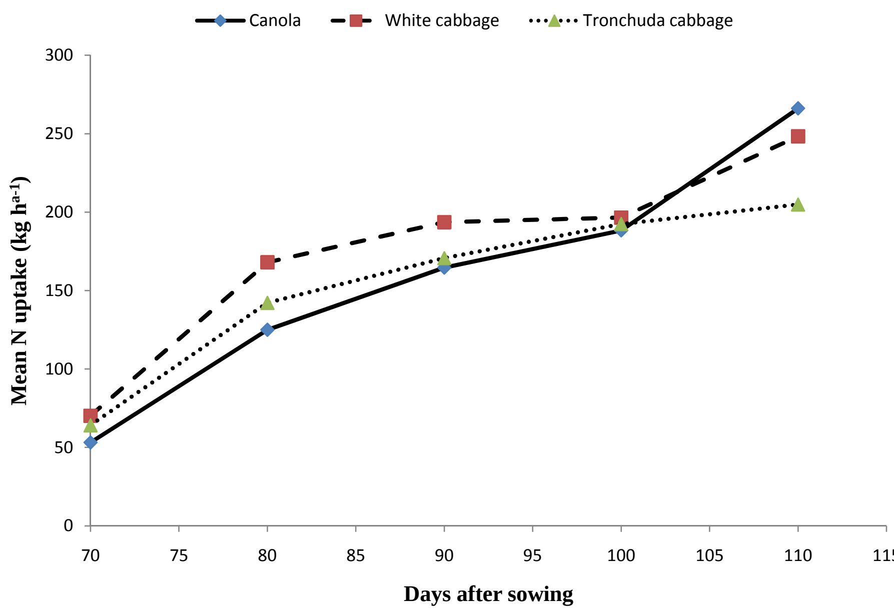


Figure 7.5: Effect of number of days on N uptake (kg ha^{-1}) for canola and cabbage raised under controlled environment (Glasshouse)

The mean yield components are presented in Table 7.1 including the crop height, root length, DM, N uptake and nutrient content of cabbage and canola during the growing season. Nutrient content is shown as tissue concentration (percent) and total uptake (kg N ha^{-1}). Dry matter accumulation at each crop stage is plotted in Figure 7.1. White cabbage was significantly different from canola but the two cabbage species were not significantly different at 80 DAS.

Table 7.1: Dry matter, N concentration and N uptake of canola and cabbage varieties

	Dry matter yield g plant-1				
	Days after sowing (DAS)				
Crop	70	80	90	100	110
Canola	1.7	4.96	10.1	16.6	23.5
White cabbage	2.2	6.78	14.0	16.9	25.7
Tronchunda cabbage	1.9	5.46	11.6	17.0	25.7
LSD	0.6	1.4	2.1	3.5	4.4
Significance level	NS	**	**	NS	NS
N concentration % in shoots					
Days after sowing (DAS)					
Crop	70	80	90	100	110
Canola	7.4	6.0	3.9	2.7	2.7
White cabbage	7.7	5.9	3.3	2.8	2.3
Tronchunda cabbage	8.0	6.2	3.5	2.7	1.9
N uptake g $plant^{-1}$					
Days after sowing (DAS)					
Crop	70	80	90	100	110
Canola	0.13	0.30	0.39	0.45	0.63
White cabbage	0.17	0.40	0.46	0.47	0.59
Tronchunda cabbage	0.15	0.34	0.41	0.46	0.49
LSD	0.112	0.1147	0.2657	0.1776	0.284
Significance level	NS	NS	NS	NS	NS
N uptake kg ha^{-1}					
Days after sowing (DAS)					
Crop	70	80	90	100	110
Canola	53.2	125.0	164.6	188.4	266.2
White cabbage	70.2	168.0	193.6	195.4	248.4
Tronchunda cabbage	64.2	141.2	170.7	192.4	204.9

NS=Not significant

**= Significant at 5%

7.3.5 Nitrogen

Over the duration of the experiment, the concentration of total N in the soil was supplied at relatively constant levels. All crop species received similar amounts of N. No significant difference was observed in concentration in N in shoots between the crop species at 100 DAS and N at 110 DAS (P=0.05). At 110 DAS, the crops had lower concentrations of shoot N as the DM increased, represented by high N uptake.

The latter was higher or equal in canola than in white cabbage and tended to be lower in tronchuda cabbage, although there was no significant difference in N uptake (P=0.05) at 110 DAS.

There was no relationship between shoot N content during the growth period and yield of cabbage and canola crop species across the whole data set tested. Shoot biomass at each sampling date showed a good relationship to yield but this relationship was improved if N uptake was considered rather than N content or shoot biomass alone (Figure 7.7). As N uptake increased, so did yield. Figure 7.6 shows the effect of days after sowing on N uptake kg ha^{-1}.

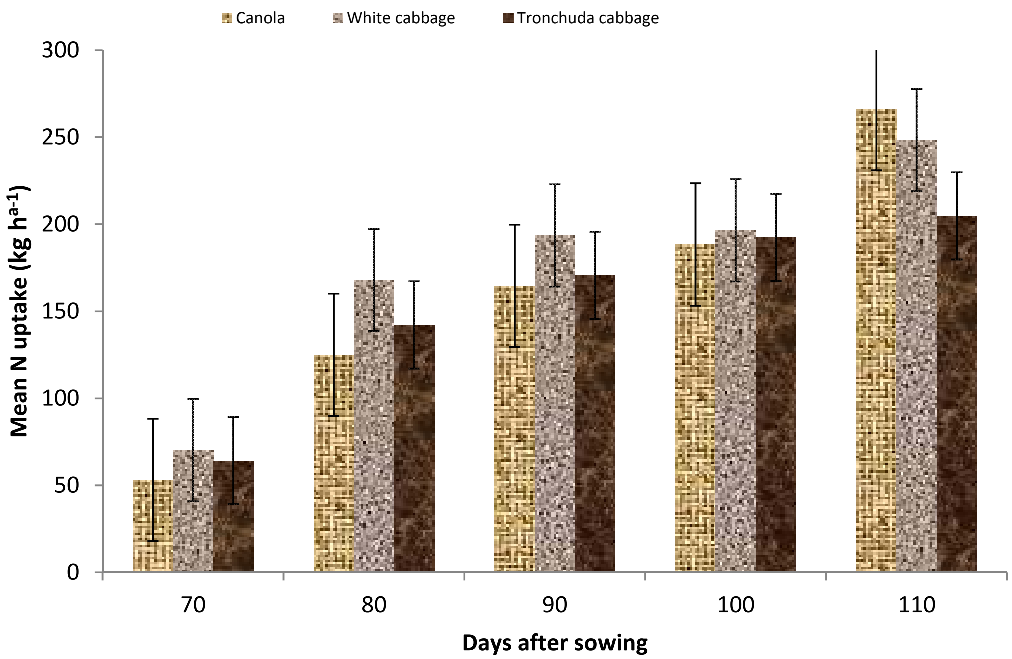


Figure 7.6: Effect of days after sowing versus N uptake (kg ha^{-1}) with standard error bars (70-110 DAS)

Mean total N uptake by the three Brassica species increased with increasing yield. There were no differences in N uptake at each of the sampling date for each crop species. Figure 7.7 presents the mean N uptake by DM yield.

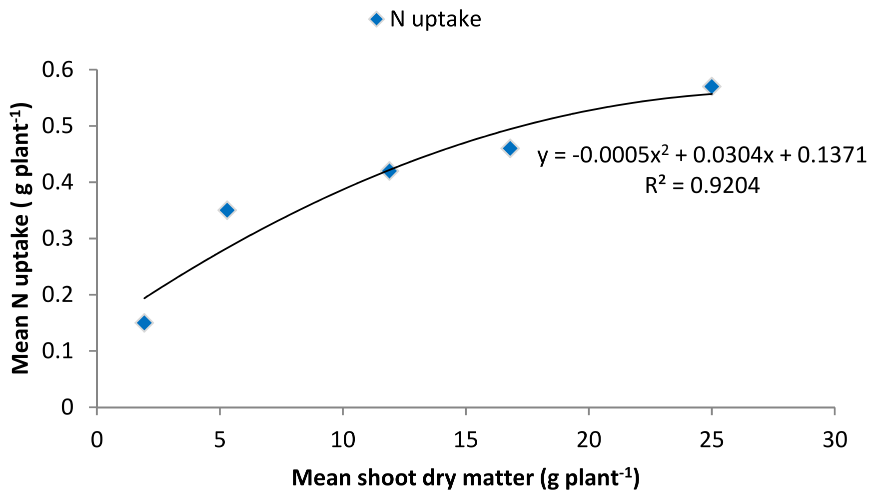


Figure 7.7: Effect of N uptake on dry matter yield over time (70-110 DAS) for mean values of combined white cabbage, tronchuda cabbage and canola

7.3.6 Number of leaves per plant

The number of leaves per plant was significantly affected by species ($P<0.001$). Canola produced the highest number of leaves (7) per plant at 70 DAS, significantly ($P<0.001$) higher than all other species (LSD=0.549). White cabbage recorded the second highest (6) and was significantly ($P<0.001$) higher than the tronchuda cabbage variety (5) (LSD =0.549). At 80 DAS, the number of leaves for white cabbage increased to 8.8 followed by canola (7.1); both significantly ($P<0.001$) higher than tronchuda cabbage (6.4) (LSD= 0.923).

At 100 DAS, the Bonferroni test showed significant ($P<0.001$) differences in the number of leaves between species (LSD=0.671). The number of leaves between species was also significant ($P=0.038$) at 110 DAS. However, the Bonferroni test showed no significant differences between the crop species ($P=0.05$).

7.3.7 Leaf length

The leaf length per plant was significantly affected by species ($P<0.002$) (Table 7.2). Tronchuda cabbage had the widest leaves compared to other species at 70 DAS (13.1 cm), significantly ($P<0.002$) wider than canola (9.4cm). White cabbage recorded the second (12.1 cm) and was significantly wider than canola. The Bonferroni test showed no significant differences between the two cabbage varieties for leaf length (LSD=1.912) but both were significantly different to canola (Table 7.3). At 80 DAS, the leaf length of the crop species were significantly ($P<0.001$) different. However, there were not significant differences between canola (11.6 cm) and white cabbage (13.8 cm) (LSD=1.987) and similarly the Bonferroni test results showed no significant differences between the cabbage varieties. At 90 DAS, the crop species had significant ($P<0.001$) effect on leaf length; 14.6 cm, 18.7 cm and 21.4 cm for canola, white cabbage and tronchuda cabbage, respectively, (LSD=1.943). At 100 DAS, there were also significant differences between the crop species (LSD =2.418). Bonferroni test results however, showed that canola (15.1 cm) and white cabbage (18.9 cm) were not significantly different in leaf length, unlike the tronchuda cabbage (21.2 cm) which was significantly different from the two crop species (LSD=2.418) at 100 DAS. There were also significant ($P<0.001$) differences at final harvest between crop species.

7.3.8 Plant height

The height of the plant species was significantly affected by crop species ($P<0.001$) (Table 7.2). Canola was the tallest at all sampling dates. Its root length (89.3cm at 110 DAS), was also significantly higher than all other species. The heights of the crop species at 70 DAS were significantly ($P<0.001$) different at 23.9 cm, 6.5 cm and 4.6 cm for canola, tronchuda cabbage and white cabbage, respectively. While at 80 DAS, their height varied significantly ($P<0.001$), including 53 cm, 9.0 cm and 5.8 cm. At 90 DAS, the heights increased as follows; 74.4 cm, 10.2 cm and 7.7 cm for canola, tronchuda cabbage and white cabbage, respectively. The two cabbage varieties did not differ significantly; however, canola height was significantly ($P<0.001$) higher than the two cabbage varieties. At 110 DAS, the height of the three crop species was significantly different ($P<0.001$). Canola height was 106.8 cm, while the heights of the two cabbage varieties were 11.1 cm and 9.0 cm for tronchuda cabbage and white cabbage, respectively. Overall, rate of height of plants increased as shown in section 7.3.1 at each respective sampling date.

Table 7.2: Plant height and leaf length (cm) of cabbage and canola from 70-110 days

	Time in days				
	70	**80**	**90**	**100**	**110**
Plant height					
Canola	23.90b	52.97b	74.4b	102.2b	106.8b
White cabbage	4.65a	5.83a	7.8a	8.1a	9.0a
Tronchuda cabbage	6.55a	9.03a	10.2a	10.2a	11.1a
LSD P=0.05	4.807	3.955	5.30	9.69	10.25
Leaf length					
Canola	9.4a	11.6a	14.6a	15.11a	15.8a
White cabbage	12.1b	13.8ab	18.7b	18.89a	19.2b
Tronchunda cabbage	13.1b	16.2b	21.1c	21.16b	22.6c
LSD P=0.05	1.912	1.987	1.943	2.418	2.166

($P<0.05$)

7.3.9 Root length

The root length of each plant was affected by species. Canola had the longest root length, significantly ($P<0.001$) longer than the two cabbage varieties at each harvest (mean length 89.3 cm at 110 DAS). White cabbage recorded the second longest root length (41.2 cm) though not significantly longer than tronchuda cabbage (39.3cm) at the final harvest. It should be noted that canola was taller, with longer roots, shorter leaves and had developed many multiple branches at 90 DAS but some plants started flowering at 80 DAS. The root length and development as highlighted in section 7.3.1 averaged about 0.7 cm, 1.5 cm and 0.75 cm for tronchuda, canola and white cabbage, respectively, per day (Table 7.3). The DM content of the tops was higher than that of roots, with white cabbage being the highest but not significantly different between the crop species.

Table 7.3: Root length (cm) of cabbage and canola at five sampling dates

		Time in days			
	70	**80**	**90**	**100**	**110**
Root length					
Canola	29.16b	55.8b	76.2b	85.31b	89.31b
White cabbage	12.9a	28.8a	36.9a	38.02a	41.19a
Tronchuda cabbage	12.4a	24.9a	35.7a	38.50a	39.34a
LSD	4.21	10.03	11.97	12.78	13.26

($P<0.001$)

7.3.10 Total root weight

Table 7.4 presents the mean root weight of canola, white cabbage and tronchuda cabbage at five sampling days. Significant differences were observed at 100 and 110 DAS, where 2.06 g and 3.00 g, 2.39 g and 3.53 g and 3.42 g and 4.49 g of DM for canola, white cabbage and trochunda cabbage were recorded, respectively. This represents 12% and 13% at 100 DAS, 14% and 15% and 20% and 17% at 110 DAS of the DM yields of canola, white cabbage and tronchuda cabbage, respectively.

Table 7.4: Root weight (g) of cabbage and canola spp from 70-110 days

	Time in days				
Root weight	**70**	**80**	**90**	**100**	**110**
Canola	0.42a	0.74a	0.85a	2.10a	3.01a
White cabbage	1.001a	1.25a	0.91a	2.40a	3.53ab
Tronchuda cabbage	0.57a	0.90a	0.80a	3.42b	4.49b
LSD P=0.05	NS	NS	NS	0.733	1.096

$P < 0.05$

NS= Not significant

White cabbage produced significantly more DM yield than any of the crop species. These crop species had started yellowing and tronchuda cabbage was consuming more water than the two *Brassica spp*, followed by canola during the later crop stages in the season.

7.4 Discussion

7.4.1 Differences in growth and development

There was uniform growth of plants observed over the season with canola increasing significantly ($P<0.001$) in height and production of leaves compared to the other Brassica species. This affected other parameters of growth including DM production, only significant at 80 and 90 DAS. At 80 DAS, the number of leaves per plant in each species increased with time till 100 and 110 DAS after sowing, except for canola crop which produced the highest number of leaves, though they were smallest.

White cabbage was shorter than Tronchuda cabbage. Taller species had less DM at some sampling dates; white cabbage had higher DM than canola and tronchuda cabbage. However, Tronchuda had wider leaves compared to the rest. Palmar et al. (1999) report that higher N levels favoured the growth of plants with larger leaf area and it was more usefully utilised in head formation. High levels of N, lead to increased partitioning of DM to the shoots than the roots was evidenced from the current study. Shoot growth is sustained by how well the roots have developed. Roots are important for absorption of water and nutrients from the growth medium (Mengel and Kirby 2001; Havlin et al. 2005; Canada Council of Canola 2011).

Nitrogen is recognized as the second most important factor limiting crop yield after water (Sieling et al. 1998; Kelly et al. 2004) and affects crop growth through its influence on radiation interception, photosynthesis and radiation use efficiency (Borrell et al. 2001; van-Oosterom et al. 2001; Hirel et al. 2007). Nitrogen has been found to increase the size of reproductive sinks in grain crops leading to higher yields (Sticksel et al. 2000; Miller et al. 2003).

Brassica napus responds to N application by increasing leaf and stem biomass and delaying maturity (Leleu et al. 2000). Campbell et al. (1987) report that N fertilisation improves soil water extraction of crops through increased plant growth.

The study established that with sufficient water and nutrients, more shoot growth is enhanced at the expense of the root. Where soil water and nutrients are abundant, the balance of root to stem and leaf growth typically shifts in favour of stem growth at the expense of roots. When water is limited, the opposite usually occurs. Root and stem growth complement one another by adjusting their relative size to meet the basic requirements of the whole plant in response to climatic and soil conditions (Allen and Morgan 1975; Mendham and Salisbury 1995**.** Canola council of Canada (2011) report that with moisture stressed canola, roots account for about 25% of plant DM at stem elongation compared to about 20% for unstressed plants. Results of the present study concur with this i.e. the unstressed plants.

Wysocki et al. (2005) report that at peak flowering and maximum stem length, roots will have reached about 85% of their maximum depth. Root depth, like plant height, will vary from 90 to 190 cm but will average about 140 cm at maturity for Brassica *napus* and 90 cm for Brassica *rapa*. The root system varies with soil type, moisture content, temperature, salinity and soil physical structure. The Brassicas of the current study were harvested at 110 DAS before maturity and were grown in pots and therefore constrained; this can explain the variation in root system recorded (89.3 cm) at 110 DAS.

7.4.2 Crop growth and biomass production

Data presented in Tables 7.1-7.4 show the effect of crop and varietal differences on yield and yield attributes. There were no significant differences between crop species on the studied characters except, that canola surpassed in plant height and root length. Plant height and shoot biomass were affected by crop species (El Kholy et al. (2007); the relative proportions of variance explained by *Brassica napus* (Rapeseed varieties) greatly depend on genotype (45%), followed by N (28%) and environment (23%) (Miller et al. 2003). For shoot biomass, the greatest proportion depends on N (72%), followed by environment (15%) and then genotype (5%) (Miller et al. 2003). This indicates that the greater plant height associated with canola was not related to greater shoot biomass. The mean plant height of canola was 21% greater than the mean of the other crop species, while shoot biomass did not differ ($P = 0.05$) at 110 DAS. The two cabbage varieties did not differ for plant height and shoot biomass ($P=0.05$) declining as the season progressed and crops had started yellowing at 100 DAS.

It is imperative to note that the growth period/DAS indeed had a significant effect on DM production at 80 DAS ($P<0.038$) and 90 DAS ($P<0.003$). The effect of the interaction of species and N nutrition on DM yield was not significant at 70 DAS, which mirrored a similar trend with field experiment. The biomass yield of canola was 75% of white cabbage at 70 (DAS), while DM yield of tronchunda cabbage variety was 88% of the yield of white cabbage (Table 7.1). By contrast the yields increased by 21.1%, 65.3% and 46.2% for white cabbage, canola and tronchunda cabbage, respectively, at 100 DAS and 52.0% 41.3% and 51.3% for the respective crops as the season progressed.

The results further indicate that the production of canola had better response as the season progressed than white cabbage and tronchuda cabbage varieties as it caught up with other two cabbage species. Among the crop species, canola was significantly taller than the rest, while in terms of DM production, all three crop species were not significantly ($P=0.503$) different at 110 DAS, although yield varied significantly during the earlier sampling dates.

Although there were linear trends in biomass yield during the growth periods, there was no yield difference at 100 DAS and 110 DAS (P=0.05) as canola developed multiple stems and increased in height (Table 7.2). The growth of the two cabbage varieties stagnated at this period and leaves began to turn yellow. On the whole, for all yield components of the *Brassica spp* depend on genotypic effects that vary from 57% to 90%, as is expected due to inherent differences among *Brassica* spp for yield-forming traits (Miller et al., 2003).

7.4.3 Nitrogen uptake and yield components

Shoot N values have been proposed as a diagnostic tool for assessing potential N response in canola (Hocking et al. 1997), although it is recognized that care needs to be taken in interpreting critical limits in terms of both sowing time and plant growth stage (Hocking 2001). Across the three crop species, the shoot N values averaged 4.54%, 4.39% and 4.46% for canola, white cabbage and tronchuda cabbage for all sampling dates, respectively; while shoot biomass values averaged 11.36 g, 13.11 g and 12.32 g plant^{-1} for the respective crops. It was apparent that shoot N contents were significantly less variable than shoot biomass, which has also been reported for canola crops prior to stem elongation by Hocking et al. (2001).

Nitrogen uptake was used as a measure of N availability for each crop species, which is the product of tissue N content and shoot biomass. Nitrogen uptake was 53.2 kg N ha^{-1}, 70.18 kg N ha^{-1}, and 64.2 kg N ha^{-1} (Figure 7.5) at 70 DAS, for canola, white cabbage and tronchuda cabbage, respectively, and it is thought to be within the range of canola and other brassica *spp* requirements for maximum growth.

Canola had high initial N concentrations in the early growth stage (>7%); projected to 53.2 kg N ha^{-1} uptake at 70 DAS. Plant N concentrations decreased throughout the season. Elsewhere, Evans et al. (2001) report that maximum uptake is attained at flower and nutrients are lost from the system either by flower and leaf senescence, below-ground partitioning, or incomplete biomass retrieval of volatile nutrient loss from the tissue. When growing canola, fertiliser nutrient needs should be supplied in adequate amounts at or prior to bolting. Nutrients supplied after this crop growth stage are likely to be ineffective because it will be distributed in the root zone for rapid uptake (Wysocki et al. 2005).

Canola started flowering at 80 DAS; resulting in slow growth rate of the crop. Wysocki et al. (2005) also report retarded growth rate during flowering resulting in loss of crop DM because of flower drop and senescence of lower leaves.

Dry matter was highest at 110 DAS but had not reached a peak commonly known as full bloom as the plants were harvested prior to maturity. However, it was expected to decline due to flower drop, leaf senescence and perhaps to partitioning of nutrients to belowground DM as reported by Evans et al. (2001). Dry matter and N uptake are plotted in figure 6.9 which show the relationship between nutrient uptake and dry matter accumulation. Nutrient uptake preceded DM accumulation (growth). Plant tissue concentrations were highest in early crop stages and declined with advancing maturity.

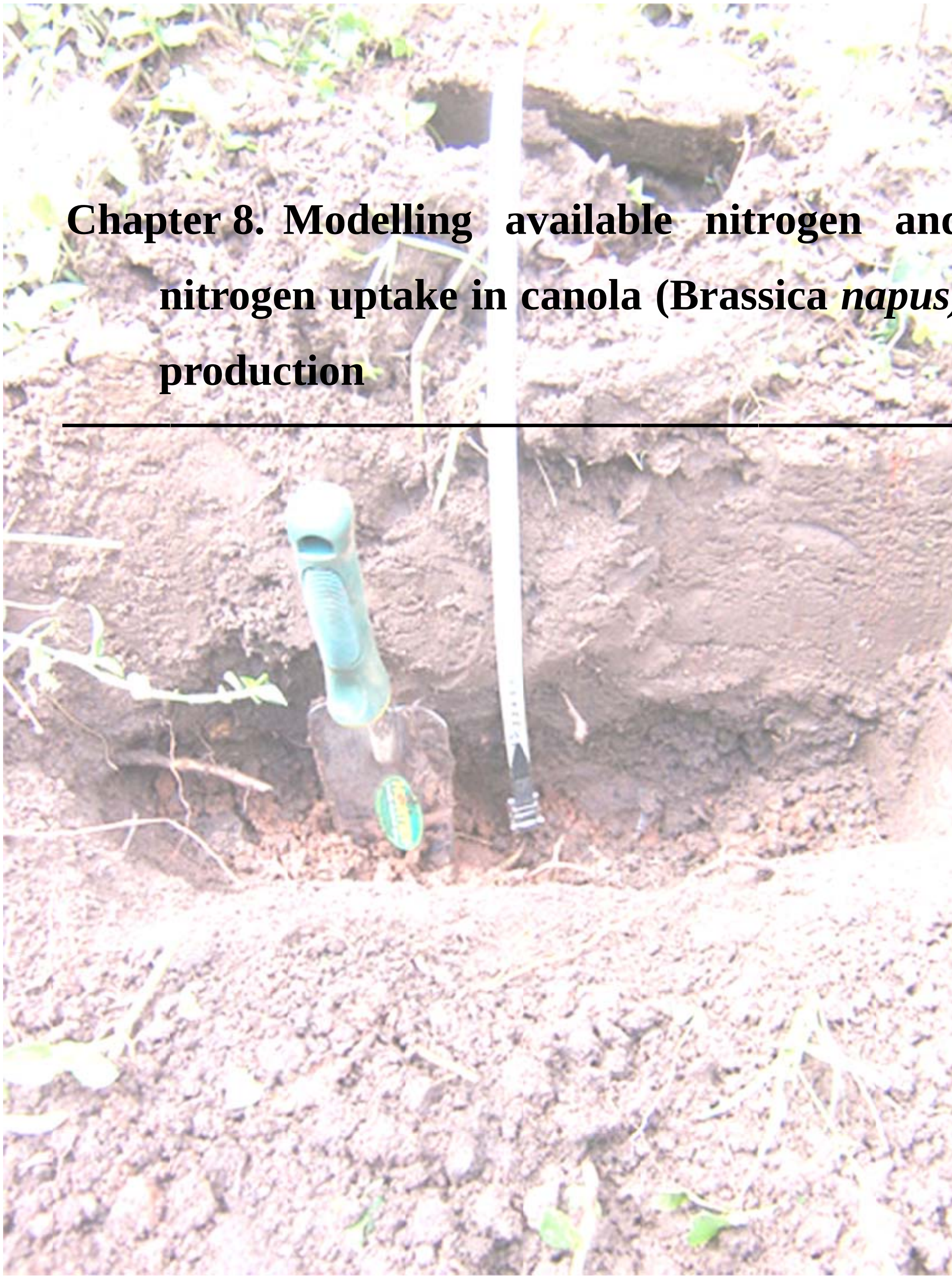
7.4.4 Rationale of the experiment

There was a need to compare growth characteristics of canola and other Brassica species, particularly cabbage, that is commonly grown in Uganda in order to generate data required for modelling. There were no growth differences among the three Brassica *spp* indicating that canola model may be a suitable proxy for cabbage production when it comes to N application response. Therefore, this in addition to previous chapters, forms a benchmark against which select your nitrogen (SYN) model (Diggle et al. 2003) is built hence the foundation for the following chapter. For this reason, N modelling has been explored in the following chapter based on these data.

7.5 Conclusions

Plant development was similar in all *Brassica* (canola and cabbage) species. Cabbage and canola crop species had high initial N concentrations in the early growth stages (>7%). This accounts for about 70 kg N ha^{-1} and 53 kg N ha^{-1} uptake at 70 DAS. The concentration of N in shoot DM of the three *Brassicas* decreased from approximately 7.4%, 7.7% and 8.0% at 70 DAS to 1.9%, 2.3% and 2.7% 110 DAS for tronchuda, white cabbage and canola crops, respectively. There were no differences between crops at 100 DAS and 110 DAS.

Chapter 8. Modelling available nitrogen and nitrogen uptake in canola (Brassica *napus)* production



8.1 Introduction

There is little scientific data available on the optimal levels of N application, in particular for cabbage production in the central districts of Uganda on soils to which cattle manure is applied. In order to make informed N management decisions, growers need quantitative knowledge of plant N availability, uptake and potential yield of the crop. This chapter presents a mechanistic dynamic model that integrates this knowledge to predict crop N availability, N uptake, potential yield and economic returns using data collected from two field experiments and a glasshouse experiment (Chapters 5 and 6). SYN model as discussed in Chapter 3 has been re-calibrated and is described in this chapter.

Although smallholder farmers in Uganda have adopted the use of cattle manure in crop production, there has been little quantitative research into its agronomic and fertiliser value. To improve the efficiency of use of nutrients from cattle manure and provide a guideline for best practices it is desirable to develop appropriate methods, including modelling, to predict N availability for crop production under field conditions. Addressing the lack of information on the agronomic value of cattle manure will enable farmers to gain the maximum economic benefit, and maximise recycling opportunities (Green Alliance 2007) and increase the use of cattle manure in agriculture. Over recent years, manure models have been developed to predict N availability to crop, including the N calculator (MANNER (MANure Nitrogen Evaluation Routine-NPK) (Chambers et al. 1998; 1999; 2000; Nicholson et al. 2000; 2008); MANNER-PSM (Chambers et al. 2010); manure application rate calculator (MARC 2008); PLANET and ENCASH nutrient management software tools widely used in England, Wales and Scotland (PLANET 2006; Sinclair et al. 2010). Modelling N is desirable:

a. To give “transferability” to limited sets of site, season and management specific to experimental results.
b. To integrate nutrient information with other factors which affect yield and its response to added nutrients.
c. To assist farmers in making decisions about fertilisers.
d. As single factor methods are often unreliable (Myers 1984).
e. To study long-term issues such as nutrient decline and the environmental issue of nutrient leaching (Angus et al. 1993; Burgess and Bowden 1993).

The overall objective of this chapter is to calibrate a model that will quantify the N availability and predict crop returns from output and potential yield of cabbage production in crop-livestock farming systems of Uganda.

8.2 Materials and methods

8.2.1 Calibrating and parameterisation of the model for canola

Modelling was adopted to predict availability of cattle manure N in Brassica *spp* production following the NAVAIL model of Burgess et al. (2003). The model was calibrated on experimental data for canola growing over several levels of applied N as either cattle manure or urea and in seasons of two differing rainfalls. Data from the two seasons of 2009 and 2010 field experiments (Chapters 5 and 6) and glasshouse experiment (Chapter 7) for canola (*Brassica napus var Cobbler*) was used to calibrate the parameters of the model. The data collected includes production/yield data (fresh and DM), N concentration, N uptake and relative effectiveness (RE) values of cattle manure N compared to inorganic fertiliser.

The data set used N treatments of 0, 40, 80, 120, 160 and 200 kg N ha^{-1}. Measurements of two types of cattle manure and urea included total N, ammonium, nitrate and N status of the soil as well as weather data were available. The data were used as independent variables to test the model's outputs. Thus, the model was built with data derived from experimental results and literature to predict N availability, N uptake and potential yield.

For organic residues, **N** transformations are dependent on soil conditions; they are unlikely to occur if the soil dries out, and the rates of the processes may be increased by high temperatures. For this reason, the time of addition for such sources must be the time during which the appropriate amount of transformation would have occurred at the stated ammonification and nitrification rates for that source as described above. The modelled rates are listed in Tables 8.1 and 8.2.

Table 8.1: Modelled parameters in NAVAIL model from 2009 data for cattle manure and urea

Source	Week Added	Organic Nitrogen	Ammonium Nitrogen	Nitrate nitrogen	Immobilized Nitrogen	Leached Nitrogen	Available Nitrogen	Ammonification rate	Nitrification rate	Availability Index
Fertiliser		kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	(/week)	(/week)	(Kn)
Soil organic nitrogen	-1	1500	0	0				0.002	0.3	0.019
Residual organic nitrogen	-4	20	0.80	0.24				0.040	0.3	0.356
Urea	4	24	10.91	34.23	2.133	0.00	45.153	0.900	0.4	0.891
Cattle manure (M_{12})*	0	197. 6	1.21	1.225				0.025	0.3	0.201

*M_{12}: Cattle manure stored for twelve months at the highest rate of 200 kg ha^{-1}

Table 8.2: Modelled parameters in NAVAIL model from 2010 data for cattle manure and urea

Source	Week Added	Organic Nitrogen	Ammonium Nitrogen	Nitrate Nitrogen	Immobilized Nitrogen	Leached Nitrogen	Available nitrogen	Ammonification rate	Nitrification rate	Availability Index
Fertiliser		kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	(/week)	(/week)	(Kn)
Soil organic nitrogen	-1	1500	0	0				0.002	0.3	0.019
Residual organic nitrogen	-4	20	0	0				0.040	0.3	0.356
Urea	4	24	10.93	33.99	2.155	0.1987	44.93	0.900	0.4	0.891
Cattle manure (M_4)*	0	196.9	1.53	1.53				0.046	0.3	0.331
Cattle manure (M_{12})	0	193.2	1.69	5.08				0.030	0.3	0.243

* M_4: Cattle manure stored for four months at the highest rate of 200 kg ha^{-1}

*M_{12}: Cattle manure stored for twelve months at the highest rate of 200 kg ha^{-1}

8.2.2 Model description

The NAVAIL model is derived for canola and other cereal crops in Western Australia that determines N availability, actual yield and crop returns following Burgess et al. (2003). The effects of root growth on availability of N were based on the approach described by Angus et al. (1993) and Burgess et al. (2003). It incorporates functionality to simulate N uptake, potential yield, net returns and responses to N application and N supply.

8.2.3 Nitrogen supply and uptake

Nitrogen supply is considered a function of available N (Navail N), the root depth of the crop and a plant uptake factor that decreases as soil water content declines. Navail N was assumed to be the nitrate and ammonia present in the root zone of the crop (Burgess et al. 2003). The NAVAIL spreadsheet uses graphic output to illustrate the interactions between mineralisation, root growth, leaching, and availability of N. It gives the annual time step fertiliser efficiency, which changes with the range of inputs (e.g. soil type, rainfall-rooting depth). In this study, SYN model (Bowden and Diggle 2002, Burgess et al. 2003) which is a production function model best describes plant function and was used to predict N uptake and potential yield. However, the NAVAIL component was used to predict N availability. NAVAIL is the N availability model and the modified form of NAVAIL model was used to include cattle manure. NAVAIL model is thus expressed as:

Nupt=A*Z*tanh

(Navail/(A*Z))…………………………………………………………………….1

Where:

Z=Constant

A=Potential yield (kg ha^{-1})

Navail=Sum

(KNi*Ni)…………………………………………………………………………..2

Where:

KNi*Ni = is the scaled unit “availability” of nitrogen from source “i”.

KN_1=Urea

KN_2=Cattle manure stored for 4 months (M_4)

KN_3= Cattle manure stored for 12 months (M_{12}) and Ni= are the kg N ha^{-1} of that source.

The relative effectiveness (RE) values and availability indexes (AVI) (Chapters 5 and 6) of cattle manure N applied in the 2009 and 2010 seasons were used to estimate N availability, N uptake and potential yield of canola. Gravimetric water holding capacity of 14.5% for the season was assumed based on (Chapter 7).

8.3 Results

The model developed in this chapter was tested using data as described in section 8.2.1. The data included different harvesting dates and N rates and were used as an independent test of the model's outputs. The results from testing showing forms of N, roots and profile of N and growth response and yield response are presented in Figures 8.1-8.6. Figure 8.7 shows the observed vs the calculated canola yield kg ha^{-1} for 2009 season.

8.3.1 Effect of rainfall on nitrogen availability

Figures 8.1 and 8.2 show the estimated amount of various forms of N as they change through time in the weeks before and after seeding due to the influence of rainfall. The amount through time, of N from all sources which was in the form of ammonium, total nitrate, nitrate in the root zone, immobilised N, and available N, where 130 mm of leaching rainfall occured from week 4 to 7 in the year 2009, and where 106 mm of leaching rainfall occured from week 4 to 7 during the 2010 season.

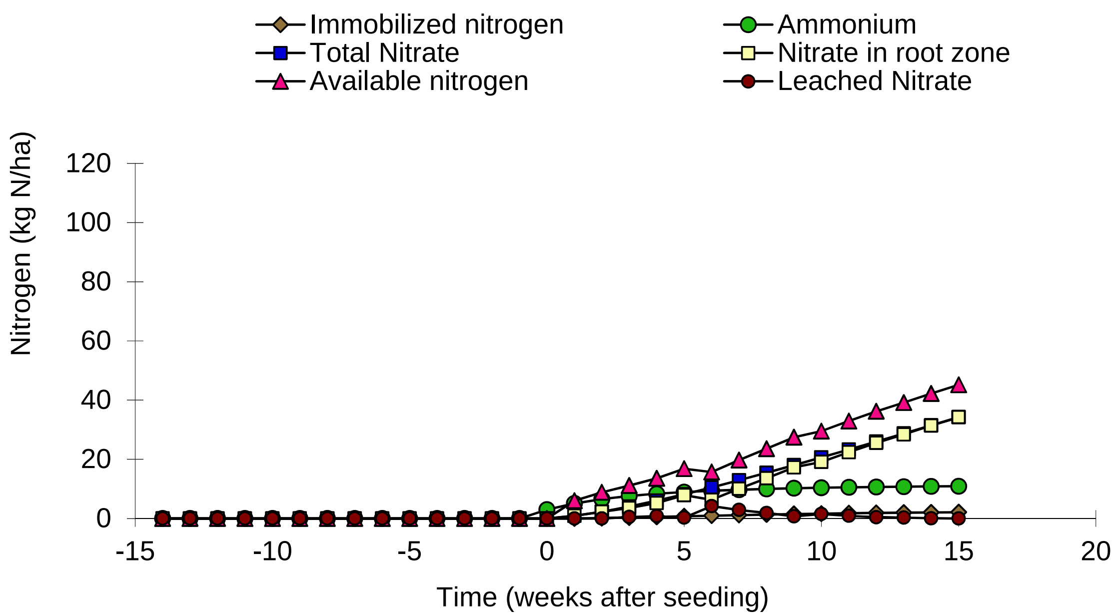


Figure 8.1: Estimated amount of immobilised nitrogen, amonium, total nitrate, nitrate in root zone, available nitrogen and leached nitrate at 130 mm of rainfall received during the 2009 season

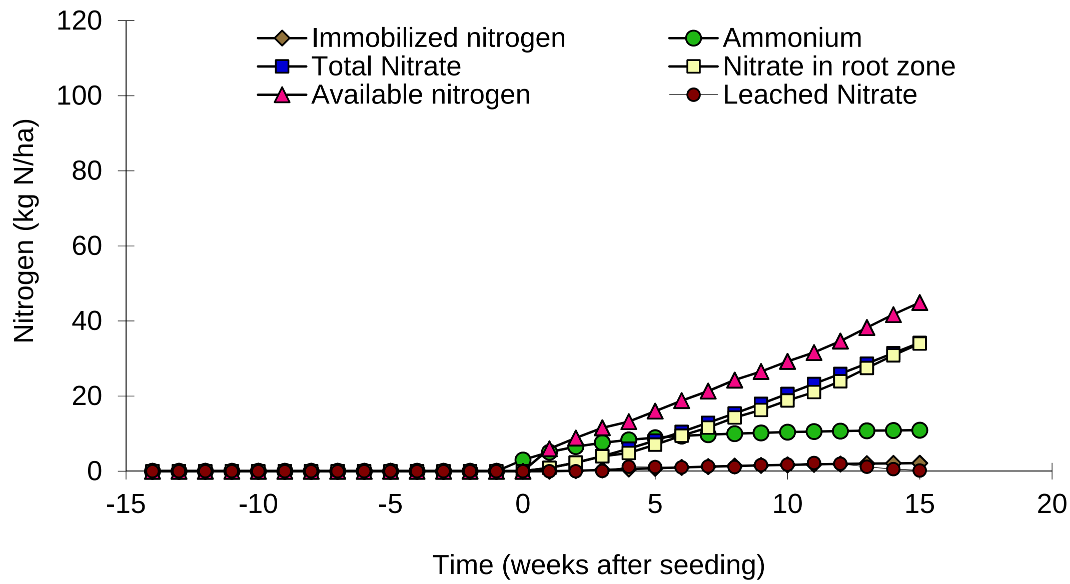


Figure 8.2: Estimated amount of immobilised nitrogen, amonium, total nitrate, nitrate in root zone, available nitrogen and leached nitrate at 106 mm of rainfall received during the 2010 season

8.3.2 Effect on root growth on availability of nitrogen

Figures 8.3 and 8.4 show the estimated rooting depth and the depth of the wetting front through time in the weeks before and after seeding. In 2009, 130 mm of leaching rainfall occured from week 4 to 7, and in 2010 the figure was 106 mm. The increased rain increased the maximum depth of the wetting front by about 46 cm. Final rooting depth was less with lower rainfall, because the roots reached the wetting front at week 13 at a depth of 133 cm. It should be noted that the root zone is the soil that is above root depth at each time.

Increased rainfall sharply reduced mineral N in the rooting zone in the weeks in which the rainfall occured. Although these figures remained low for several weeks, they returned to a similar value as the roots grew into leached nitrate N. The wetting front for 2010 season was reached at 101.6 cm of root depth at 102 mm of rainfall at week 12 and root depth reached 92.2 cm at week 15.

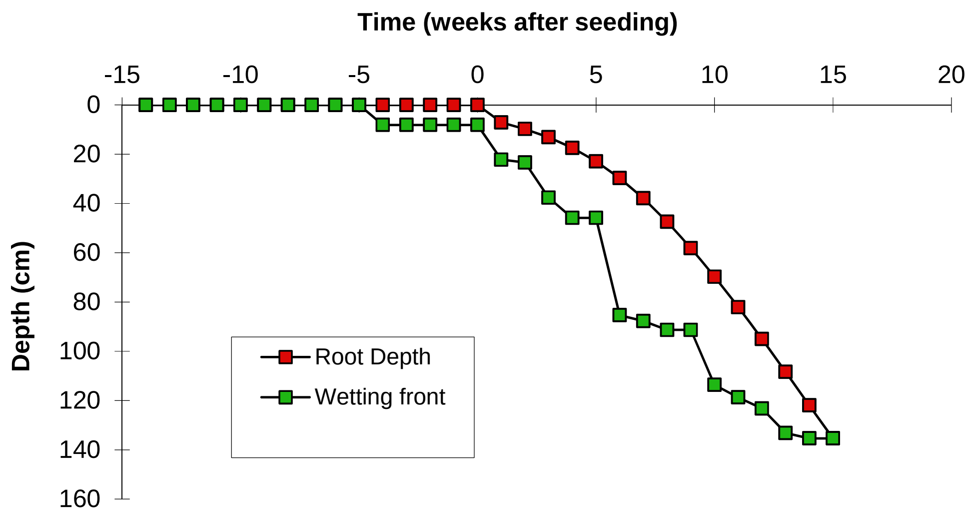


Figure 8.3: Estimated root depth and wetting front over time as influenced by rainfall during 2009 season from week 4 to 7.

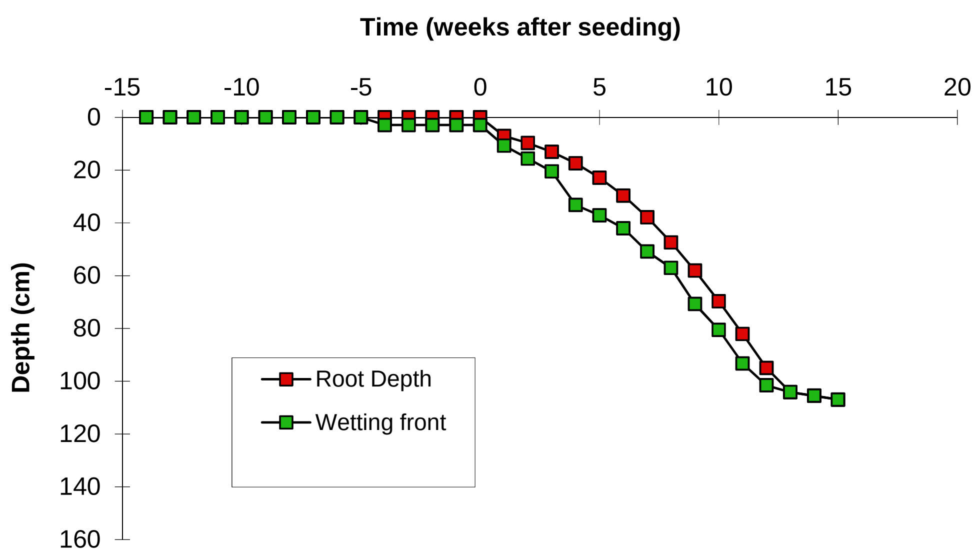


Figure 8.4: Estimated root depth and wetting front over time as influenced by rainfall during 2010 season from week 4 to week 7.

Figures 8.5 and 8.6 show the estimated mineral N (ammonium plus nitrate) concentration (mg Nl^{-1}) at different soil depths for specified weeks after seeding. This can help to show leaching and root depth through time.

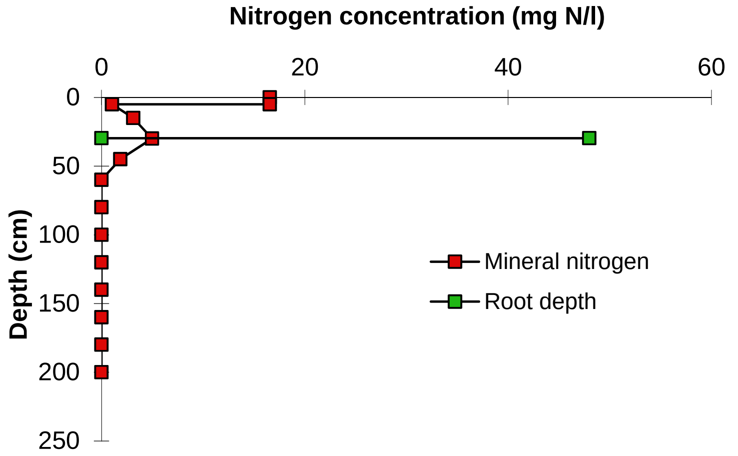


Figure 8.5: Estimated profile of the available nitrogen from the fertiliser, and the root depth, at 8 weeks after seeding where 130 mm of leaching rainfall occurred from week 4 to 7.

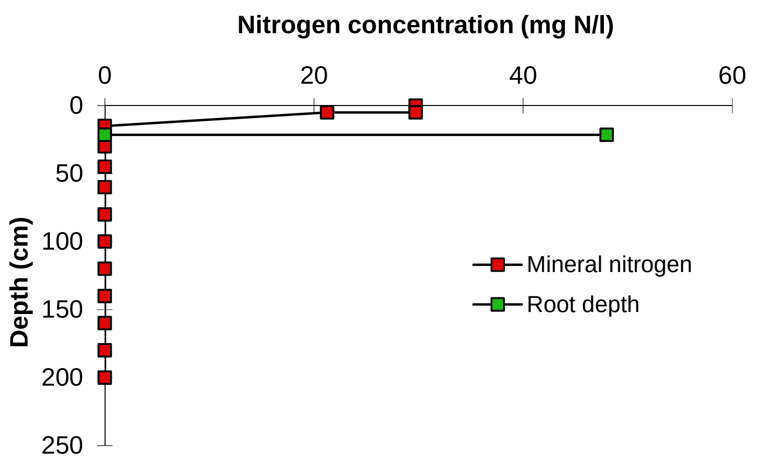


Figure 8.6: Estimated profile of the available nitrogen from the fertiliser, and the root depth, at 8 weeks after seeding where 106 mm of leaching rainfall occurred from week 4 to 7.

8.3.3 The observed and calculated canola yields.

Figure 8.7 and 8.8 present the observed and predicted canola yields in the field experiment at Ucarty of 2009 and 2010 seasons at 93 days after sowing (DAS). The observed and calculated yields were linearly related with slopes not significantly different to unity with root mean square error (RMSE) of 178 for example for 2009. Actual and modelled DM estimates had a close linear relationship for the field data observed, though the model tended to over predict yield, particularly for the cattle manure (M_4 and M_{12}) which had low N concentrations compared to urea.

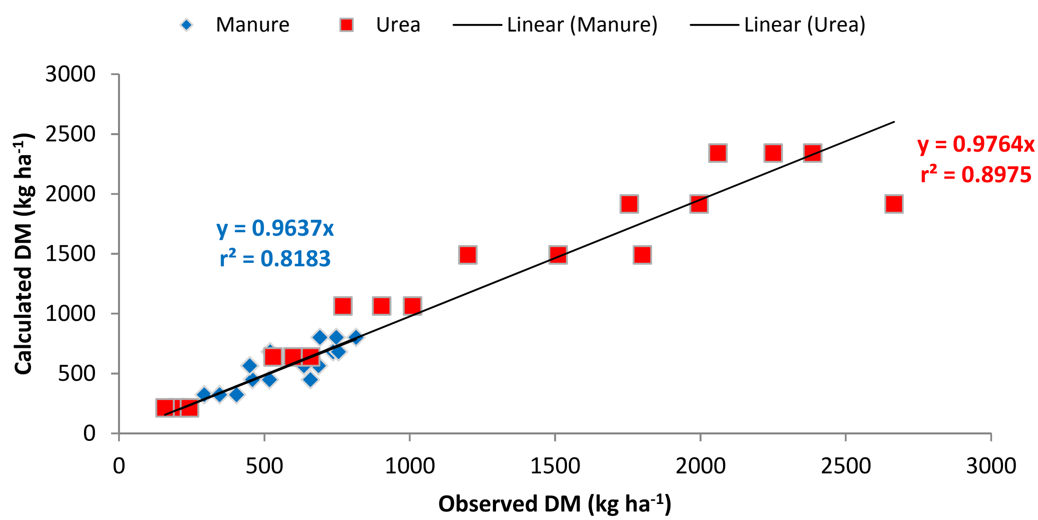


Figure 8.7: Observed vs calculated canola yield kg ha^{-1} for 2009 season

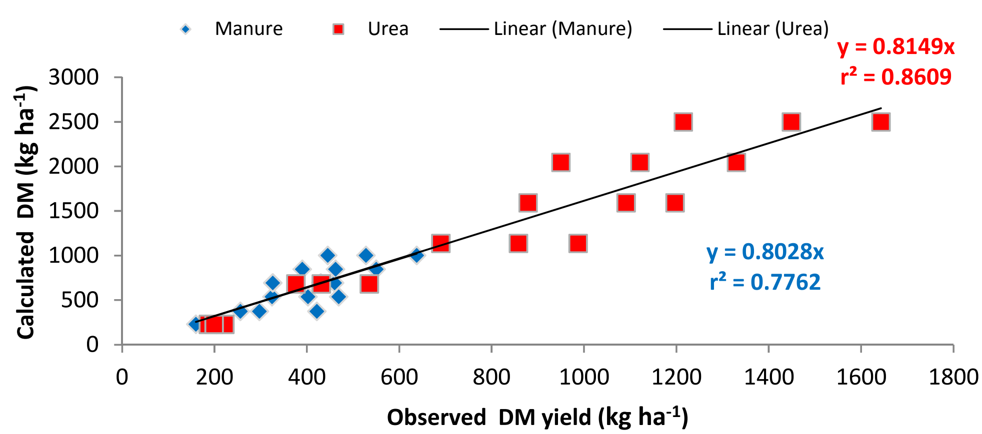


Figure 8.8: Observed vs calculated canola yield kg ha^{-1} for 2010 field experiment

8.3.4 Nitrogen uptake

The measured and modelled N was linearly related with slopes not significantly different to unity (Figures 8.9 and 8.10). The N estimates had a close linear relationship for the field data observed, however, the model over predicted N, for both cattle manure; stored for 4 and 12 twelve months, M_4 and M_{12}, respectively, and had low N concentrations in comparison to urea.

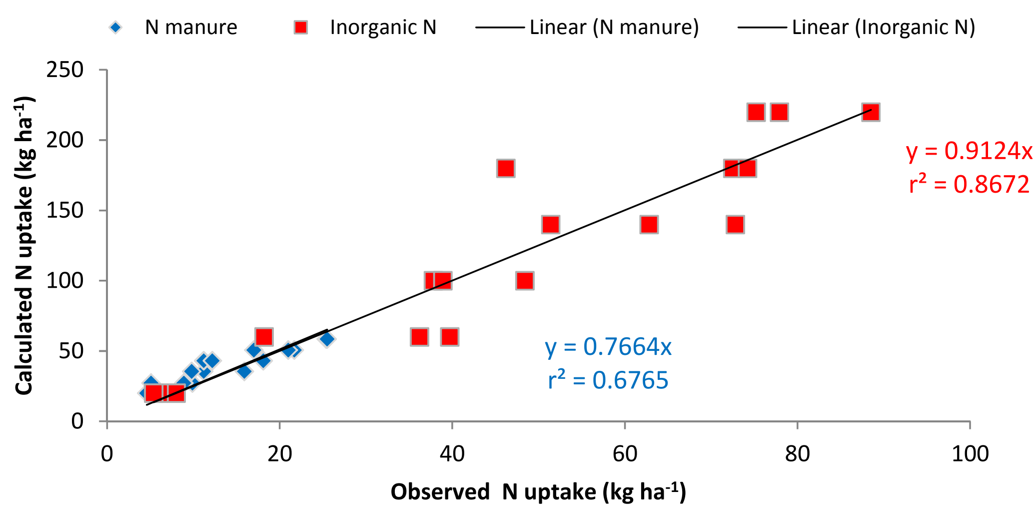


Figure 8.9: Observed vs calculated total N uptake at final harvest for six rates of N for the 2009 season

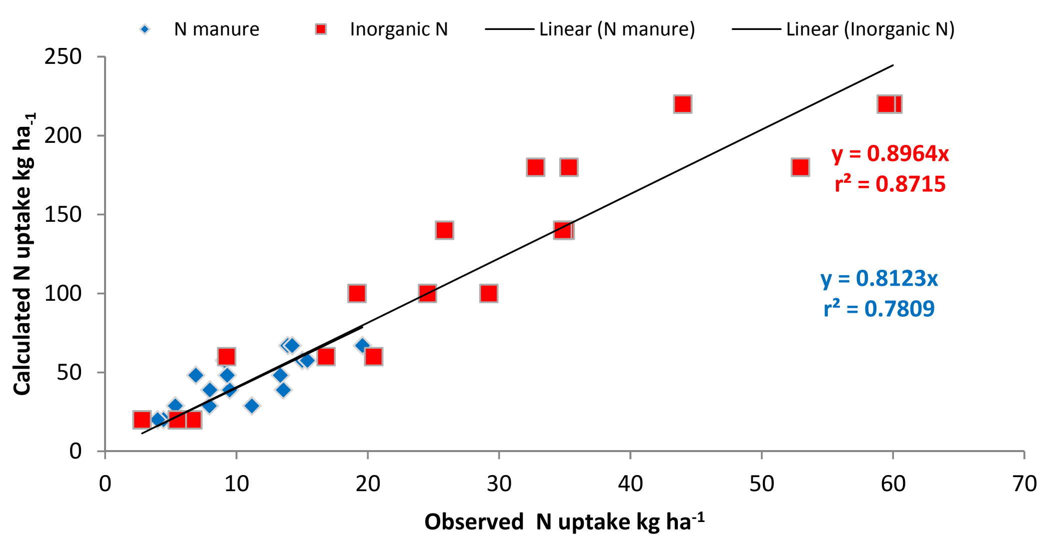


Figure 8.10: Observed vs calculated total N uptake at final harvest for six rates of N for the 2010 season.

8.4 Discussion

The calibrated model predicted the response of canola crop to soil N availability. Nitrogen is only available to the plant if it is in the root zone (Burgess et al. 2003; Bowden and Chmielewski 2006). The results indicated that rainfall increased the maximum depth of the wetting front by about 46 cm. Final rooting depth was less with lower rainfall and increased rainfall significantly reduced nitrate in the rooting zone in the weeks in which the rainfall occured due to increased leaching. Burgess et al. (2003) report that mineral N that is above the root depth is available for crop uptake.

The first year rains resulted in N leaching further below the root zone as indicated in Figure 8.3. If the wetting front is below the root zone, then much of the nitrate may be unavailable to the plant (Bowden and Diggle 2002; Burgess et al. 2003).

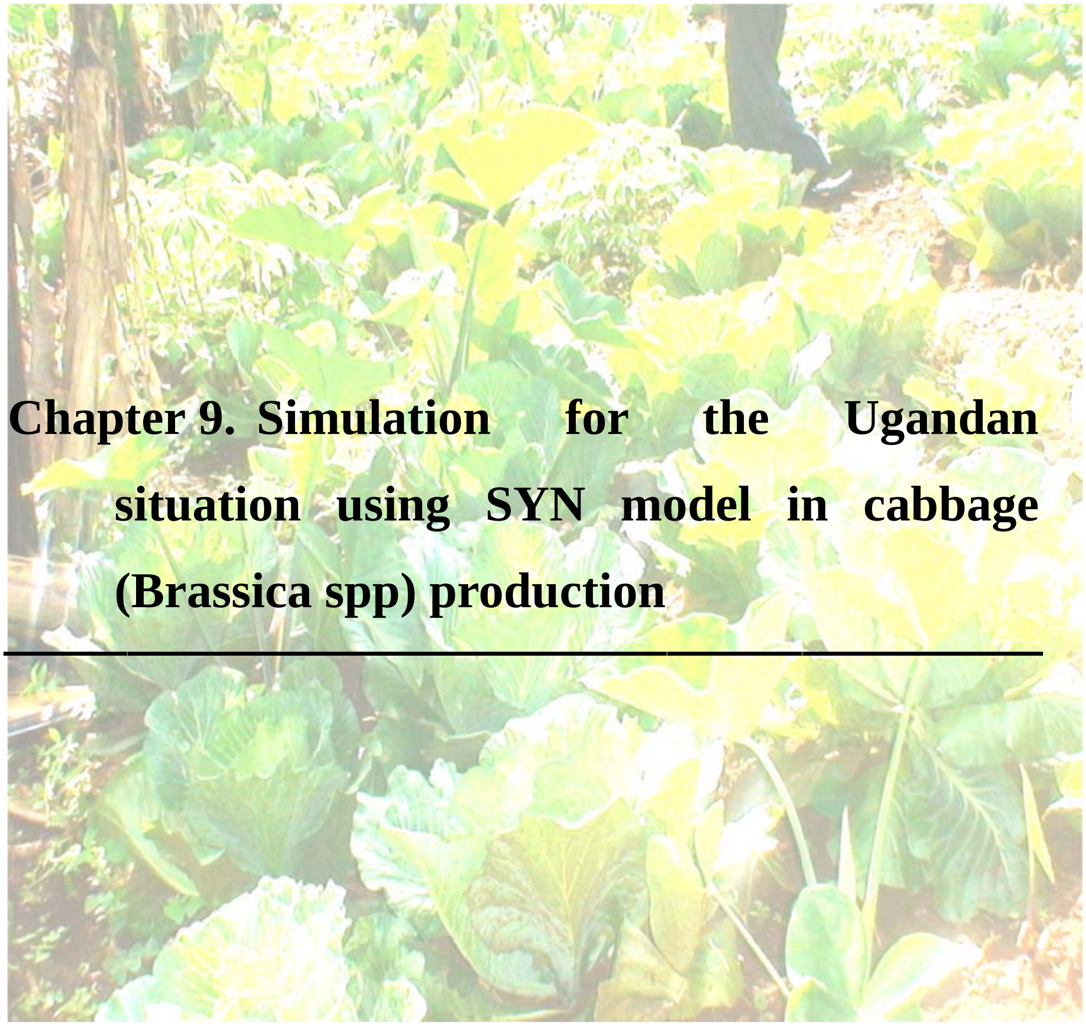
Figures 8.5 and 8.6 show the amount of mineral N concentration at different soil depths for specified weeks after seeding. Therefore, the availability of N from any source in any week is highly dependent on the amount of N in the nitrate form as well as the rooting depth of the crop. Nitrogen availability can increase with time as roots grow down into previously leached nitrate (Bowden and Chmielewski 2001).

Crop development of the Brassica species seem to be uniform and as such, the same assumption was assumed when calibrating for cabbage for the Ugandan situation as there was no significant growth differences between cabbage and canola which were grown under optimum conditions in the glasshouse experiment (Chapter 7).

Overall, the enhancements incorporated into NAVAIL enable robust estimates to be made of the quantity and economic value of fertiliser including organic manure nutrients available to the crops under Western Australian (WA) conditions (Burgess et al. 2003). This is expected to be replicated in Uganda given that there are favourable climatic conditions, which enhance mineralisation of cattle manure N that is key to N availability. The calibrated model is discussed in the simulation of cabbage production for Uganda in the following chapter.

8.5 Conclusion

- The calibrated model predicted the response of the canola crop to N availability. It quantified N availability and predicted yield of canola under cattle manure and inorganic fertiliser application. The first year rains resulted in N leaching further below the root zone as opposed to the second year.
- The model based on data from this case study marked a significant step towards addressing soil fertility management problems in Uganda and is possibly more suitable to cattle manure for Ugandan situation given its dynamic nature in handling manure N.



Chapter 9. Simulation for the Ugandan situation using SYN model in cabbage (Brassica spp) production

9.1 Introduction

A large number of weather, soil and management variables, which vary significantly across space, determine crop growth and productivity (Tisdale et al. 1999; Dadhwal 2003; White 2006; Panda 2008). These include factors such as genetic potential of crop cultivar, soil, weather, biotic stresses and cultivation practices such as date of sowing, pest and disease control and fertiliser application (Dadhwal 2003) including cattle manure. However, there is a need to find ways to apply the right quantities of the latter to reduce soil fertility decline in the central districts of Uganda that will avail nutrients to the crop.

Generally for a given area, year-to-year yield variability has been mostly modelled through fertiliser inputs as a predictor using either empirical or crop simulation approach. With the advent of manure models such as MANNER-NPK (Chambers et al. 1999; 2010) and MARC (2008) to mention a few as discussed in chapter three, it is necessary to select the right model applicable to a particular situation. Given that most nutrients in cattle manure especially N are in organic forms and therefore not readily available or are released slowly, a simulation approach is required to help famers apply correct rates. This requires a model that is able to predict N uptake, potential yields and economic returns following fertiliser application. SYN model calibrated in Chapter 8 has used experimental data to derive the functional form of cabbage for the Ugandan situation.

Experimental data have become an important tool for yield modelling. Data in Navail spreadsheet provide timely, accurate, synoptic and objective estimation of the nutrients particularly N that will be available to the crop for its optimal growth conditions. The model helps to predict potential yields, N uptake and economic returns. The SYN model through its twin Navail spreadsheet as a crop production simulation model allows the adjustment of input levels, input costs, and crop revenues while growing a virtual cabbage crop. By experimenting with different levels of inputs, costs and revenues, it helps to determine the optimum or economic yield for each economic situation. The model can provide an excellent solution to applying the right rates of fertilisers including cattle manure to obtain the potential yields.

In this study an attempt has been made to introduce a basic framework and indicate through specific case scenarios; (a) how rates of inorganic N and manure N influence N uptake, potential yields and economic returns and (b) what if both manure N and inorganic N are applied together, how would the parameters in (a) be influenced.

Select your nitrogen (SYN) simulation model has been successful in field-scale applications in Western Australia and has been calibrated in Chapter 8 for its possible adoption in Uganda to predict N availability in cattle manure and inorganic fertiliser (urea) to improve soil fertility for crop production. A number of scenarios that demonstrated such use of Navail spreadsheet are presented in section 9.3 and discussed in 9.4.

This chapter presents the simulation approach adopted using the SYN model to obtain potential yields for cabbage production in Uganda. The main objective was to simulate the model for its possible adoption for N management decisions in Uganda. The specific objectives were to quantify the N availability, predict crop returns from output and potential yield of cabbage production in crop-livestock farming systems of Uganda and to determine the comparative financial cost of cattle manure N compared to inorganic N in cabbage production. It is anticipated that the adoption of the SYN model as a decision support system will help farmers, extension agents, and researchers by producing a quick estimate of the fate of manure N following its application. This is crucial in order to increase and sustain crop production in Uganda. However, some assumptions and coefficients in the model will need to be field-tested and the model output verified for Ugandan conditions before it can be used to provide recommendation to rural advisers and farmers. However, it should be noted that the steps taken in the thesis go a long way towards the full applicability of SYN for Ugandan conditions, this needs extra steps including training the technical advisors to smallholder farmers in addition to the discussion in section 3.4.7 and chapter 10 that are required for full applicability. Ugandan soil and weather data were not used in the simulation because it required resources to set up field experiments; however, skills acquired in WA experiments are adequate to replicate the model under Ugandan conditions.

9.2 Materials and methods

Crop yield data were generated with the SYN model using simulation techniques, which use climatic and soil conditions and related risks as well as other factors including inorganic N and cattle manure N inputs. The SYN model was simulated to Ugandan conditions for cabbage production to a potential yield level of 29 t ha^{-1} (fresh weight) (MAAIF 1999; Ssonko et al. 2005) to estimate N requirements kg ha^{-1} using data described in section 8.2.2. A simulation model that predicts available N (NAVAIL), N uptake, and potential yield is developed and described for cabbage. The model replicated experimentally observed total N for three Brassicas (canola and two cabbage varieties), which had taken up between 10 and 81 kg N ha^{-1} per crop.

9.2.1 Analysis of data

Data were analysed using the computer based model SYN (Bowden and Diggle 2002) revised by incorporating cattle manure data (Chapter 8). A sensitivity analysis was carried out on two variables including rate of fertiliser applied, price of N and cabbage, and potential yield of cabbage. The model estimates N availability for 4-15 weeks after application.

9.2.2 Calculation of the potential of economic returns of cabbage

A simple system for modelling nutrient responses to given returns can be estimated from the price ratio of product and nutrient, and the yield response to the applied nutrient (Angus et al. 1993), such that the potential economic return is (Py/CN) dy/dN;

Where:

Py is the price of cabbage in dollars (A$).
CN is the cost of nutrient in dollars (A$), and
dy/dN is the response of cabbage to nutrient N.

The actual response, dy/dN, is determined empirically for a particular environment, but a first approximation to the potential response is the inverse of the nutrient concentration in cabbage since a proportion of the marginal applied nutrient, depending on the efficiency of uptake and the mobility of the nutrient in the plant, will be accumulated in an increasing amount of rain with little change in its concentration (Angus et al. 1993).

For profit maximisation, an objective function is numerically expressed as; Profit in $ = f(N input, yield potential etc) and thus:

Profit = Y*Py-X*Px -variable costs-fixed costs

Where:

Y=Total cabbage output kg ha^{-1}
Py= Price of cabbage in $ per kg
X=Total fertiliser input (Manure N and inorganic fertiliser N kg ha^{-1})
Px=Price of manure N and inorganic N in $ per kg

The variable costs are cattle manure N, inorganic N, cabbage/canola seed (yield and quality), acidification, non-wetting, and nutrient export.

9.2.3 Model inputs

The inputs required for the model are described in section 3.4.7. Following the pot experiment where the growth characteristics of the three Brassicas were not significantly different (P=0.05), cabbage substituted canola as the latter was found to be a suitable proxy for its production. The prices of a cabbage and cattle manure N have been computed based on the survey data in Uganda (section 4.31). Shadow pricing has been used to calculate the cost of manure N per tonne, while the current fertiliser price in Uganda (MFPED 2010) and world fertiliser trends (FAO 2008) were used. This was necessary because to assign value to both tangibles and intangibles inherent in the decision to use cattle manure N and /or estimate the full cost following manure application, shadow price was the only method to adopt. Shadow price is the true economic price/cost of an activity; its opportunity cost. This method was used because shadow prices can be calculated for items that don't have a market price (Shaik et al. 2002; Cochrane 2005; Kanbur 2008) to capture all variables relative to the decision, not just those that can be priced on the market such as labour and capital. Shadow prices accurately reflect the opportunity cost of the goods and services used (Shaik et al. 2002). Although, the price of cabbage varied from area to area an average selling price of 700 UGX (AUD$0.25) per kg of cabbage (farm gate price), A$40 per t of cattle manure with a 1.2%, N and A$$4 per kg inorganic N (urea at 46% N) were used in the modelling to calculate the returns following cattle manure N and inorganic N application in cabbage production.

9.3 Results

9.3.1 Effect of nitrogen availability on the yield of cabbage

The simulated yields of cabbage to achieve the potential yield for Uganda are presented in Figure 9.1. The figure shows the three yield potentials described as low, medium and high in this study, simulated at a relative effectiveness (RE) value of N from cattle manure of 0.25 compared to inorganic N as calculated following the methodology as described in section 5.2.8.

The results indicate that 9,300 kg ha^{-1}, 11,200 kg ha^{-1}and 14,600 kg ha^{-1} (fresh weight) can be produced before yields begin to decline for the low, medium and high yield potentials, respectively.

Twenty levels of N were used in the simulation for each year. Three levels of outputs were generated. The N levels were 0, 40, 80, 120, 160, 200, 240, 280, 320, 360, 400, 440, 480, 520, 560, 600, 640, 680, 720 and 760 kg N ha^{-1}. These levels are in accordance with the rates used during the field experiments (Chapters 5-6) and allowed for better comparison between simulated and experimental yields.

Average simulated yield data for each input level are presented in Figures 9.1-9.3. At input levels greater than 240 kg N ha^{-1}, a plateau was reached, with average yields at these levels being 15,708 kg ha^{-1}. In each yield potential, these input levels showed a plateau where yield did not increase further or decline. The maximum yield obtained in any yield potential was 29,976 kg ha^{-1}. At lower input levels, stage III production characteristics can be observed with average yields declining when N uptake is less than 80 kg^{-1}.

Comparing the average experimental yields of 2,500 kg ha^{-1} (DM) from 0 to 200 kg N ha^{-1} with the yields obtained from the simulation using the same N levels, shows a greater range in yields (5.9 t ha^{-1} DM) from the NAVAIL model than the experimental yields. At lower levels of N, yields are lower for the simulator, 1,999 kg ha^{-1} but still higher than the experimental DM yield (1,500 kg ha^{-1}) at final harvest for the 2010 experiment.

Figure 9.2 also presents three yield potentials at an N availability index of 0.80 typical for urea. The availability of urea can range from 0.8 to 0.89 (Burgess and Bowden 2002) and for this study the minimum has been used. About, 19,081, 22,725 and 28,469 kg ha^{-1} (fresh weight) can be produced before yields begin to increase at a declining rate for the low, medium and high yield potentials, respectively.

Figure 9.3 presents the simulated yield potentials for the availability index of 0.33 of N from cattle manure stored for a period of 4 months. Under Ugandan conditions, N mineralisation rate is likely to be higher. For this potential yield, up to 14,600 kg ha^{-1}, 18,500 kg ha^{-1} and 21,000 kg ha^{-1} (fresh weight) can be produced under manure application with favourable conditions.

Figure 9.4 shows the varying yield potentials when the N availability index increases to 0.95. This is assuming a situation with minimal N leaching. In this scenario, potential yields can reach 17,000, 23,000 and 27,880 kg ha^{-1} (fresh weight) before they begin to decline at this availability index. This can occur especially in clay soils characteristic of Ugandan soils.

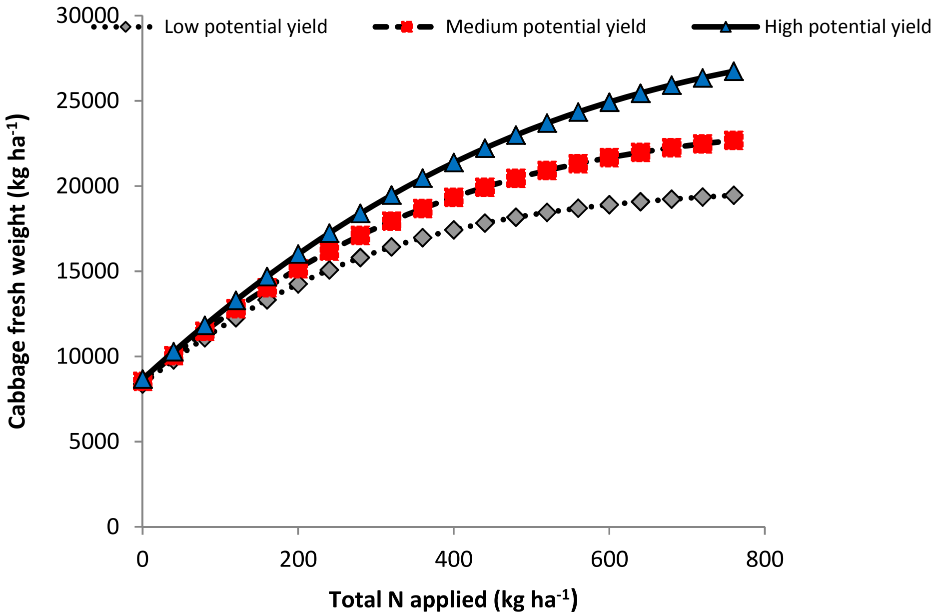


Figure 9.1: Yield potentials of cabbage at relative effectiveness value of 0.25 of N from cattle manure N compared to inorganic N

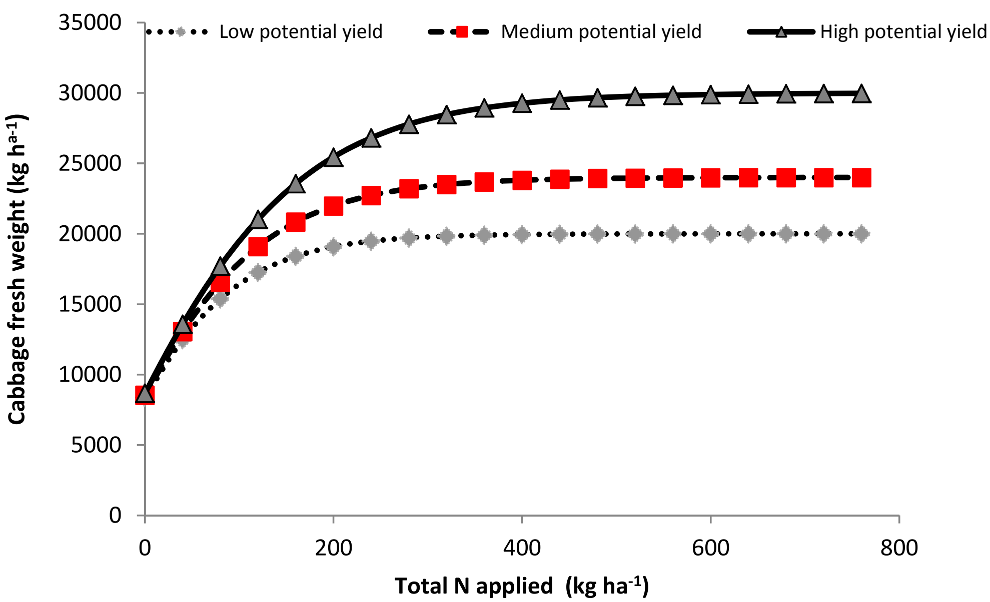


Figure 9.2: Yield potentials of cabbage at a N availability index of 0.80 of inorganic nitrogen fertiliser application (urea)

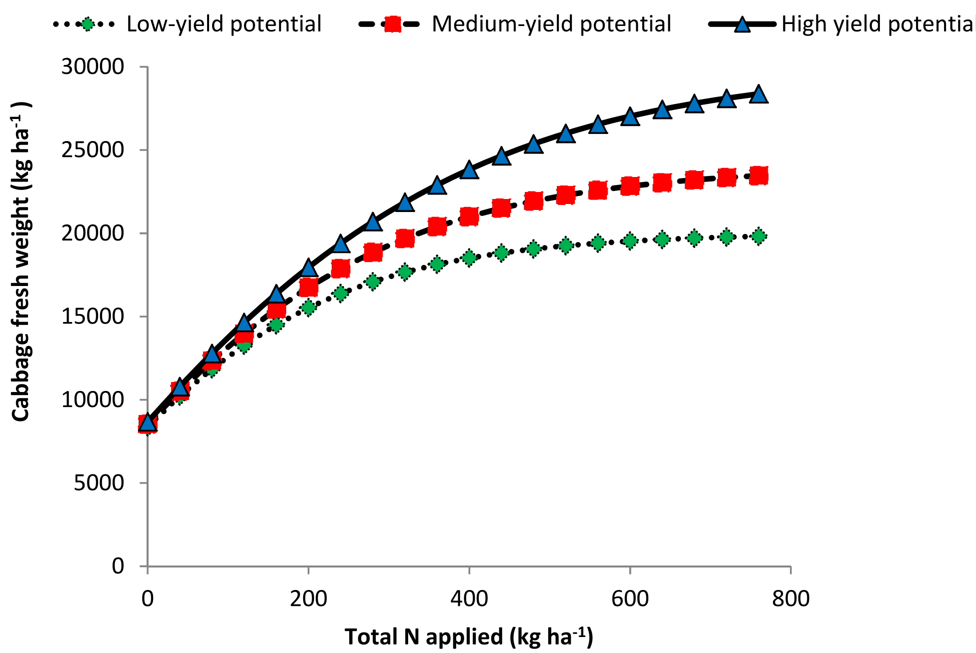


Figure 9.3: Yield potentials of cabbage at availability index of 0.33 of cattle manure N, stored for 4 months compared to inorganic N simulated for Uganda

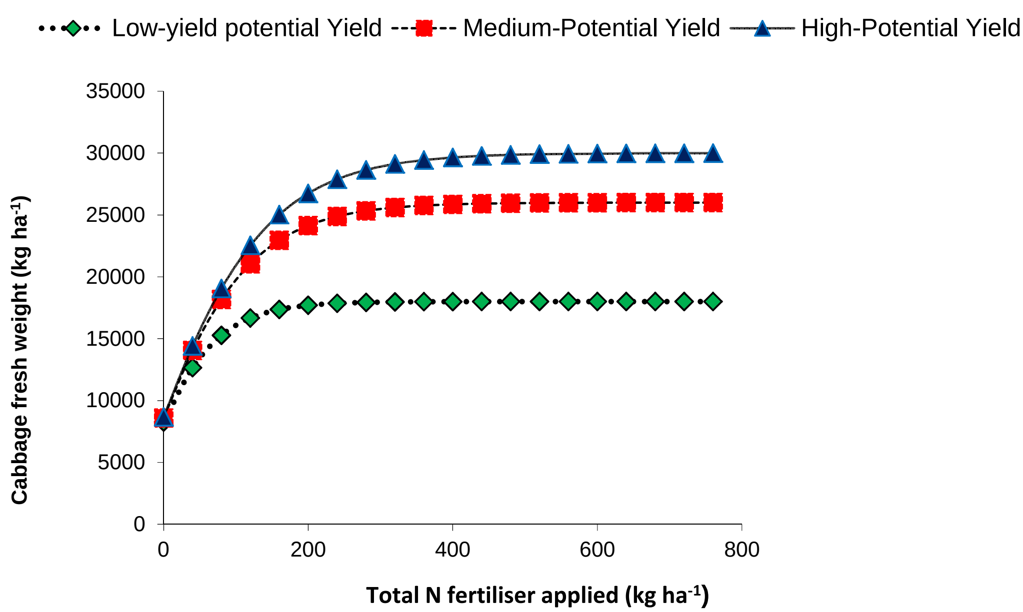


Figure 9.4: Yield potentials of cabbage at availability index of 0. 95 under inorganic N application simulated for Ugandan situation

9.3.2 Simulated crop N uptake

The simulated crop N uptake for the cabbage crop is shown in Tables 9.1 and 9.2 for both inorganic N and manure N, with a total N uptake of 112, 134 and 168 kg N $ha^{-1}$and 109, 127 and 150, respectively, for the low, medium and high yield potentials. This disregards some errors due to the under prediction of N uptake in the high N treatments of above 200 kg N ha^{-1}, where it predicts only (less than) half of the final N taken up.

Table 9.1: Total N uptake (kg N ha-1) simulated under different N levels for inorganic **N**

Potential N uptake of the three yield potentials under inorganic application				
N applied	**Navail**	**Low**	**Medium**	**High**
0	50	47	48	49
40	82	70	73	76
80	114	86	93	99
120	146	97	107	118
160	178	103	117	132
200	210	107	123	143
240	242	109	127	150
280	274	110	130	156
320	306	111	132	159
360	338	111	133	162
400	370	112	133	164
440	402	112	134	165
480	434	112	134	166
520	466	112	134	167
560	498	112	134	167
600	530	112	134	167
640	562	112	134	168
680	594	112	134	168
720	626	112	134	168
760	658	112	134	168

Table 9.2: Total N uptake (kg N ha^{-1}) simulated under different N levels for manure N

Potential N uptake of the three yield potentials under manure N application				
N applied	**Navail**	**Low**	**Medium**	**High**
0	50	47	48	49
40	60	55	56	58
80	70	62	64	66
120	80	69	72	74
160	90	75	79	82
200	100	80	85	90
240	110	84	91	97
280	120	88	96	103
320	130	92	100	109
360	140	95	105	115
400	150	98	108	120
440	160	100	112	124
480	170	102	115	129
520	180	103	117	133
560	190	105	119	136
600	200	106	121	140
640	210	107	123	143
680	220	108	125	145
720	230	108	126	148
760	240	109	127	150

9.3.3 The potential of economic returns of cabbage

Figures 9.5 and 9.6 present potential returns of cabbage. The results indicate that up to a maximum of 12,000 kg ha^{-1} should be produced for the medium yield at RE value of 0.25. Tables 9.4 and 9.5 show the summary of yield increases and returns from N additions on simulated potential yields at optimal level with details in appendix Tables (A9-A10). This is assuming high yield potential soils of Uganda and other factors for crop growth to be constant. Maximum returns of 3,041, 3,518 and 4,230 A$ ha^{-1} would be obtained under manure N application rates of 360, 440 and 600 kg N ha^{-1} at a cost of A$$1,188, A$1,452 and A$1,980, respectively.

The cost of N would be 800, 960 and 1,280 A$ ha^{-1} under inorganic N at optimal levels at maximum returns of A$3970, A$4721 and A$5837 ha^{-1} for low, medium and high, respectively.

To obtain same returns (Table 9.3) as top dressed inorganic N under cattle manure N requires 470, 591 and 828 kg N ha^{-1} equivalent to 35,250 kg, 44,288 kg and 62,093 kg ha^{-1} of cattle manure (M_{12}) (on dry basis at 1.2% N) for the low, medium and high potential yields, respectively.

Table 9.3: Comparison between inorganic N and manure N required to produce similar returns under three yield scenarios (low, medium and high)

Potential yield	Inorganic N kg ha^{-1}	Manure N kg ha^{-1}	Manure DM kg ha^{-1}	Returns $ ha^{-1}
Low	200	470	35,250	3,970
Medium	240	591	44,288	4,721
High	320	828	62,093	5,837

Table 9.4: Cabbage yield increase and returns from N additions on yield potential for optimal inorganic N

Potential yield	N rate kg ha^{-1}	Yield kg ha^{-1}	Returns $ ha^{-1}
Low	200	19,081	3,970
Medium	240	22,725	4,721
High	320	28,469	5,837

Potential yields in kg ha^{-1}, and returns $ ha^{-1} N based on $0.25 kg^{-1} Cabbage price and $4 N Price of inorganic N

Table 9.5: Cabbage yield increase and returns from N additions on yield potential for optimal manure N

Potential yield	N rate Kg ha^{-1}	Yield kg ha^{-1}	$ Returns kg ha^{-1}
Low	360	16,966	3,041
Medium	440	19,937	3,518
High	600	24,922	4,230

Potential yields in kg ha^{-1}, and returns $ ha^{-1} N based on $0.25 kg^{-1} Cabbage price and $3.3 N Price of manure

9.3.4 Economic optimum N rate

To identify the economic optimum N rate for a specific set of production conditions; information is needed about how cabbage yields change with increasing rates of applied N as well as the cabbage price ratio. Figures 9.5 and 9.6 show the N response functions describing cabbage yield changes with changes in N rate following NAVAIL modelling for both manure N and inorganic N. The interactive spreadsheet of NAVAIL model allows comparison of several N fertiliser rates at a given price, provides the average yield increase expected at various N rates for the selected levels, and calculates the net return at the N rate and price of cabbage ($0.25 kg^{-1}). The spreadsheet is designed in such a way that users can then select the N rate that provides the best economic return. In this study, the cabbage, manure N and inorganic N prices were $0.25, $3.30 and $4.00 kg $^{-1}$, respectively. Tables 9.6 and 9.7 present a summary of the potential yields, total value of cabbage, maximum returns, marginal product and value of marginal product under inorganic N and manure N applications at optimal levels for the low, medium and high yield potentials, respectively.

Table 9.6: Potential yields and maximum returns for inorganic N at optimal level

Yield	X[a]	Px[b]	Py[c]	TP[d]	TVP[e]	TC[f]	Returns[g]	MP[h]	VMP[i]
Low	200	4	0.25	19,081	4,770	800	3,970	17	4
Medium	240	4	0.25	22,725	5,681	960	4,721	18	4.7
High	320	4	0.25	28,469	7,117	1,280	5,837	17.09	41

a X=rate of inorganic N input applied Kg ha^{-1}

b PX=Price of inorganic N

c Py=Price of cabbage head

d Total cabbage yields

e TVP=Total value of cabbage

f TC=Total cost of inorganic N inputs

g Returns=E-F

h MP=dy/dx

i VMP=MP*Py or (H*C)

Table 9.7: Potential yields and maximum returns for manure N at optimal level

Yield	X[a]	Px[b]	Py[c]	TP[d]	TVP[e]	TC[f]	Returns[g]	MP[h]	VMP[i]
Low	360	3.3	0.25	16,966	4,241	1,188	3,053	13	3.48
Medium	440	3.3	0.25	19,937	4,984	1,452	3,532	14	3.68
Maximum	640	3.3	0.25	25,449	6,362	2,112	4,250	13	3.30

a X=rate of inorganic N input applied Kg ha^{-1}
b PX=Price of inorganic N
c Py=Price of cabbage head
d Total cabbage yields
e TVP=Total value of cabbage
f TC=Total cost of inorganic N inputs
g Returns=E-F
h MP=dy/dx
i VMP=MP*Py or (H*C)

9.3.5 Potential economic production of cabbage under N fertiliser

Economics of cattle manure application in crop production

Figures 9.5 and 9.6 present the economics for manure N and inorganic N following their application to cabbage production. The results show that higher returns are obtained from inorganic N compared to manure N. Beyond the maximum returns there is a sharp decline of the curve with inorganic N, whereas with the manure N, the response curve is flatter.

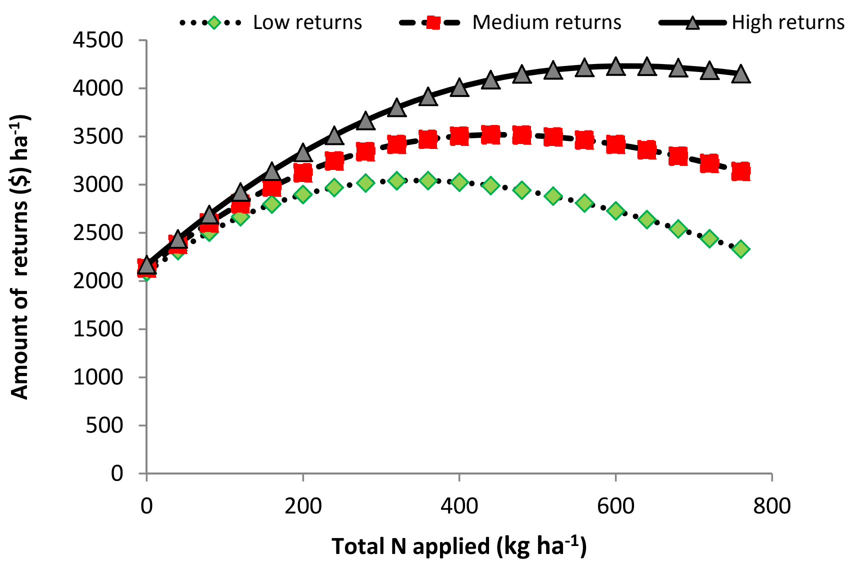


Figure 9.5: Showing cabbage returns (A\$ ha^{-1}) under cattle manure application at a price of A\$3.3 kg^{-1}

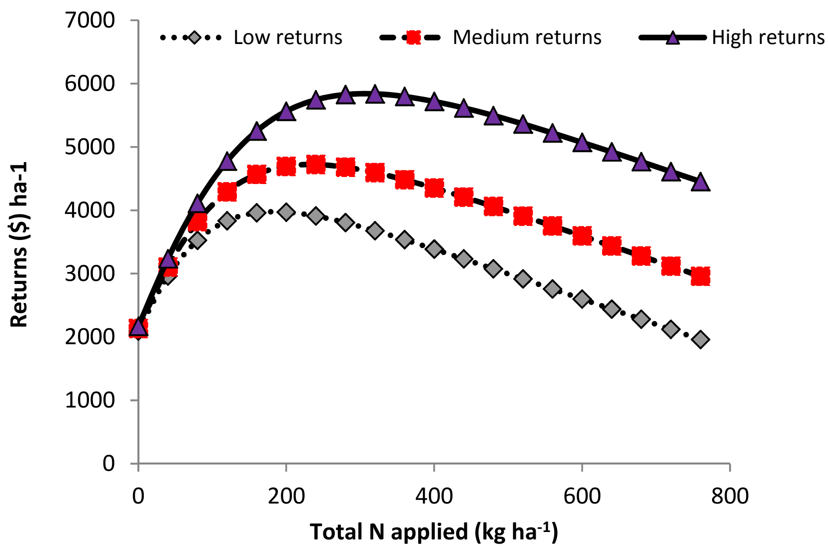


Figure 9.6: Showing cabbage returns under inorganic N application at a price of \$4 kg^{-1}

9.3.6 Potential cabbage production with nitrogen fertiliser application

The simulated results show the practical approach of N rate and the price effects on the economic optimum N rate and a summary as illustrated in Tables 9.6 and 9.7. The data shows cabbage yield response to applied N and assumes a constant cabbage price of \$0.25 kg^{-1}. The size of the yield increase and its value along with N fertiliser cost at the two N prices is shown for 40 kg increments of added N. In this study, N fertilisation would be profitable at all of the N prices shown up to 600 kg ha^{-1} for manure N and 320 kg N ha^{-1} for inorganic N. The 480 kg N ha^{-1} rate would not be profitable at \$3.25 kg $^{-1}$ return, about breakeven at \$3.30/kg N for medium, and still profitable at 600 kg ha^{-1}and 640 kg N ha^{-1} for the high yield potentials (\$3.60 and \$3.30 kg^{-1} return) for manure N and less profitable at N 680 kg ha^{-1} with a return of \$3.00.

9.3.7 Sensitivity analysis results

Figures 9.7 and 9.8 present results when combinations of different N rates were applied as manure and inorganic (urea) to give the effects of urea at different levels of manure. Figure 9.9 presents results of a sensitivity analysis when different N rates were applied as manure at varying prices. Significant yield potentials and respective returns were obtained at varying rates when both manure N and inorganic N were combined. The analysis also looked at the effect of price changes in N rates and assumed that cabbage prices and other factors held constant. Details showing all series analysed are in appendix figures A1 and A2.

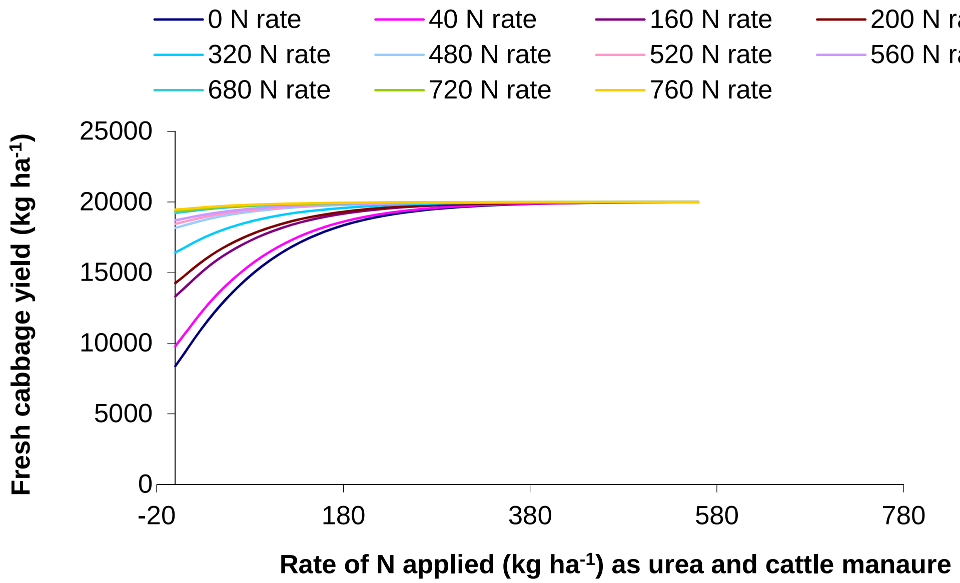


Figure 9.7: Cabbage yield response (kg ha^{-1}) in relation to rate of a total combination of N from both cattle manure and inorganic fertiliser (urea) at different levels

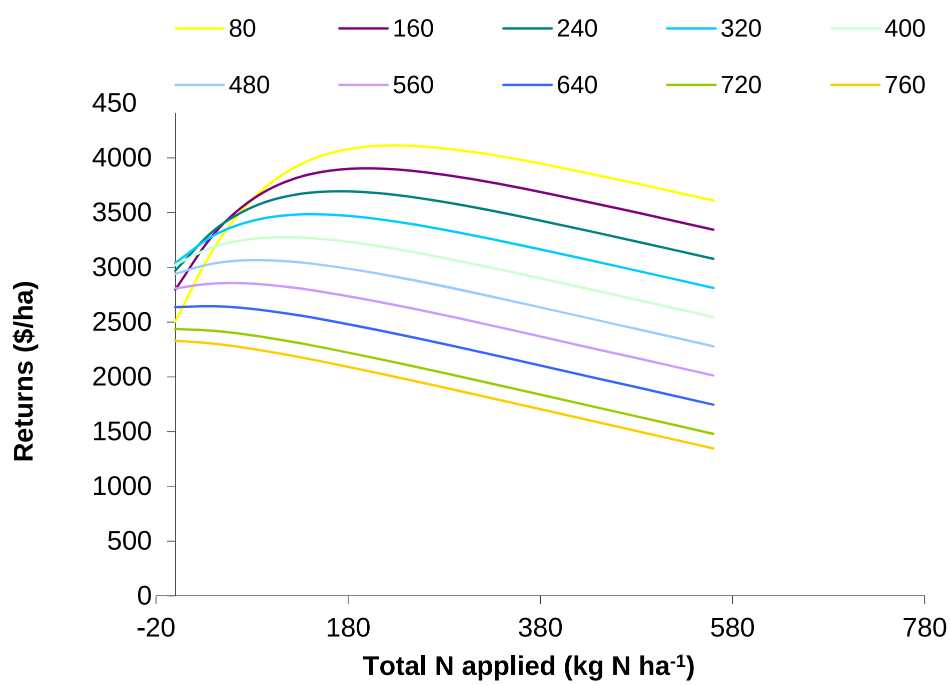


Figure 9.8: Profit ($/ha) from a combination of urea and cattle manure applied at various rates

Table 9.8 presents the effect of price changes on returns of cabbage. The varying price changes in N gave significant differences on cabbage returns of A$8,253, A $7,670, A $7163, A $6,715 and $6,323 at a price of A $2, A $3, A $4, A $5 and A 6$, respectively. The higher the price, the low the returns when cabbage prices remained the same as illustrated in figure 9.9.

Table 9.8: Effect of price of N rate (kg^{-1}) on returns (AUD$ ha^{-1})

	Price of manure N(AUD$)				
Rate N kg ha^{-1}	**2$ rate**	**3$ rate**	**4$ rate**	**5$ rate**	**6$ rate**
0	4,190	4,190	4,190	4,190	4,190
40	4,817	4,777	4,737	4,697	4,657
80	5,386	5,306	5,226	5,146	5,066
120	5,894	5,774	5,654	5,534	5,414
160	6,340	6,180	6,020	5,860	5,700
200	6,728	6,528	6,328	6,128	5,928
240	7,060	6,820	6,580	6,340	6,100
280	7,340	7,060	6,780	6,500	6,220
320	7,573	7,253	6,933	6,613	6,293
360	7,763	7,403	7,043	6,683	6,323
400	7,915	7,515	7,115	6,715	6,315
440	8,034	7,594	7,154	6,714	6,274
480	8,123	7,643	7,163	6,683	6,203
520	8,187	7,667	7,147	6,627	6,107
560	8,230	7,670	7,110	6,550	5,990
600	8,253	7,653	7,053	6,453	5,853
640	8,247	7,547	6,847	6,147	5,447
680	8,172	7,372	6,572	5,772	4,972
720	8,054	7,154	6,254	5,354	4,454
760	7,906	6,906	5,906	4,906	3,906

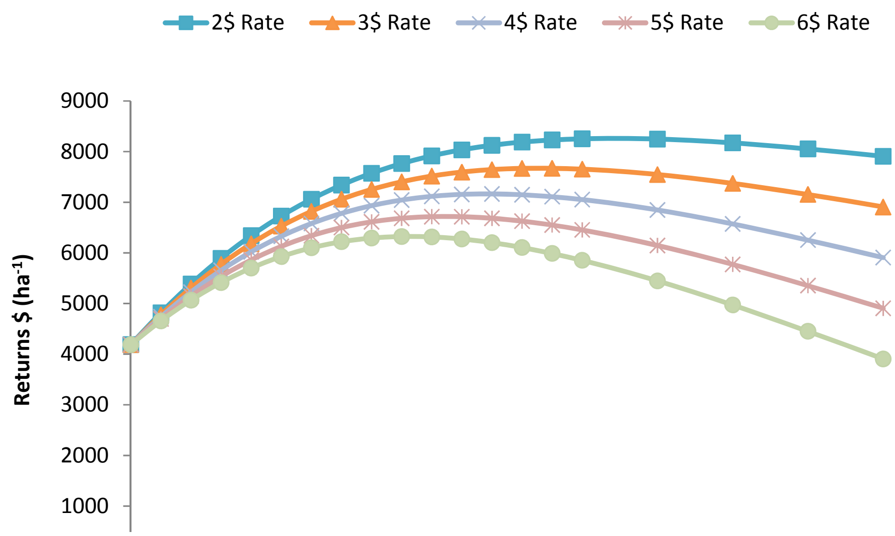


Figure 9.9: Cabbage returns under different N prices

9.4 Discussion

9.4.1 Potential crop N uptake

The application of NAVAIL model to cabbage and canola crops achieved total N uptakes, which were higher in inorganic N than in manure N (Figure 8.8). It showed a significant correlation of measured and estimated N uptake. The estimation, however, may be biased, probably because the SYN model (Diggle et al. 2003) calculates N uptake by the critical percentage N, i.e. the minimum N content needed for maximum growth. The brassica crops used in the simulation, however, were fertilised according to their crop nutrient requirements. Estimated N uptake was significantly ($P<0.001$) correlated with measured N content (Figure 8.8). Elsewhere, Fink and Feller (1998) suggest that proper fertiliser recommendations should allow for big variations in N uptake of white cabbage crops at harvest. In order to account for different expected yields, some fertiliser recommendation systems that are used in European countries including Switzerland, Germany and Netherlands provide tables with up to 6 different N uptake rates, depending on the intended use of the product (i.e. fresh market or processing) and planting date (Fink and Feller 1998). A simple model to estimate N uptake for arable and vegetable crops was suggested earlier by Greenwood and Draycott (1989) which could also be explored.

Although a significant correlation of measured and estimated N uptake was observed, the model considerably overestimated N uptake when applied to a data set with quite low fertilisation (Tables 9.1 and 9.2). In this case, the N content in plant matter was lower than estimated. It is known that N content in plant matter is affected by several factors particularly by N supply (Caloin and Yu 1984; Fink and Feller 1998; Walker et al. 2001). In a model that is to be used to calculate optimal fertiliser recommendations for growers, however, it is justified to consider non-limiting N conditions only.

9.4.2 Effect of nitrogen availability on the yield of cabbage

As the rate of N increases, the difference between the simulated and experimental yields decreases. The experimental yields then decline between 160 and 200 kg N ha^{-1}, whereas the simulator yields continue to increase, though at a decreasing rate. At N greater than 200 kg ha^{-1}, the model produces higher yields, partly because it takes soil to be uniform, and that the crop receives the nutrients uniformly. The N transformations in NAVAIL are assumed to occur at constant rates. Again, this is not the case in reality, where factors such as temperature and soil water content often have an important effect and does not account for dry weather patterns, which occurred at the experimental site during the 2010 crop-growing season. The yield response to N by vegetable crops depends on the partitioning of DM between plant parts (Huett and Dettmann 1991) Although vegetative growth is usually very responsive to N, the situation is less clear where reproductive growth is a major sink. Huett (1986) and Huett and Dettmann (1988) show that increased yields of tomatoes in response to increasing N are associated with higher ratios of fruit DM to total plant DM. It therefore appears that the partitioning of DM within the plant, particularly between reproductive and vegetative growth, can be influenced by N level. Such effects of N on DM distribution will be superimposed on any stimulation of total plant biomass (Huett and Dettmann (1991).

9.4.3 Application of manure model

As presented in figure 9.4 the production of 29,000 kg ha^{-1} of fresh weight of cabbage, the potential yield at Kawanda research station in Uganda, (MAAIF 1999; Ssonko et al. 2005) would require 800 kg N ha^{-1}. It should however, be noted that cabbage producing farmers in central districts of Uganda harvest less than this. Furthermore, farmers can plant cabbage twice in a season implying that some farmers can double the 29,000 kg ha^{-1} in the two seasons a year (29*4) obtaining 116,000 kg ha^{-1} cabbage fresh weight year^{-1}. Farmers along the shores of Lake Victoria plant cabbage three to four times a year. Since farmers do not apply fertilisers due to costs associated with its application (Ethiagiator 1998; Nkonya et al. 2002; Pali et al. 2003; Ngoze et al. 2008), 54.9 t ha^{-1} and 60.3 t ha^{-1} (dry basis) of stored cattle manure for 4 months (M_4) and 12 months (M_{12}) period, respectively, would be required to provide adequate N to realise this potential. The overriding guiding principle should be to apply the right rate, at right time and right place. According to the returns obtained, only a maximum of 11,220 kg ha^{-1}, 22,725 kg ha^{-1}and 28,469 kg ha^{-1} of cabbage can be produced per season where the most profitable levels are 200 kg N ha^{-1}, 240 kg N ha^{-1}, 320 kg N ha^{-1} for the low, medium and high potential yields for inorganic N, respectively. The price of manure N and effects of inorganic N on the profitability of N use in cabbage production is shown in Tables 9.4 and 9.5. In this study, the N response function for the data set was used to calculate gross return per kg of applied N at various rates using a \$0.25 kg cabbage price. This information provides an indication of the N prices that would be profitable at the N rates used. For example, N prices would have to be higher than \$4 kg^{-1} before it would be unprofitable to apply the 320 kg N ha^{-1} rate for inorganic N. Rates up to 600 kg ha^{-1} N would be profitable up to a \$3.6 kg^{-1} N cost for the manure N. The recommended rate at which N would be most profitable is 320 kg ha^{-1} at N prices up to \$4 kg ha^{-1} for the high potential yield and 240 kg ha^{-1} for the medium (Table 9.4). The medium and high yield potentials show that maximum returns are higher but also need more N. Maximum returns that can be obtained are \$4,721 ha^{-1} and \$5,837 ha^{-1} for the medium and high yield potentials, respectively.

While, the maximum returns ha^{-1} would be obtained at yield potentials of 16,966 kg ha^{-1}, 19,937 kg ha^{-1} and 24,922 kg ha^{-1} at manure N rates of 360, 440 and 600 kg N ha^{-1}, respectively (Table 9.5).

The well-known law of diminishing returns applies to crop production (Addiscott et al. 1991), most usually seen with respect to nutrients and to N fertiliser in particular. Finger and Werner (2007) modelled crop yield using a response curve derived from the Quadmod system (ten Berge et al. 2000) because this links N uptake with response and application rate. The choice of a different response curve might make a small difference to the amounts of yield. The study, attempted to re-parameterise Quadmo for the arable crops used in the analysis with data from their own experiments in the UK. Whereas the study concentrated on farming close to the economic optimum, the calculations included benefits from economies of scale and used data pertaining to efficient production (ABC 2005).

The application of manure models is necessary as a guide to apply the right amount required for crop production. Manure models including MANNER (MANure Nitrogen Evaluation Routine) have provided a reliable estimate of the fertiliser N value of farm manure spread to arable land (Chambers et al. 1999) and correct and adequate quantities of manure have been applied with substantial yields obtained. While a number of factors contribute to poor utilisation of N content of manures at the farm level, it seems likely that lack of confidence in technical advice is an important issue (Smith and Chambers 1995).

Therefore, farmers and extension agents should adhere to technical information guidelines when adopting technologies. However, studies in the UK have indicated that farmers will only use models where the required input information is easily available (Chambers et al. 2010). Given the farming level of Ugandan farmers, the model will be useful to technical personnel advising smallholder farmers.

9.4.4 Mineralisation of nitrogen and crop uptake

Tables 9.1 and 9.2 show N uptake simulated under the different N levels consistent with the simulted yields. Results indicate that as more N is available, more is taken up and so is likely N concentration. Beyond 80 kg N ha^{-1} applied at a low yield potential, a constant amount is taken up and at 200 kg ha$^{-1,}$ an equal or less N is available.

Mineralisation of organic manure N over an extended period will result in some N becoming available for crop uptake; even if the entire amount of readily available N has previously been lost through ammonia volatilisation or nitrate leaching.

It has been suggested that mineralisation rates depend not only on manure type, but also on soil texture (Van Faassen and Vandijk 1987.), temperature and moisture content (Smith et al. 1994)). Care needs to be taken when applying near water bodies, due to risk of N leaching and run-off, etc.

9.4.5 Economics of fertiliser application

The economic optimum N rate for a crop occurs where the value of the yield increase produced by the last increment of applied N just pays for the cost of the N. Therefore, with the typical shape of the cabbage N response curve (Figures 9.1-9.4); the economic optimum rate should occur near the top of the response function. In this region, moderate changes in crop response of cabbage inclusive of the N price do not greatly influence the optimum rate which is the cost of last increment of N added that equals the value of yield increase produced (Thompson 1981; Beattie and Taylor 1985; Chiang 1988; Bundy and Kelling 1994; Vanotti and Bundy 1994; Bundy 2000; Kelling and Bundy 2001). However, practically, a farmer will probably apply fertiliser at less this rate because the extra benefit near the optimum level is relatively small, while the risks associated with climate and output price plus shortage of capital mean that the farmer may prefer to use levels where the response is more certain and larger (Bowden 2011 personal comm.). Figures 9.5 and 9.6 present the maximum returns under manure N and inorganic N applications, respectively.

Elsewhere, Innes (2000) report that the optimal rates of an input are higher near the source because the marginal cost of the input, say manure for this study is primarily transport cost, is higher at a distant location. There is need to know how much nutrients will be available in manure especially N so that right quantities are applied for the benefit of the crop. This requires modelling to estimate how much nutrients, particularly N, that will be available for crop uptake, and or to estimate potential yield among others hence the basis of the study.

9.4.6 Effect of N application on cabbage crop yields and returns

The typical N response curve in Tables 9.3 and 9.4 show that the largest yield responses to N occur with the first increments of applied N. This is where the gains in economic return per kg of N will be greatest, and the size of those returns diminishes as the N rate approaches the economic optimum (see Tables 9.6-9.11). Therefore, if a situation develops where enough fertiliser N to meet the entire need within a production unit cannot be obtained due to insufficient capital or short N fertiliser supplies, applying some N to all of the N responsive area gewill usually produce a greater return than applying the full rate of N to some area and no N to the remaining area. The results indicate that N should be applied to all responsive land.

The significant variability of crop response to inputs common in agricultural processes has rendered farmers to apply too little or too much of the inputs. Variation in crop response to input applications has been well documented (Angus et al. 1993; Rafsnidrafer et al. 1983; Pingali and Gerpacio 1997; Vanlauwe et al. 2007) and this coupled with slow mineralisation rates of organic manures including cattle manure has heightened the situation. Only 25-33% of manure N was available (Section 6.3.5). Elsewhere, Johnson (1953) recognized the importance of variable weather and reported both a "good" weather and a "bad" weather response function. Ryan and Perrin (1974) concluded that Peruvian farmers were applying inadequate N due to risks perceived by producers and their reactions to fertiliser use. Janvry (1972) also noted the importance of non controllable climatic events. He concluded that risk aversion could reduce the level of fertiliser application.

On the other hand, U.S farmers apply more N than would be warranted by the equation of marginal product and factor costs (Babcock 1992). Babcock used simulation to show that the uncertainty about future growing conditions causes farmers to apply more N on corn than if growing conditions were known.

9.5 Conclusions

- The model simulated fresh yield potentials of cabbage for the Ugandan conditions. This needs to be adequately tested in the field for the successful replication of the model. However, it can be concluded that the basic model that predicts N availability, potential yields and N uptake for cabbage has been developed, but further refinement is required to better explain N dynamics under high N supply.
- There is need for validation of the model against a wide range of experimental data from cattle manure applications to a range of crops including cabbage and Amaranthus *spp* and other arable crops to benefit a wider community including cereals, root crops, bananas, and cash crops for Ugandan conditions. This will provide a reliable estimate of the fertiliser N replacement value of cattle manure spread under a range of conditions.
- Underpinning the success of the developed models, especially the SYN model, to help guide the farmers is the ability of farmers and growers to adopt improved management practices to maximise the utilisation of fertiliser and manure nutrients. However, for its effective application and management it requires technical knowhow about levels of crop nutrients available for crop uptake.
- Areas for further research include testing the model when cattle manure is combined with inorganic manure given the fact that the availability of N in the manure was between 25-33%, which is less than 50% of what is known to be available from cattle manure for crop uptake. In addition, the model should be calibrated to include more organic fertilisers including urine as 26% of the respondents in the study area were using cow urine as fertiliser (Chapter 4) and should include other inorganic fertilisers such as P and K.
- Need soil mapping to empirically replicate the model for a wider community. Further economic modelling to ascertain the practical N application level for the Ugandan situation. This will enhance successful transferability of the model and its subsequent adoption.
- There is need to test whether an economic optimum approach as used for grain farmers in WA is appropriate for small landholders in Uganda. This is because inputs to such a model could be valued differently taking into account the factors that the Ugandan farmers expressed in Chapter 4.

Chapter 10. General discussion, recommendations and conclusions

10.1 Introduction

One of the key challenges facing farmers in Uganda is soil degradation, which adversely affects crop yields. Resource-poor farmers who dominate the agricultural sector cannot afford costly input technologies. In many cases, farmers have limited access to inorganic fertilisers or find investment in them unprofitable. A few farmers have, as a result resorted to cattle manure as an alternative. In the past Africa's farmers, used low external input farming methods, including rotations and long fallows to control pests and diseases and maintain soil fertility. These were well suited to situations of land abundance and labour scarcity. Subsequently, however, technological change has not kept pace with rapid population growth. These soil protection techniques, which used to allow soil nutrients to regenerate and protected soils from erosion, are no longer sufficient. Because of inaccessibility of inorganic fertilisers, livestock manure is the principal soil amendment available to a large number of crop-livestock farmers.

Soil N depletion and fertility in general and low crop productivity in the central districts of Wakiso and Kampala can be improved by promoting both organic and inorganic N fertilisers.

This section will discuss and summarise the potential of using cattle manure application for N replacement in smallholder crop-livestock systems in Uganda taking into account the research generated by the socio economic survey, two field experiments and a glasshouse trial that were carried in Uganda and Western Australia, the bio-economic model adapted from select your nitrogen (SYN) and the glasshouse experiment to compare crop growth response of canola to cabbage to quantify the relative growth. The survey identified N as the most limiting nutrient in the study area (Chapter 4) and hence the focus of this discussion.

10.2 Fertiliser application in the study area

10.2.1 Inorganic fertiliser application

Only 5% of farmers surveyed in Kampala and Wakiso that used cattle manure were applying inorganic fertilisers. Lack of farmer awareness of appropriate fertilisers to apply appears to be an important constraint to improved land management. However, the result may be biased because participants were farmers exclusively applying cattle manure. The study identified a number of factors that may inhibit inorganic fertiliser use including perceived health risks, inaccessibility, costs and need for continuous application of the fertilisers. These perceptions and beliefs could be due to the biased sample of manure users. Elsewhere, Abdoulaye and Sanders (2005) report that lack of cash in hand at planting and low produce prices in SSA contribute to limited adoption of fertilisers. However, Buresh and Giller (1998) advise that boosting plant nutrient availability does not necessarily require heavy applications of inorganic fertiliser. Thus, efforts should be geared towards farmer training on fertiliser use.

During group discussions with farmers, it emerged that varying crop responses to fertilisers in some cases were also reasons for non-use of inorganic fertilisers. The negative attitudes about fertiliser use is also partly caused by the promotion of organic farming by non-governmental organisations (NGOs) without due effort to explain the varying crop responses to inorganic fertilisers. Thus, for inorganic fertilisers to be used effectively there is need to strengthen farmers' knowledge about their potential benefits and limitations in the context of Ugandan farms.

Elsewhere, there have been variable responses of crops to mineral fertilisers observed on farms due to their spatial soil variability. However, Buerkert et al. (2001), Tittonell et al. (2005) and Vanlauwe et al. (2005) report that this is a result of the inherent soil landscape variability interacting with past and present soil and crop management. Indeed disparate crop responses to fertilisers caused by this variability discourage fertiliser use among farmers. This is heightened by lack of access and costs of fertiliser purchases. However, Tittonell et al. (2007) indicate that the variability in the response of crops to fertilisers can also be caused by poor agronomic practices such as poor seedbed preparation, narrow spacing, limited use of improved genotypes, delay in planting, incorrect fertiliser placement and weed and pest problems, which are typical characteristics of Ugandan farmers. Place et al. (2003) suggest that many of these problems result from poor labour availability. This situation is aggravated by poor market infrastructure **(**Crawford et al. 2003), management related constraints (Ellis 1992; Howard et al. 2000) and lack of subsidies (Ellis 1992; IFDC 2003) in SSA region that includes Uganda.

Buresh and Giller (1998) suggest that lack of recommended rates of application may be the cause of variable yield responses to fertiliser, as the latter applications do not follow specific recommendations. In addition, fertiliser use corresponds to the wealthier families in the community (Manyong et al. 2001; FAO 2004; Tegemeo Institute 2006). However, Poulton et al. (2006) argue that even if recommended rates are used, if local variability or other circumstances such as lack of rain or seed quality are not favourable, commensurate yields for increased application of fertiliser are unlikely.

There is therefore a need to clarify intricacies of fertiliser use among farmers, such as the causes of variable crop responses, the short and long-term effects of fertiliser use on soil productivity, and the technicalities of fertiliser formulations and application rates.

Like the rest of Africa, in Uganda, there is no specific accurate formula or agreed-upon guide for fertiliser use. The design of programs to promote fertiliser use in Uganda should take into account the variability of crop yields in response to fertilisers across agro-ecological zones, the types of crops grown, the sizes of local farms, and other social conditions as recommended by Shalit and Binswanger (1984). However, Poulton et al. (2006) report that such factors vary greatly within short distances in SSA.

10.2.2 Cattle manure use in central Uganda

Chapter 4 shows that there were other organic N sources that were locally available in the area, which could be intensified, including compost, mulch, leguminous cover crops and trees. The last is constrained by lack of land and cannot be extensively adopted. The feasible alternative to improve soil fertility is using cattle manure, which is used widely as a crop fertiliser and a soil amendment in SSA. Cattle manure is a reliable alternative to synthetically produced inorganic fertilisers in Africa due to its easy access and easy procurement from local environments.

Ninety-five percent (95%) of the farmers were applying cattle manure and acknowledged that cattle manure is a valuable source of nutrients in their crop production systems because it increases crop yields. This concurs with Roka and Haag (1996) and Petersen (2006) who assert that this is a common practice where farmers usually regard manure as a major resource provided by cattle, largely because much of the land is characterised by poor productivity that results from continuous cultivation on soils that are often inherently poor in nutrients. However, the level of cattle manure application should be increased from an estimated 22 t ha^{-1} to 62 t ha^{-1} for the aged manure and to 44 t ha^{-1} for the four month stored manure and manure should be tested to ascertain its nutrient levels for effective and proper application. Elsewhere, cattle manure at 75 kg N ha^{-1} supported the same fresh biomass yield of Amarathus and cabbage as urea at the same N application rate (Van Hiep and Preston 2006). Abou El-Magd (2006) report that the increase in growth parameters following cattle manure application and other animal manures such as sheep manure may be attributed to enhancing soil aggregation, soil aeration, increasing water holding capacity and offers good environmental conditions for root systems .

Several studies have reported similar promotion effect of cattle and sheep manure on various plants including Van Hiep and Preston (2006) on *Ipomoea aquatica* (water spinach), Ewulo et al. (2007) on pepper**,** Jahan et al. (2008) on *Cucurbita pepo* (Schneider squash), Azzaz et al. (2009) on fennel and Hendawy et al. (2010) on thyme plants *(Thymus vulgaris)*.

Cabbage has a high need of organic matter in the soil in order to grow well. This can also be obtained from cattle manure in addition to supplying the needed N, which is the element that most limits crop growth in Uganda, especially on low organic-matter soils as confirmed by the field survey (Chapter 4).

Cabbage production in central Uganda has shown that the use of cattle manure gives high yields and consequently positive economic returns; although the profitability appears lower than obtained from inorganic fertiliser (section 4.4.13). However, higher returns occur when organic manure is fully incorporated and supplemented with other agronomic practices. This implies that farmers who do not have enough money to purchase the inorganic fertilisers would still be in a better position with cattle manure application. Farmers should be encouraged to use cattle manure, since the net benefits from the input are encouraging. The results emphasise the fact that cattle manure application needs farmers' patience as it takes a long time for manure to decompose and is labour intensive particularly in peri-urban areas.

Further, results of this study indicate that crop farmers applying cattle manure were more likely to be from Wakiso districts than Kampala district. This is expected as Kampala farmers are more constrained by land.

The major benefits obtained from cattle manure were increased yields (41%) and low cost (29%), while negative factors were poor hygienic conditions (25%) and bad odour (19%) (Chapter 4). Respondents noted that the smell of manure bothers many farmers.

Although solid cattle manure can be an excellent nutrient source and soil amendment, the maximum value out of cattle manure requires applying the manure at proper rates and frequency for crop uptake as suggested by Ribaudo et al. (2003). Thus, it can be concluded that adopting best management practices for cattle manure application requires knowing the storage conditions, period of storage and nutrient availability particlualry N.

10.3 Soil fertility management options in the area

Although different organic manure sources were mentioned that could be used to manage soil fertility in the area, the farmers surveyed (Chapter 4) reported that manure is inadequate and therefore may not replenish nutrient stocks in already depleted soils. This is attributed to a lack of pasture due to small paddocks supporting only a few animals. It implies a need to diversify fertiliser sources, including adoption of inorganic fertilisers.

Since there is not sufficient manure in the area as reported by 55% of the farmers and the latter are unable to use inorganic fertilisers due to costs, use of fertiliser and organic manures are not mutually exclusive, and an integrated soil nutrient approach is needed. Cattle manure is not a substitute to inorganic fertiliser as most nutrients are in organic forms and some organic practices, such as application of manure and compost, are very labour intensive and therefore not practical for farmers with more than a few acres of land or working on distant land/farms. Less labour-intensive approaches, such as planting leguminous cover crops or legumes in crop rotation could be promoted to replenish N in the soil. However, selecting the right cover crop is important to reducing nitrate leaching. Cover crops have been reported to reduce nitrate leaching and even mine nitrates from underground water while contributing to increases in vegetable yields (Delgado 1998; Delgado et al. 2001a; 2007; Hepperly et al. 2010).

Options for increasing nutrients and for adding organic matter are imperative as soil organic matter plays an important part in establishing the intrinsic properties of a soil that make plant growth possible. Soil organic matter helps to sustain fertility by improving retention of mineral nutrients, increasing water holding capacity of soils, and increasing the amount of soil flora and fauna. Low input systems including application of cattle manure can maintain and enhance soil organic matter.

Balanced application of appropriate fertilisers is key to increasing crop production and productivity. Fertilisers need to be applied at the level required for optimal crop growth based on crop requirements and agronomic considerations (Kumar and Shivay Kumar 2008). However, over application of fertilisers, while inexpensive for some countries induces neither substantially greater crop nutrient uptake nor significantly higher yields. Rather, excessive nutrient applications are economically wasteful and can damage the environment (Bailey et al. 2003; Zyskowski et al. 2010). Under application, on the other hand, retards crop growth and lower yields in the short term and in the long term jeopardises sustainability through soil mining and erosion. However, developing an appropriate fertility plan using manure is still a challenge (Baldwin 2006 and Gaskell et al. 2006; Edelman 2009). Nutrient management is sometimes referred to as fertility although the latter is a far more dynamic phenomenon with physical, chemical, and biological characteristics (Weil and Magdoff 2004).

10.4 Relative effectiveness of nitrogen in cattle manure compared with inorganic N

There was a positive relationship between the rate of N application and crop response with the N in cattle manure between 16% and 33% as effective as the N in urea (Chapters 5-6). The effectiveness of the N in cattle manure was dependent on the age of the manure and the time of year of the application i.e, the four month stored cattle manure was more effective as toped dressed inorganic manure than the 12 month stored manure.

In the first season and following incorporation by disc plough, the RE of N in cattle manure was significantly less than the inorganic source of N. In the first season, RE values for Mitscherlich equation coefficients for N uptake in the dry matter of canola shoots for cattle manure compared with top-dressed inorganic N at 63 DAS was 13%, although this gradually improved over the season at 93 DAS to 18%. By DM harvest of canola at 93 DAS, the RE of cattle manure compared with top-dressed inorganic N was 22% indicating that N availability in cattle manure increased with time, consistent with other studies (Beauchamp 1983; Ma et al. 1999; Vinten 2002; Pansu et al. 2003; Carbrera et al. 2005). In the second experiment, which comprised two manure types (stored at two periods of time i.e. 4 months (M_4) (1.31% N) and 12 months (M_{12}) (1.18% N) and following incorporation by the disc plough during seeding, the RE of M_4 and M_{12} compared with top-dressed urea ranged from 25%-30%, 27%-33% and 20%-28% for fresh weight, DM and N uptake for M_4 and 18%-24%, 19%-26% and 11%-21% for fresh weight, DM and N uptake for M_{12} at 100 DAS over the season. Compared with first year results (Chapter 5), the RE values in this experiment are in the same range. Application of cow manure to the soil to supply 200 kg ha^{-1} increased the biomass yield of canola from 190 to 537 for M_4 and 230, 670 kg DM ha^{-1} for M_{12} at 100 DAS. While for urea, yield increased from 200 to 1436 kg ha^{-1} at a similar rate; implying 7 kg DM kg^{-1} of inorganic-N, 2.7 kg DM kg^{-1} of M_{12} and 3.0 kg DM kg^{-1} of M_4 added were obtained.

Overall, the RE of cattle manure and subsequent N uptake compared to inorganic N was low in both seasons. Factors such as reduced and variable soil moisture throughout the growing season and the spatial heterogeneity of cattle manure in the soil matrix contributed to the lower effectiveness of cattle manure N under field conditions (Chapters 5 and 6). As noted in Chapter 6, the second season comprised M_4 and M_{12} treatments, which were also incorporated with a disc plough at seeding. The resultant incorporation of cattle manure in both seasons ensured that N was accessible to plant roots but there was a significant difference in yield measured compared to inorganic N. Incorporation was necessary, because the availability of N in animal manures is reduced when surface-applied rather than incorporated (King and Morris 1973; Pastene 1981; Maerere et al. 2001; Mooleki et al. 2004; Carrera et al. 2007; Shaffer 2011). Depending on manure application method, manure type (animal species), and handling system, N availability can range from 10% to 95%. Producers that wish to minimize N losses (maximize the manure value) will use application methods such as injection or immediate incorporation (Shaffer 2011).

The N equivalency for N uptake measured here was lower than the equivalencies calculated for DM yield, 0.21 for N uptake compared to 0.24 and 0.26 for fresh weight and dry yields, respectively, at 100 DAS. This indicated that, as suggested by Kiemnec et al. (1987), N uptake might have been a more sensitive indicator of N availability than yield. However, if the supply of nutrients other than N were contributing to increased crop growth in cattle manure N (M_{12}) treatments relative to the inorganic N control, then N uptake would, of course, increase to some extent as a function of increased yield. The N equivalency of cattle manure N (M_{12}) calculated from dry yield was particularly high. This may be explained by examining the inorganic N control response curve for DM yield. It appeared that there was a diminishing increase in response of dry yield to N application of 200 kg N ha^{-1}, however, the linear regression was highly significant ($P<0.001$).

The application of high rates (≥160 kg total N ha^{-1}) of manure was shown to decrease N uptake at the early stages of the canola crop growth, in comparison to the non-amended soil, due to early season immobilization of manure and soil N. Although canola production was compensated at the end of the growing season, care should be taken for shorter growing season crops.

10.5 The application of the select your nitrogen (SYN)

The importance of modelling N is heightened by its widespread deficiency, highly mobile properties, capacity for loss from the soil and potential for pollution of both surface and groundwater (Angus et al. 1993; Smith et al. 2003; Chambers et al. 2010). However, vigilance is also required to empirically detect deficiencies of the minor nutrients as they are depleted due to continuous cropping (Angus et al. 1993; Panda 2008). Farmers should aim to apply N to meet crop demand in order to reduce environmental losses and maximise fertiliser efficiency.

The SYN model predictions of crop yield and N uptake compared reasonably well with the respective measured parameters for canola (Brassica *spp*) (Chapter 8) production conditions. It can be inferred that through a literature review and this research the optimal combination of N fertiliser for crop production were developed. Therefore, the SYN model used in this study compared three different scenarios, low, medium and high potential yields. The model predicted that up to 800 kg $ha^{-1}$of cattle manure N (66.7 tonnes ha^{-1}) could produce the Ugandan potential yield of 29 tonnes of fresh cabbage with maximum returns. However, this may be constrained by manure availability as well as its bulkiness. Nevertheless, with small plots of land, this rate is feasible for farmers. It should also be noted that much as research station yield has been used during modelling approach, this may not constitute the potential yield, but even if it does, validation requires data from more than one site and one season, or even the average of several seasons. It is thus recommended that full validation can now proceed on the very sound basis provided by the study as presented in the thesis as futher discussed in section 10.7.

The study has contributed to the understanding of N availability in cattle manure, the most limiting nutrient in the area. This is a step forward, which can be used when designing strategies and policies that encourage appropriate manure application. One policy alternative could be further education and extension programs that increase awareness of the potential for application of manure to land and other sources of N by farmers to improve soil fertility and thus crop production. However, further research is required to compare farmers' perceptions to reality; which could facilitate the development of these extension and education programs. It would be important for environmental incentive programs in other parts of the country to recognise the benefits of applying cattle manure to land by crop farmers in areas where manure production on livestock farms exceeds their ability to apply it to their own land at agronomic rates.

As discussed in Chapter 9, an empirical model Select Your Nitrogen (SYN) (Diggle et al. 2003) that can predict N availability for the Brassicas, especially cabbage, is hoped to assist smallholder Ugandan farmers who can't afford inorganic fertilisers to apply more optimal quantities of cattle manure N. Although the model can be used to predict N availability, it must be noted that recommendations of manure rates can only serve as a guide due to high variability of N content of manure and variable yield responses that are as yet unexplained.

10.6 Economics of cattle manure application

The SYN model predicted three levels of potential yields including low, medium and high yields with subsequent calculation of total value of cabbage, maximum returns, marginal product and value of marginal product under either inorganic N or manure N applications as presented in Tables 9.6 and 9.7 (details in appendix Tables A11-16) following NAVAIL spreadsheet. Table 10.1 presents estimations of loading rates of cattle manure that may be required to optimise yield of cabbage and shows costs of N either from cattle manure or inorganic fertiliser.

Table 10.1: Optimal loading rates of cattle manure and inorganic N required providing cabbage crop with maximum returns of nitrogen application

Manure N	Rate	Potential yield	Cost	Returns
Low	360	16,966	1,188	3,041
Medium	440	19,937	1,452	3,518
High	600	24,922	1,980	4,230
Inorganic N				
Low	200	19,081	800	3,970
Medium	240	22,725	960	4,721
High	320	28,469	1,280	5,837

Potential yields in kg ha^{-1}, and returns \$ ha^{-1} N based on \$0.25 kg^{-1} Cabbage price, \$4 N Price of inorganic N and \$3.3 N Price of cattle manure

It should be noted that when determining the loading rates, other nutrients are also added when cattle manure is applied including P, K, Mg and B to mention a few. For the farmer, an economic optimum may differ from physical optimum, depending on the added cost of inputs and the value of benefits derived from any increased output. It is envisaged that long-term benefits of cattle manure application may attract its adoption. However, farmers renting land for one season may be at a disadvantage.

Based on the SYN model results, applying cattle manure to cabbage production was shown to be less profitable than inorganic fertilisation in the short term. This was confirmed with the gross margin analysis during the survey (section 4.20). However, this may vary in subsequent years due residual value of N in the soil. This needs further investigation.

Key factors influencing the costs of using cattle manure in agriculture are the DM and N content of the cattle manure and the likely haulage distance. Using cattle manure, however, is a sustainable practice due to the significantly increasing inorganic fertiliser prices, the improvement of soil quality and benefits of decreasing N leaching. Others include reducing the production of greenhouse gases, decreasing the depleting of non-renewable resources, carbon sequestration to the soil, and organic waste diversion from landfills and increase the water holding capacity of soils, thus resulting in better crop production and water conservation.

10.7 Further research

10.7.1 Nitrogen value and other agronomic benefits of animal manure

There are various types of livestock manure such as rabbit manure, poultry manure, and goat manure being applied to land in Uganda. These manures provide a wide range of nutrients and research is required with a further selection of nutrients limiting crop production including P, K and B to mention a few and also to determine their N value and other agronomic benefits using the developed SYN model. Other organic manures, which could be studied, are marketable crop wastes particularly in Kampala where over 1,000 mt of garbage is generated every daay (Sabiiti et al. 2004).

The experimental approach taken in the cattle manure crop response trials at Ucarty covered in Chapters 5 and 6 is suitable for future investigation under Ugandan conditions, although some modifications may be required.

10.7.2 Cattle manure storage methods

The cattle manure crop response trials (Chapters 5 and 6) indicated that length of storage might influence the amount of available N. Further studies should look at storage methods. For example, there was a significant response to application of cattle manure in both seasons but varied with different storage periods in the two years. This was possibly due to loss of NH_3 during stockpiling prior to application/collection of cattle manure stored for 12 months compared to manure stored for four months. Both years 2009 and 2010, M_{12} had a lower N equivalency than M_4 as would be expected and possibly a lower mineralisable N content, due to continued mineralisation during storage and loss of N by volatilisation.

Future investigations should look at mineralisation rates including controlled experiments with different storage periods to determine and quantify the significance of this for N release and availability. Storage conditions and the influence of covering on NH_3 volatilisation losses also require investigation. The field mineralisation and nitrification studies under Ugandan conditions will help to validate the model.

The method of application may influence the N fertiliser value of organic manures including cattle manure, as reported by Beauchamp et al.(1978), Sutton et al. (1982), Robinson and Polglase (2000) and Shaffer 2011, where they indicate that surface broadcasting may result in losses of N due to NH_3 volatilisation. This study provided evidence that the quality of cattle manure influences the availability of cattle manure N. It was suggested that for higher yields, manure should not be kept longer than 4 months.

10.7.3 Studies on the effect of environment and type of soil on cattle manure N

The longer-term effects of cattle manure application need to be assessed, especially in terms of N leaching potential as a large amount of organic N is being built up in the soil. Long-term studies of the effects of using cattle manure in agriculture are necessary for the development of the optimum system for managing the utilization of cattle manure for sustainable agriculture, which will ensure the environmental risk is minimised and the agronomic benefit is maximised. Only a sandy soil and a limited range of Brassica crop varieties were considered within this study. Cattle manure application to heavier soils and a wider range of crops, especially high value crops, is suggested for a better agronomic and economic evaluation. This needs to be replicated under Ugandan conditions.

Furthermore, the development of equipment able to apply cattle manure at more precise rates to ensure that the manure is spread more evenly on the soil, and the crops receive a better balanced supply of nutrients constitutes a potential area for future work, so that the efficiency of cattle manure utilisation is improved.

Future studies should look at other environmental factors as applications of cattle manure during the rainy seasons may result in lower N equivalencies, as the mineralised N may be leached from soils over the season and not be available for uptake during the growth period of the crop. Therefore, it is necessary to investigate the effects of frequency, different methods and timing of application to optimise the fertiliser value of the cattle manure. This could be investigated by using field-scale equipment, as has been done for animal manures and slurries (Nicholson et al. 1999).

There is a need to carry out soil mapping in other areas of Uganda to identify the limiting nutrients for ease of model replication. Also important is the need to promote widespread adoption of correct fertiliser application rates where yields are limiting. This can be through farmer training. Low-input approaches are necessary to address soil fertility problems, and there is evidence that some of these can be effective in increasing yields of farmers.

10.7.4 Socio economic factors influencing cattle manure use

There is need to investigate the effect of odour on cattle manure use and to compare how farmers make decisions regarding commercial fertiliser and manure use. This could be useful for designing policy and further education and extension programs. Increasing benefits involved with manure application as a practice is another need.

Research is required to assess the distance over which it is economically viable to transport manure for farmers. Technologies to increase manure use where cattle manure can be applied economically are warranted. Composting is one way to improve manure quality; however, this may increase costs though it reduces bulkiness of manure.

The factors affecting the substitutability between commercial fertilisers and manure such as nutrient content, effects on soil characteristics and moisture content should also be investigated. Further research might compare these findings to the farmer's perceptions, to determine further educational needs.

This study found female farmers had adopted manure use more than their male counterparts had. Further research might investigate why this is the case. The studies should be expanded to other regions of the country with different types of farming systems.

10.8 Conclusions

- In this thesis, the socio economic survey, field and glasshouse experiments and simulation techniques allowed for the comparison of cattle manure N and inorganic N, in agronomic, environmental and economic terms. These two fertiliser types are of agricultural interest and they have been considered for agricultural use in SSA, following their application to land. The research undertaken has added to the current knowledge regarding the availability of N following cattle manure amendment. It demonstrated that properly managed cattle manure stored for four months and twelve months, whilst relatively low in nutrient status, can be utilized in agriculture leading to increased crop production.
- The relative effectiveness of manure N following the application of cattle manure stored for twelve months ranged from 13% to 22% on DM and from 11% to 18% on N uptake, which was 20% of total N applied at top rate compared to 40% for inorganic N. The greatest RE value for the field investigation at Ucarty, near Goomalling were from M_4, as predicted from its high mineral N content. The RE value of M_4 was 26-33% as top dressed inorganic N on DM basis and 20-28% on N uptake. Therefore, the M_4 that had an N equivalency value of 33% was an effective source of available N. The variation in N value may be due to differences in input feedstock materials to the two types of manure applied.
- Dry cattle manure at 62 tonnes ha^{-1} of M_{12} and 44 tonnes $ha^{-1}$of M_4 would be required to achieving the high potential yield which would also bring in other advantages including aggregate stability, increased organic carbon content and improved soil hydraulic properties as reported by Nyamangara (2008), N'Dayegamiye (2009) and Hulugalle et al. (2009).

It must however, be emphasized that the application rate suggested in this study needs experimental validation, this case study is at least a direction towards that investigation.

- The search for alternative sources of N to maintain the depleted soils of central Uganda, where cattle manure is applied could play a significant role in increasing crop production and is outlined in the literature review. The optimal rate of application to guarantee the maximum canola DM yield requires 640 kg N ha^{-1} with 62 tonnes of cattle manure ha^{-1}. It appears that 20% of the required inorganic N fertiliser could be replaced by cattle manure application, but application of 200 kg N ha^{-1} with inorganic N only increased the canola DM yield substantially.
- Based on the findings from experiments conducted, the calibrated model marked a significant step towards addressing soil fertility management problems in Uganda.

Chapter 11. References

ABC. 2005. The Agricultural Budgeting and Costing Book No. 60. Melton Mowbray, UK: Agro Business Consultants Ltd.

Abler, David G., and James S. Shortle. 1995. "Technology as an Agricultural Pollution Control Policy." American Journal of Agricultural Economics 77 (1): 20-32. http://www.jstor.org/stable/1243885.

Abou El-Magd, M. M., A. M. El-Bassiony, and Z. F. Fawzy. 2006. "Effect of Organic Manure with or without Chemical Fertilisers on Growth, Yield and Quality of Some Varieties of Broccoli Plants." Journal of Applied Science Research 2 (10): 791-798.

Abro, S. A., and A. R. Mahar. 2007. "Reclamation of Saline-Sodic Soils under Rice-Wheat Crop Rotation." *Pakistan Journal of Botany* 39 ((7): 2595-2600.

Abunyewa, A. A., and K. N. Karbo. 2005. "Improved Fallow with Pigeon Pea for Soil Fertility Improvement and to Increase Maize Production in a Small Holder Crop-Livestock Systems in the Sub-Humid Zone of Ghana." *Land degradation development* 16: 447-454.

Abunyewa, A. A., C. Osei, E. K. Asiedu, and E. Y. Safo. 2007. "Integrated Manure and Fertiliser Use, Maize Production and Sustainable Soil Fertility in Sub Humid Zone of West Africa." *Journal of agronomy* 6 (2): 302-309.

Ackello-Ogutu, C., Q. Paris, and W. A. Williams. 1985. "Testing a Von Liebig Crop Response Function against Polynomial Specifications." *American Journal of Agricultural Economics* 67: 873-880.

Addiscott, T. M. 2005. *Nitrate, Agriculture and the Environment*. Wallingford, Oxfordshire, UK, CABI.

Addiscott, T. M., A. P. Whitmore, and D.S. Powlson. 1991. *Farming Fertilisers and the Nitrate Problem*: CAB International, pp170.

Adekalu, K. O., D. A. Okunade, and J. A. Osunbitan. 2006. "Compaction and Mulching Effects on Soil Loss and Runoff from Two South western Nigeria Agricultural Soils" *Geoderma* 137: 226-230.

Adhikari, K. R., and Z. Chen. 2011. "Combining Compost with Urea: Nitrogen and Phosphorus Recovery by Cabbage and Leaching under Imposed High Rainfall Condition in the Greenhouse." *Scientific Research and Essays* 6 (4): 819-829.

Aerts, R., R. Van Logtestijn, M. Van Staalduinen, and S. Toet. 1995. " Nitrogen Supply Effects on Productivity and Potential Leaf Litter Decay of Carex Species from Peatlands Differing in Nutrient Limitation *Oecologia* 104 (4): 447-453

Agbenin, J. O. 2003. "Zinc Fractions and Solubility in a Tropical Semi-Arid Soil under Long-Term Cultivation." *Biology and Fertility and Soils* 37: 83-89.

Agbenin, J. O., and J. T. Goladi. 1997. "Carbon, Nitrogen and Phosphorus Dynamics under Continuous Cultivation as Influenced by Farmyard Manure and Inorganic Fertilisersin the Savanna of Northern Nigeria." *Agriculture, Ecosystems and Environment* 63: 17-24.

Alliance for a Green Revolution in Africa, 2007Allen, D. G., N. J. Barrow, and M. D. A. Bolland. 2001. "Comparing Simple Methods for Measuring Phosphate Sorption by Soils." Australian Journal of Soil Research 39: 1433-1442.

Allen, D. G., R. C. Jeffery and Chemistry Centre (W.A.) 1990. *Methods for Analysis of Phosphorus in Western Australian Soils. Report of Investigation No. 37.* Perth, W.A: Chemistry Centre of WA.

Allen, E. J., and D. G. Morgan. 1975. "A Quantitative Comparison of the Growth, Development and Yield of Different Varieties of Oilseed Rape." *Journal of Agricultural Science (Cambridge)* 85: 159-174.

Alley, M. M., and B. Vanlauwe. 2009. *The Role of Fertilisersin Integrated Plant Nutrient Management*: International Fertiliser Industry Association (IFA), Paris, and Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture (TSBF-CIAT), Nairobi.

Alva, A., J. Marcos, C. O. Stöckle, V. Reddy, and D. Timlin. 2004. Cropsyst VB - Simpotato, a Crop Simulation Model for Potato-Based Cropping Systems: II. Evaluation of Nitrogen Dynamics. Paper read at Proceedings of the 4th International Crop Science Congress, 26 September -1 October 2004, at Brisbane, Australia.

Amudalat, O. B., H. A. Akintoye, and B. Olasanmi. 2006. "Effect of Different Sources of Nitrogen on Growth and Yield of Solanum Macrocarpon in Derived Savanna of Nigeria." *Agronomy journal* 5 (2): 182-185.

Anderson, J. R. 1968. "A Note on Some Difficulties in Response Analysis." *Australian Journal of Agricultural Economics* 12 (1): 46-53.

Andrews, N., and J. Foster. 2007. "Organic Fertiliser Calculator: A Tool for Comparing the Cost, Nutrient Value, and Nitrogen Availability of Organic Materials. Em 8936-E. Oregon State University Extension Service, Corvallis.

Angus, J. F., J. W. Bowden, and B. A. Keating. 1993. "Modelling Nutrient Responses in the Field." *Plant and Soil* 155/156 (1): 57-66. Angus, J. F., and R. A. Fischer. 1992 "Grain Protein Responses to Nitrogen Applied to Wheat Growing on a Red Earth." *Australian Journal of Agriculture Research* 42: 735-746.

Angus, J. F., M. Sudjadi, C. F. de St Groth, N. Sri Mulyani, M. D. Hadiwahyono, and R. Wetselaar. 1991. "Simulating Nitrogen Response of Irrigated Rice." *Plant and Soil* 127: 219-229.

Aniku, J. D., P. Kataama, Nkedi-Kizza. N., and S. Ssessanga. 2001. PDCO and Soil Fertility Management: Uganda Results and Experience. Soil Nutrient Management in Sub-Saharan Africa in Support of the Soil Fertility Initiative Paper read at Proceedings of the conference 6-8 December, 1999, Lusaka, Zambia.

Antil, R. S., and M. Singh. 2007. "Effects of Organic Maures and Fertiliserson Organic Matter and Nutrients Status of the Soil." *Archives of Agronomy and Soil Science* 53: 519-528.

Antwi, C., E. L. K. Osafo, D. S. Fisher, J Baah, and K. Oppong Anane. 2010. The Role of Livestock Production in Greenhouse Gases Emissions in Ghana. Paper read at Greenhouse Gases and Animal Agriculture Conference October 3-8, 2010, at Banff, Canada.

Ariga, J., and T. S. Jayne. 2006. *Can the Market Deliver? Lessons from Kenya's Rising Use of Fertiliser Following Liberalization*. Nairobi, Kenya: Tegemeo Institute for Agricultural Development and Policy. 2006. Policy Brief No. 7.

Arnold, Z. 1951. "An Interesting General Form for a Production Function". *Econometrica* 19: 188-89.

Ashiono, G. B., J. P. Ouma, and S. W. Gatwiku. 2006. "Farmyard Manure as Alternative Nutrient Source in Production of Cold Tolerant Sorghum in the Dry Highlands of Kenya." *Agronomy Journal* 5: 201-204.

Assefa, B. A., J. J. Schoenau, and M. C. J. Grevers. 2004. "Effects of Four Annual Applications of Manure on Black Chernozemic Soils." *Canadian Biosystems Engineering* 46 (6): 39-6.46.

Atallah, T., F. Andreux, T. Chone, and F. Gras. 1995. "Effect of Storage and Composting on the Properties and Degradability of Cattle Manure." *Agriculture Ecosystems and Environment* 54 (3): 203-213.

Atukunda, G., F. Baseke, S. David, J. Jagwe, M. Kalyebara, M. Kaweesa, R. Miiro, et al. 2003. "Farming in the City: Participatory Appraisal of Urban and Peri-Urban Agriculture in Kampala, Uganda. CIAT Africa Occasional Publications Series, No. 42. CIAT, Kampala, Uganda."

Ayoo, S. J. 2000. *Land and Poverty in Uganda: Learning from the Poor. Uganda Participatory Poverty Assessment Project*. Kampala, Uganda: Ministry of Finance, Planning and Economic Development, Government of Uganda.

Ayoub, A. T. 1994. Technical, Institutional and Legal Issues for the Protection and Utilization of Soils. Paper read at African Crop Science Conference Proceedings, 14th - 18th June 1993 at Kampala, Uganda.

Azzaz, N. A., E. A. Hassan, and E. H. Hamad. 2009. "The Chemical Constituent and Vegetative and Yielding Characteristics of Fennel Plants Treated with Organic and Bio-Fertiliser." *Australian Journal of Basic & Applied Science* 3 (2): 579-587.

Babcock, B. A. 1992. "The Effects of Uncertainty on Optimal Nitrogen Applications." *Review of Agricultural Economics* 14 (2): 271-280.

Baker, G., D. L. Michalk, W. Whitby, and S. O' Grady. 2002. "Influence of Sewage Waste on the Abundance of Earthworms in Pastures in South-Eastern Australia." *XIII International Colloquium on Soil Zoology* 38 (3-4): 233-237.

Baker, S., and G. Harris. 2005. *Nitrogen Fertilisation*. Tifton, GA: University of Georgia.

Baldwin, K. R. 2006. "Soil Fertility on Organic Farms. Production-Soil Fertility. North Carolina Cooperative Extension, Raleigh, NC." .

Balint, T., and Z. Rengel. 2008. "Nitrogen Efficiency of Canola Genotypes Varies between Vegetative Stage and Grain Maturity." *Euphytica* 164: 421-432.

Balint, T., Z. Rengel, and D. G. Allen. 2008. "Australian Canola Germplasm Differs in Nitrogen and Sulphur Efficiency." *Australian Journal of Agriculture research* 59 (2): 167-74.

Banga, R. S., R. S. Bisht, and A. Yadav. 2007. Variation in Growth Rate and Seed Yield of *Brassica Juncea* Genotypes as Affected by Nitrogen Levels. Paper read at Proceedings of the 12th International Rapeseed Congress 26-30 March, Sustainable Development in Cruciferous Oilseed Crops Production, at Wuhan, China. 3:246-247.

Bannink, A., H. Valk, and A. M. Van Vuuren. 1999 "Intake and Excretion of Sodium, Potassium, and Nitrogen and the Effects on Urine Production by Lactating Dairy Cows." *Journal of Dairy Science* 82: 1008-1018.

Barbarick, K. A. 2011. "Nitrogen Sources and Transformations No 0.550."

http://www.ext.colostate.edu/pubs/crops/00550.html accessed on 10.11.2011.

Barker, A. V. 2010. *Science and Technology of Organic Farming*. New York, USA: CRC Press, Taylor and Francis Group, LLC.

Bary, A. I., C. G. Cogger, and D. M. Sullivan. 2000. "Fertilizing with Manure. Pacific Northwest Extension Publication 533. Washington State University Cooperative Extension, Pullman, WA."

Bashaasha, B., D. S. Kraybill, and D. D. Southgate. 2001. "Land Use Impacts of Agricultural Intensification and Fuelwood Taxation in Uganda." *Land Economics* 77 (2): 241-249. .

Basweti, E. A., B. A. Jana, E. K. Koech, and J. R. Okalebo. 2011. "Effect of Improved Fallows and Phosphorus Application on Weeds and Maize Yield in Smallholder Systems of Western Kenya." *American-Eurasian Journal of Agriculture & Environmental Science* 10 (4): 507-514.

Bationo, A., A. Hartemink, O. Lungu, M. Naimi, P. Okoth, E. M. A. Smaling, and L. Thiombiano. 2006. African Soils: Their Productivity and Profitability of Fertiliser Use. Paper read at Proceedings of the African Fertiliser Summit, June 9-13, 2006, at Abuja, Nigeria.

Bationo, A., F. Lompo, and S. Koala. 1998. "Research on Nutrient Flows and Balances in West Africa: State of-the-Art." *Agriculture, Ecosystems and Environment* 71 (1-3): 19-35.

Bationo, A., S. P. Wani, C. L. Bielders, P. L. G. Vlek , and A. U. Mokwunye. 2000. "Crop Residue and Fertiliser Management to Improve Soil Organic Carbon Content, Soil Quality and Productivity in the Desert Margins of West Africa." In *Global Climate Change and Tropical Ecosystems*, eds R Lar, J. M Kimble and B.A Stewart Boca Raton, FL: CRC Press.

Battese, G. E., A. N. Rambaldi, and G. H. Wan. 1997. "A Stochastic Frontier Production Function with Flexible Risk Properties." *Journal of Productivity Analysis* 8 (3): 269-280.

Baxter, C., C. A. M. Laboski, J. B. Peters, and L. G. Bundy. 2006. *Nutrient Availability from Treated Manures*. UW-Platteville, UW-Madison.

Beattie, B. R., and C. R. Taylor. 1985. *The Economics of Production*. New York: John Wiley and Sons.

Beauchamp, E. G. 1983. "Response of Corn to Nitrogen in Preplant and Sidedress Applications of Liquid Dairy Cattle Manure." *Canadian Journal of Soil Science* 63: 377–386.

Beauchamp, E. G., and J. W. Paul. 1989. "A Simple Model to Predict Manure Nitrogen Availability to Crops in the Field." In *Nitrogen in Organic Wastes Applied to Soils*, eds J. A. Hansen and K. Henrikson, 140-149. Harcourt Brace Jovanovich Publication, Boston, pp. 140–149.

Beckley, V. A. 1934. *Organic Manures, with Special Reference to Composts*. Nairobi: Kenya Department of Agriculture Bulletin No 9.

———. 1937. "Compost and Compost Making." *East Africa Agricultural Journal* 2: 384-386.

Bekunda, M. A., A. Bationo, and H. Ssali. 1997. "Soil Fertility Management in Africa: A Review of Selected Research Trials." In *Replenishing Soil Fertility in Africa*, ed. R . J Buresh, 63-79. Madison, USA: SSSA special publication, American Society of Agronomy and Soil Science.

Bekunda, M. A. 1998. Nutrient Status and Requirements of Ugandan Soils. Paper read at Proceedings of a Planning Workshop: Towards Sustainable Nutrient management in Uganda, at Kampala, Uganda.

Bekunda, M. A. 1999. "Farmers' Responses to Soil Fertility Decline in Banana-Based Cropping Systems of Uganda. Managing Africa's Soils No. 4.

Bekunda, M. A., E. Nkonya, D. Mugendi, and J. J. Msaky. 2002. Soil Fertility Status, Management, and Research in East Africa.

Benbi, D. K., C. R. Biswas, S. S. Bawa, and K. Kumar. 1998. "Influence of Farmyard Manure, Inorganic Fertilisers and Weed Control Practices on Some Soil Physical Properties in a Long-Term Experiment." *Soil Use Management* 14: 52-54.

Benke, M. B., C. Chang, and X. Xiying Hao. 2008. *Effects of Long-Term Cattle Manure Applications on Soil, Water, and Crops: Implications for Animal and Human Health*, *Development and Uses of Biofortified Agricultural Products, 135 -151*

Benneh, G. 1997. *Towards Sustainable Smallholder Agriculture in Sub-Saharan Africa*. Washington, D.C: International Food Policy Research Institute (IFPRI).

Berkowitz, S. 1997. *Analysing Qualitative Data*. Edited by J. Frechtling, L. Sharp and Westat, *User-Friendly Handbook for Mixed Method Evaluations (Chapter 4). Retrieved from National Science Foundation Website* http://www.Nsf.Gov/Pubs/1997/Nsf97153/Chap_4.Htm.

Best, E. K. 1976. "An Automated Method for the Determination of Nitrate Nitrogen in Soil Extracts." *Queensland Journal of Agricultural and Animal Sciences* 33 161-166.

Bhat, K. K. S., T. H Flowers, and J. R. O'CALLAGHAN. 1980. "A Model for the Simulation of the Fate of Nitrogen in Farm Wastes on Land Application." *The Journal of Agricultural Science* 94 (01): 183-193.

Bhattacharyya, R., S. Kundu, V. Prakash, and H. S. Gupta. 2008. "Sustainability under Combined Application of Mineral and Organic Fertilisersin a Rainfed Soybeanâ-Wheat System of the Indian Himalayas." *European Journal of Agronomy* 28 (1): 33-46.   .

Bhatti, A. U., Q. Khan, A. H. Gurmani, and M. J. Khan. 2005. "Effect of Organic Manure and Chemical Amendments on Soil Properties and Crop Yield on a Salt Affected Entisol." *Pedosphere* 15 (1): 46--51.

Birchall, S., C. Dillon, and R. Wrigley. 2008. "Effluent and Manure Management Database for the Australian Dairy Industry." *Effluent and Manure Management Database for the Australian Dairy Industry*.

Bittman, S., C. G. Kowalenko, T. Forge, D. E. Hunt, F. Bounaix, and N. K. Patni. 2007. "Agronomic Effects of Multi-Year Surface-Banding of Dairy Slurry on Grass." *Bioresource Technolgy* 98: 3249-3258.

Bitzer, C. C., and J. T. Sims. 1988. "Estimating the Availability of Nitrogen in Poultry Manure through Laboratory and Field Studies." *Journal of Environmental Quality* 17: 47-54.

Blackie, M. J. 1994. Maize Productivity for the 21st Century: The African Challenge Paper read at the Forth Regional Eastern and Southern Africa Conference, 28th March-1st April, at Harare, Zimbabwe.

Blackshaw, R. E., and L. M. Rode. 1991. "Effect of Ensiling and Rumen Digestion by Cattle on Weed Seed Viability." *Weed Science* 39: 104-108.

Blaise, D., J. V. Singh, A. N. Bonde, K. U. Tekale, and C. D. Mayee. 2005. " Effects of Farmyard Manure and Fertiliserson Yield, Fibre Quality and Nutrient Balance of Rainfed Cotton (Gossypium Hirsutum)." *Bio-resource Technology* 96 (345-349).

Blakemore, L. C., P. L. Searle, and B. K. Daly. 1987. "Methods for Chemical Analysis of Soils." *New Zealand Soil Bureau Scientific Report* 80.

Boehje, M. D., and V. R. Eidman. 1984. *Farm Management*: John, Wiley and Sons New York, pp,806.

Boesch, D. F., R. B. Brinsfield, and R. E. Magnien. 2001. "Chesapeake Bay Eutrophication: Scientific Understanding, Ecosystem Restoration, and Challenges for Agriculture." *Journal of Environment Quality* 30: 303-320.

Bolton, F. E., and D. M. Glenn. 1980. Precipitation Variation and Nitrogen Requirement of Dry Land Winter Cereals: A Proposed Moisture Nitrogen Yield Management Model. Paper read at Proceedings of the International Congress of Dry Land Farming, at Government Printer, South Australia.

Borrell, A. K., G. L. Hammer, and E. Van Oosterom. 2001. "Stay-Green:A Consequence of the Balance between Supply and Demand for Nitrogen During Grain Filling." *Annals of Applied Biology* 138: 91-95.

Bouman, B. A. M., and H. H. van Laar. 2006. "Description and Evaluation of the Rice Growth Model Oryza2000 under Nitrogen-Limited Conditions." *Agricultural Systems* 87 (3): 249-273.   .

Bourn, D., K. Milligan, and W. Wint. 1986. *Tsetse, Trypanosomiasis and Cattle in a Changing Environment*. Edited by R. Von Kaufmann, S. Chater and R. Blench, *Livestock Systems Research in Nigeria's Sub Humid Zone*. AddisAbaba: ILCA.

Bourn, D., and W. Wint. 1994. Livestock, Land Use and Agricultural Intensification in sub-Saharan Africa. Pastoral Development Network Network Paper 37a: London: Overseas Development Institute.

Bowden, B., and M. Chmielewski. 2006. "Summer Rain, Nitrogen and Your Crop." Department of Agriculture Western Australia, Locked Bag No.4, Bentley Delivery Centre, Perth, WA 6983.

Bowden, B. 1989. "Predicting Phosphorus Fertiliser Requirements in Australia." *Journal of Agricultural Science* 2 (5): 22-25. .

Bowen, W. T., J. W. Jones, R. J. Carsky, and J. 0. Quintana. 1993. "Evaluation of the Nitrogen Submodel of Ceres-Maize Following Legume Green Manure Incorporation." *Agronomy Journal* 85: 153-159.

Brady, N. C. . 1996. *The Nature and Properties of Soils*. New York: Macmillan.

Bravo-Ureta, B. E., and R. E. Evenson. 1994. "Efficiency in Agricultural Production: The Case of Peasant Farms in Eastern Paraguay." *Agricultural Economics* 10 (1): 23-37.

Breman, H. 1990. “No Sustainability without External Inputs” in Beyond Adjustment; Africa seminar, Maastricht, the Netherlands. Ministry of Foreign Affairs, Den Haag, 1990, 124 - 133.

Breman, H. 2001. *Soil Fertility Management through Agroforestry to Combat Desertification; Respective and Common Responsibilities of the Rural Development Triangle*. International Institute For Soil Fertility Management IFDC-Africa.

Breman, H., and K. Debrah. 2003. "Improving African Food Security. Special Volume on “Food, Global Market, National Policies, and the International Community”, Sais Review." *A Journal of International Affairs. Johns Hopkins University* 23 (1): 153-170.

Bridle, T. R., L. Molinari, S. Skypsi-Mantele, P. D. Ye, and J. Mills. 2000. "Start up of the Subiaco Enersludge Plant." *Water Science and Technology* 41 (8): 31-36.

Briggs, L., and S. J. Twomlow. 2002. "Organic Material Flows within a Small Holder Highland Farming System in South West Uganda." *Agriculture, Ecosystems and Environment* 89: 191-212.

Bullock, D. G., and D. S. Bullock. 1994. "Quadratic and Quadratic-Plus-Plateau Models for Predicting Optimal Nitrogen Rate of Corn - a Comparison." *Agronomy Journal* 86 (1): 191-195.

Bullock, D.G. 1992. " Crop Rotation. Critical Reviews in Plant Sciences 11: 309-326.

Bundy, L. G., and J. J. Meisinger. 1994. *Nitrogen Availability Indices. Methods of Soil Analysis. Part 2. Microbiological and Biochemical Properties.* EdW. Weaver. Madison, WI: SSSA.

Bundy, L.G. 2000. Nitrogen Recommendations and Optimum Nitrogen Rates: How Do They Compare? Paper read at Proceedings of the 30th North Central Extension Industry Soil Fertility Workshop, 15-16 November, 2000, at St. Louis, MO.

Burgin, A. J., and S. K. Hamilton. 2007. "Have We Overemphasized the Role of Denitrification in Aquatic Ecosystems? A Review of Nitrate Removal Pathway." *Frontiers in Ecology and the Environment* 5: 89-96.

Burgess, S. J., A. J. Digglel, J. W. Bowden, and I. R. P. Fillery. 2003. *Navail Spreadsheet*. Division of Plant Industries, Department of Agriculture, Baron-Hay Court. South Perth. W A. 6151.

Burgess, S. J. 1988. "Going Beyond Single-Figure Fertiliser Recommendations." *Journal of Agriculture, Western Australia* 29: 12-16.

Burkart, M. R., and D. E. James. 1999. "Agricultural Nitrogen Contributions to Hypoxia in the Gulf of Mexico." *Journal of Environment Quality* 28: 850-859.

Burt, J. 1998. "Growing Cabbages in Western Australia. Bulletin 4346." Department of Agriculture

Butler, T. J., and J. P. Muir. 2006. "Dairy Manure Compost Improves Soil and Increases Tall Wheatgrass Yield." *Agroomy Journal* 98 (4):1090-1096.

Calderón, F. J., G.W. McCarty, J. S. Van Kessel, and J. B. Reeves. 2004. "Carbon and Nitrogen Dynamics During Incubation of Manured Soil." *Soil Science Society American Journal* 68: 1592-1599.

Caloin, M., and O. Yu. 1984. "Analysis of the Time-Course of Change in Nitrogen Content in *Dactylis Gromerata* L. Using a Model of Plant Growth." *Annals of Botany* 54: 69-76.

Campbell, C. A., R. J K. Myers, and D. Curtin. 1995. "Managing Nitrogen for Sustainable Crop Prdoduction." *Fert Res* 42: 272-296.

Campbell, C. A., R. P. Zentner, and H. Steppuhn. 1987. "Effect of Crop Rotations and Fertilisers on Moisture Conserved and Moisture Use by Spring Wheat in South western Saskatchewan." *Canadian Journal of Soil Science* 67: 457-472.

Canola Council of Canada 2011. "The Basis of Canola Yields." Available at http://www.canolacouncil.org/chapter1.aspx accessed on 16.11.2011

Cantore, N. 2011. *The Crop Intensification Program in Rwanda*. London, United Kingdom: Overseas Development Institute (ODI).

Carbrera, M. L., D. E. Kissel, and M. F. Vigil. 2005. "Nitrogen Mineralisation from Organic Residues: Research Opportunities." *Journal of Environmental Quality* 34: 75-79.

Carriker, G. L., and J. R. Williams. 1990. *Validation of the Wgen and Ceresmaize Simulation Models for North Eastern Kansas*. Department of Agricultural Economics Research Report No. 11, Kansas State University.

Carsky, R. J., Y. Hayashi, and G. Tian. 1998. "Benefits of Mulching in the Subhumid Savanna One: Research Needs and Technology Testing. Resource and Crop Management Research Monograph No. 26." *International Institute of Tropical Agriculture*.

Carter, S., and H. K. Murwira. 1995. "Spatial Variability in Soil Fertility Management and Crop Response in Mutoko Communal Area." *Zimbabwe AMBIO* 24 (2): 77 - 84.

Castillo, A. E., S. G. Benito, and J. A. FernÃ¡ndez. 2003. "Using Organic Manures as Liming Materials." *Agrochimica* 47 (1-2): 14-20.

CCWA. 2000. *Methods Manual, Natural Resources Chemistry Laboratory*. Perth, Land Resources Section, Chemistry Centre of Western Australia (CCWA).

Cerrato, M. E., and A. M. Blackmer. 1990. "Comparison of Models for Describing Corn Yield and Response to Nitrogen Fertiliser." *Agronomy Journal* 85: 138-143.

Chadwick, D. R., F. John, B. F. Pain, B. J. Chambers, and J. Williams. 2000. "Plant Uptake of Nitrogen from the Organic Nitrogen Fraction of Animal Manures: A Laboratory Experiment." *The Journal of Agricultural Science* 134 (02): 159-168.

Chae, Y. M., and M. A. Tabatai. 1986. "Mineralisation of Nitrogen in Soils Amended with Organic Wastes." *Journal of Environmental Quality* 15 (2): 193-198.

Chambers, B. J., E. I. Lord, F. A. Nicholson, and K. A. Smith. 1999. "Predicting Nitrogen Availability and Losses Following Application of Organic Manures to Arable Land: Manner." *Soil Use and Management* 15 (3): 37-143. .

Chambers, B. J., F. A. Nicholson, P.M. R. Dampney, K. A. Smith, J. R. Williams, and D. R. Chadwick. 2010. "Nutrient Management Tools: The Fertiliser Manual and Manner-NPK

Chambers, B. J., K. A. Smith, and B. F. Pain. 2000. "Strategies to Encourage Better Use of Nitrogen in Animal Manures." *Soil Use and Management* 16: 157-161.

Chang, C., and H. H.Janzen. 1996. "Long-Term Fate of Nitrogen from Annual Feedlot Manure Applications." *Journal of Environment Quality* 25: 785-790.

Chang, C., T. G. Sommerfeldt, and T. Entz. 1990. "Rates of Soil Chemical Changes with Eleven Annual Application of Cattle Feedlot Manure." *Canadian Journal of Soil Science* 70: 673-681.

———. 1991. "Soil Chemistry after Eleven Annual Applications of Cattle Feedlot Manure." *Journal of Environment Quality* 20 (2): 475-480.

Chantigny, M. H., J. MacDonald, C. Beaupré, P. Rochette, D. A. Angers, D. Massé, and L. Parent. 2009. "Ammonia Volatilization Following Surface Application of Raw and Treated Liquid Swine Manure." *Nutrient Cycling in Agroecosystems* 85 (3): 275-286.

Chefurka, P. 2008. "Africa in 2040 .The Darkened Continent. Available at Http://www.Paulchefurka.Ca/Africa/Africa.Html."

Chennareddy, V. 1967. "Production Efficiency in South Indian Agriculture." *Journal of Farm Economics* 49: 816-820.

Cheshire, M. V., and S. J. Chapman. 1996. "Influence of the N and P Status of Plant Material and of Added N and P on the Mineralisation of 14C-Labelled Ryegrass in Soil." *Biol. Fertil. Soils* 21: 166-170.

Chiang, A. 1988. *Fundamental Methods of Mathematical Economics*. 3rd ed:McGraw Hill International editions.

Chikowo, R., P. Mapfumo, P. Nyamugafata, and K. E. Giller. 2004. "Maize Productivity and Mineral N Dynamics Following Different Soil Fertility Management Practices on a Depleted Sandy Soil in Zimbabwe." *Agriculture, Ecosystems & Environment* 102 (2): 119-131.

Chuma, E., B. G. Mombeshora, H. K. Murwira, and J. Chikuvire, eds. 2000. *The Dynamics of Soil Fertility Management in Communal Areas of Zimbabwe*. Edited by T. Hilhorst, F. M. Muchena, H.A Elwell and M. A. Stocking. 7/8 vols. Vol. 22, *Nutrients on the Move -Soil Fertility Dynamics in African Farming Systems*. London International Institute for Environment and Development.

Cleaver, T. J., D. J. Greenwood, and J. T. Wood. 1970. "Systematically Arranged Fertiliser Experiments." *Journal of Horticultural Science and Biotechnology* 45 (4): 457.

Cobb, C., and P. Douglas. 1928. "A Theory of Production." *American Economic Review* 18: 139-250.

Cochrane, J. 2005. *Asset Pricing*. Revised edition ed: Princeton University Press

Cohen, D., and B. Crabtree. 2006. "Qualitative Research Guidelines Project." July 2006. Http://www.Qualres.Org/Homefocu-3647.Html ".

Culley, J. L. B., P. A. Phillips, F. R. Hore, and Patni. N. K. 1981. "Soil Chemical Properties and Removal of Nutrients by Corn Resulting from Different Rates and Timing of Liquid Dairy Manure Applications." *Canadian Journal of Soil Science* 61: 35-46.

Cusick, P., J. Powell, K. Kelling, R. Hensler, and G. MuÅˆoz. 2006. "Dairy Manure N Mineralisation Estimates from Incubations and Litterbags." *Biology and Fertility of Soils* 43 (2): 145-152.

Dadhwal, V. K. 2003. Crop Growth and Productivity Monitoring and Simulation Using Remote Sensing and GIS. Paper read at Proceedings of the Training Workshop on Satellite Remote Sensing and GIS Applications in Agricultural Meteorology, 7-11 July, 2003, at Dehra Dun, India.

Dagg, P. H., J. A Hosegood, and S. M. Kinyali. 1965. *Soil Physics*. Muguga, Kenya: EAAFRO Record of Research, Annual Report 1965 EAAFRO.

Das, L., D. Lohar, I. Sadhukhan, S. A. Khan, A. Saha, and S . Sarkar. 2007. "Evaluation of the Performance of Oryza2000 and Assessing the Impact of Climate Change on Rice Production in Gangetic West Bengal." *Journal of Agrometeorology* 9: 1-10.

Davidson, R., and J. G. McKinnon. 1981. "Several Tests for Model Specification in the Presence of Alternative Hypothses." *Econometrica* 49: 781-793.

Dawson, P., and J. Lingard. 1989. "Measuring Farm Efficiency over Time on Philippine Rice Farms." *Journal of Agricultural Economics* 40 (2): 168-177.

De Jager, A., D. D Onduru, M.S Van Wijk, J. Vlaming, and G. N. Gachini. 2001. "Assessing Sustainability of Low-External-Input Farm Management Systems with the Nutrient Monitoring Approach: A Case Study in Kenya." *Agriculture Ecosystems* 69: 99-118.

De Jager, A., D. D. Onduru, L. N. Gachimibi, F. M. Muchena, G. N. Gachini, and C. L. Van Beek. 2007. "Farmer Field Schools for Rural Empowerment and Life-Long Learning in Integrated Nutrient Management: Experiences in Central and Eastern Kenya In: Practice Makes Perfect." Wageningen University, Wageningen, The Netherlands.

de Ridder, N., and H. van Keulen. 1990. "Some Aspects of the Role of Organic Matter in Sustainable Intensified Arable Farming Systems in the West-African Semi-Arid-Tropics (Sat)." *Fertiliser Research* 26: 299-310.

de Wit, J., H. van Keulen, H. G. van der Meer, and A. J. Nell. 1997. "Animal Manure: Asset or Liability? World Animal Review 88 (1) 30-37 ".

Defra. 2001b. *Department of Environment, Food and Rural Affairs (2001b) Managing Livestock Manures. Making Better Use of Livestock Manures on Arable Land. Booklet 2*. Notts, UK: ADAS.

Delgado, C. L. 1989. "The Changing Economic Context of Mixed Farming in Savanna West Africa: A Conceptual Framework Applied to Burkina Faso." *Reprinted from Quarterly Journal of International Agriculture* 28 (No. 3/4).

Delgado, J. A, M. A Dillon, T. S Richard, and Samuel Y. C. Essah. 2007. "A Decade of Advances in Cover Crops: Cover Crops with Limited Irrigation Can Increase Yields, Crop Quality, and Nutrient and Water Use Efficiencies While protecting the Environment." *Journal of Soil and Water Conservation* 62: 110A-117A.

Delgado, J. A. 1998. "Sequential NLEAP Simulations to Examine Effect of Early and Late Planted Winter Cover Crops on Nitrogen Dynamics." *Journal of Soil and Water Conservation* 53: 241-244.

———. 2001. "Use of Simulations for Evaluation of Best Management Practices on Irrigated Cropping Systems." In *Modelling Carbon and Nitrogen Dynamics for Soil Management*, ed. M. J. et al. Shaffer, 355-381. Boca Raton, FL: Lewis Publishers.

Delgado, J. A., and R. F. Follett. 2002. "Carbon and Nutrient Cycles." *Journal of Soil and Water Conservation* 57: 455-464.

Delgado, J.A., R.J. Ristau, M.A. Dillon, H.R. Duke, A. Stuebe, R.F. Follett, M.J. Shaffer, R.R. Riggenbach, R.T. Sparks, A. Thompson, L.M. Kawanabe, A. Kunugi, K. Thompson. 2001a. "Use of Innovative Tools to Increase Nitrogen Use Efficiency and Protect Environmental Quality in Crop Rotations " *Communications in Soil Science and Plant Analysis* 32: 1321-1354.

DeLuca, T. H., and D. K. DeLuca. 1997. "Composting for Feedlot Manure Management and Soil Quality" *J. Prod. Agric* 10: 235-241.

Delve, R. J., M. E. Probert, J. G. Cobo, J. Ricaurte, M. Rivera, E. Barrios, and I. M. Rao. 2009. "Simulating Phosphorus Responses in Annual Crops Using Apsim: Model Evaluation on Contrasting Soil Types." *Nutr Cycl Agroecosyst* 84: 293-306.

Derbertin, L. P. 1989. *Agricultural Production Economics*. New York: MacMillan publishing Co

Diamond, J. 1998. "Ants, Crops, and History." *Science* 281 (5385): 1974-1975.

Dick, R. P. 1992. "A Review: Long-Term Effects of Agricultural Systems on Soils Biochemical and Microbial Parameters." *Agriculture Ecosystems and Environment* 40: 25-36.

Diggle, A. J, B. Bowden, and S. Burgess. 2003. "Select Your Nitrogen: A Decision Tool for Quantifying Nitrogen Availability and Crop Response in Broadacre Farming Systems: Users Manual. Department of Agriculture, Western Australia.

Dillon, J. l., and J. P. E. Anderson. 1990. *The Analysis of Response in Crop and Livestock Production*. Oxford, UK: Pergamon.

Dillon, J. L., and D. J. McConnell. 1997. *Farm Management for Asia: A Systems Approach*. Department of Agricultural and Resource Economics University of New England Armidale, New South Wales Australia: FAO Farm Systems Management Series-13.

Dixon, J, A. Tanyeri-Abur, and H. Wattenbach. 2003. Context and Framework for Approaches to Assessing the Impact of Globalization on Smallholders. Paper read at Approaches to Assessing the Impact of Globalization on African Smallholders: Household and Village Economy Modelling, Proceedings of Working Session Globalization and the African Smallholder Study, at Rome, Italy.

Doll, J. P., and F. Orazem. 1992. *Production Economics: Theory with Applications*. 2 ed. Malabar, Florida: Krieger Publishing company.

Donovan, G., and F. Casey. 1998. Soil Fertility Management in Sub-Saharan Africa. World Bank Technical Paper No. 408. Washington, DC: World Bank.

Douglas, P. 1948. "Are There Laws of Production?" *American Economic Review* 38: 1-41.

Drechsel, P., L. Gyiele, D. Kunze, and O. Cofie. 2001. "Population Density, Soil Nutrient Depletion, and Economic Growth in Sub-Saharan Africa." *Ecol. Econ* 38: 251-258.

Dwight, D. B. 2009. *Manure Pathogens: Manure Management, Regulations, and Water Quality Protection*. New York: WEF Press: McGraw-Hill.

Ecochem. 2011. "Innovative Solutions for Sustainable Agriculture. Available at Http://Www.Ecochem.Com/T_Manure_Fert.Html."

Edmeades, D. C. 2003. "The Long-Term Effects of Manures and Fertiliserson Soil Productivity and Quality: A Review." *Nutrient Cycling in Agroecosystems* 66 (2): 165-180.

Edwards, P. 2000. Wastewater-Fed Aquaculture: State of the Art. Paper read at Proceedings of the International Conference on Ecological Engineering, 23-27 November at Science City, Calcutta.

Eghball, B. 2002. "Soil Properties as Influenced by Phosphorus and Nitrogen-Based Manure and Compost Applications." *Agronomy Journal* 94: 128-135.

Eghball, B., J. E. Gilley, D. D. Baltensperger, and J. M. Blumenthal. 2002. "Long-Term Manure and Fertiliser Application Effects on Phosphorous and Nitrogen in Runoff." *Transactions of the ASAE* 45 (3): 687-694.

Eghball, B., J. F. Power, J. E. Gilley, and J. W. Doran. 1997. " Nutrient, Carbon, and Mass Loss During Composting of Beef Cattle Feedlot Manure." *Journal of Environment Quality* 26: 189–193.

Egrinya, E. A., S. Yamamoto, and T. Honna. 2001. "Rice Growth and Nutrient Uptake as Affected by Livestock Manure in Four Japanese Soils." *Journal of Plant Nutrition* 24 (2): 333-343.

El-Habbasha, S. F., and M. S. Abd El-Salam. 2010. "Response of Two Canola Varieties (Brassica napus L.) to Nitrogen Fertiliser Levels and Zinc Foliar Application." *International Journal of Academic Research* 2 (2): 60-66.

El Kholy, M. H. , E. M. M. El Zeky, S. Z. Saleh, and Metwaly S. G. 2007. 2007. Physical and Chemical Studies on Some Rapeseed Varieties under Different Levels of Nitrogen Fertilisation. Paper read at Proceedings of the 12th International Rapeseed Congress 26-30 March, Sustainable Development in Cruciferous Oilseed Crops Production, at Wuhan, China.

Ellis, F. 1992. *Agricultural Policies in Developing Countries*. Cambridge, UK: Cambridge University Press.

Elwell, H. A., and M. A. Stocking. 1988. "Loss of Nutrients by Sheet Erosion as a Major Hidden Farming Cost." *The Zimbabwe Science News* 22 (7/8): 79-82.

Endelman, J. B. 2009. "Optimal Compost Rates for Organic Crop Production Based on a Decay Series" (2009). All Graduate Theses and Dissertations. Paper 358." Utah State University, Utah. http://digitalcommons.usu.edu/etd/358.

EPA. 2002a. Developing Document for the Final Revisions to the National Pollutant Discharge Elimination Systems Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations; *EPA 821-R-03-001*. Washington, DC: Environmental protection Agency

Epstein, E., and A. J. Bloom. 2005. *Mineral Nutrition of Plants: Principles and Perspectives*. 2nd ed. Sunderland, Mass: Sinauer, pp. 400.

Eriksen, J., M. Askegaard, and K. Søegaard. 2008. "Productivity and N-Leaching in Organic Dairy Grass-Arable Crop Rotations." *Grassland Science in Europe* 13: 556-558.

Esilaba, A.O., P. Nyende, G. Nalukenge, J. B. Byalebeka, R. J. Delve, and H. Ssali. 2005. "Resource Flows and Nutrient Balances for Crop and Animal Production in Smallholder Farming Systems in Eastern Uganda." *Agriculture, Ecosystems and Environment* 109 (192-201).

Ethiagiator, J. O. 1998. "Farmyard (FYM). Need for Its Adoption as an Alternative to Chemical Fertiliser Use in Nigeria." *Nigeria Journal of Horticultural Science* 3: 1-5.

Evans, M., A. McCutcheon, R. Norton, and S. Marcroft. 2001. "Early Nitrogen Uptake in Canola." *Australian J.Exp.Agr*. 37: 83-92.

Evanylo, G. K. 2010. "Land Application of Biosolids. Department of Crop and Soil Environmental Sciences, Virginia Tech."

Ewulo, B. S., K. O. Hassan, and S. O. Ojeniyl. 2007. "Comparative Effect of Cowdung Manure on Soil and Leaf Nutrient and Yield of Pepper." *Inter. J. Agric. Res* 21 (12): 1043-1048.

FAO. 2001. Soil and Nutrient Management in Sub-Saharan Africa in Support of the Soil Fertility Initiative. Paper read at Proceedings of the Expert Consultation, at Lusaka, Zambia 6-9 December 1999.

———. 2005. "The Importance of Soil Organic Matter." *FAO Soils Bulletin*.

———. 2006. *The State of Food Security in the World, 2006*. Rome: Food and Agriculture Organization of the United Nations.

———. 2007. *FAO Statistical Yearbook 2005–2006. Country Reports*. Vol. 2. Rome: Food and Agriculture Organization of the United Nations.

Felipe, J., and J. McCombie. 2005a. "How Sound Are the Foundations of the Aggregate Production Function? ." *Eastern Economic Journal* 31 (3).

Fening, J. O., N. E Ewusi-Mensah, and E.Y. Safo. 2010. "Improving the Fertiliser Value of Cattle Manure for Sustaining Small Holder Crop Production in Ghana." *Journal of Agronomy* 9 (3): 92-101.

Fening, J. O., N. E. Ewusi-Mensah, and E.Y. Safo. 2011. "Short-Term Effects of Cattle Manure Compost and NPK Application on Maize Grain Yield and Soil Chemical and Physical Properties." *Agricultural Science Research Journal* 1 (3): 69-83.

Ferguson, B. R., J. A. Nienaber, R. A. Eigenberg, and B. L. Woodbury. 2005. "Long-Term Effects of Sustained Beef Feedlot Manure Application on Soil Nutrients, Corn Silage Yield, and Nutrient Uptake." *Journal of Environmental Quality* 34: 1672-1681.

Finger, R., and H. Werner. 2007. "The Application of Robust Regression to a Production Function Comparison-the Example of Swiss Corn. Available at Http://Mpra.Ub.Uni-Muenchen.De/9097/."

Fink, M., and C. Feller. 1998. "An Empirical Model for Describing Growth and Nitrogen Uptake of White Cabbage (*Brassica Oleracea Var. Capitata*)." *Scientia Horticulturae* 73 (2-3): 75-88.

Fischler, M., and C.S. Wortmann. 1999. "Green Manures for Maize-Bean Systems in Eastern Uganda: Agronomic Performance and Farmers Perceptions." *Agroforestry Systems* 47: 123-138.

Fontenot, J. P., L. W. Smith, and A. L. Sutton. 1983. "Alternative Utilization of Animal Wastes." *Journal of Animal Science* 57: 221-233.

Ford, R. E. 1990. "The Dynamics of Human-Environment Interactions in the Tropical Montane Agrosystems of Rwanda: Implications for Economic Development and Environmental Stability." *Mountain Res Dev* 10 (1): 43-63.

Frank, M. D., B. R. Beattie, and M. E. Embleton. 1990. "A Comparison of Alternative Crop Response Models." *American Journal of Agricultural Economics* 72: 597-603.

Franke, A. C., S. Schulz, B. D. Oyewole, J. Diels, and O. K. Tobe. 2008. "The Role of Cattle Manure in Enhancing on-Farm Productivity, Macro- and Micro-Nutrient Uptake, and Profitability of Maize in the Guinea Savanna." *Experimental Agriculture* 44 (3): 313-328.

Fraser, D. G., J. W. Doran, W. W. Sahs, and G. W. Lesiong. 1988. "Soil Microbial Populations and Activities under Conventional and Organic Management." *Journal of Environmental Quality* 17: 585-590.

Freney, J. R. 1996. *Efficient Use of Fertiliser Nitrogen by Crops. Appropriate Use of Fertiliser in Asia and the Pacific*. Edi A Taipei: Food and Fertiliser Technology Center.

Fronning, B. E., K. D. Thelen, and D. Min. 2008. "Use of Manure, Compost, and Cover Crops to Supplant Crop Residue Carbon in Corn Stover Removed Cropping Systems." *Agronomy Journal* 100: 1703-1710.

Fukuda-Parr, S. 2002. *UN Development Programme, Human Development Report 2002*. UNDP.

Fulhage, C. D. 2000. "Reduce Environmental Problems with Proper Land Application of Animal Manure." *Department of Biological and Agricultural Engineering*.

Gachene, C. K. K., C. A. Palm, and J. G. Mureithi. 1999. Legume Cover Crops for Soil Fertility Improvement in the Eastern Africa Region. Paper read at Africa Highlands Ecoregional Programme Workshop, 18th-19th February 1999. AHI and TSBF, at Nairobi.

Gachimbi, L., J. Zake, P. Ebanyat, K. Ergano, M. Abduke, and H. van Keulen. 2009. *Cattle Manure Management in East Africa: Review of Manure Quality and Nutrient Losses and Scenarios for Cattle and Manure Management. Report 258*. Lelystad: Wageningen UR Livestock Research, Partner in Livestock Innovations.

Gachimbi, L. N., P. T. Kamoni, S. N. Wanjogu, P. N. Macharia, and P.T. Gicheru. 2007. *Land Use Practices in Mbeere District: Biophysical and Socio Economic Challenges, Copping Strategies and Opportunities: A Baseline Survey Report*. Nairobi: KARI.

Gachimbi, L. N., D. D. Onduru, de Jager., F. Maina, and F. N. Muchena. 2003. *Integrated Nutrient Management to Attain Sustainable Productivity Increases in East African Farming Systems. Semi-Arid Agriculture and Rural Livelihoods of Eastern Kenya. Report of a Baseline Survey Carried out in Muthanu Village of Siakago Division, Mbeere District*. INMASP Report No. KE-05.

Gale, E. S. 2005. "Estimating Plant-Available Nitrogen Release from Manures, Composts, and Crop Residues. M.S. Thesis." Oregon State University, Corvallis, Oregon.

Gale, E. S., D. M. Sullivan, C. G. Cogger, A. I Bary, D. D. Hemphill, and E. A. Myhre. 2006. "Estimating Plant Available Nitrogen Release from Manures, Composts, and Speciality Products." *Journal of Environmental Quality* 35 (6): 2321-2332.

Gallardo, M., R. B. Thompson, J. S. Rodriguez, F. Rodriguez, M. D. Fernandez, J. A. Sanchez, and J. J. Magan. 2009. "Simulation of Transpiration, Drainage, N Uptake, Nitrate Leaching, and N Uptake Concentration in Tomato Grown in Open Substrate." *Agricultural Water Management* 96 (12): 1773-1784.

Gana, A. K. 2009. " Evaluation of the Residual Effect of Cattle Manure Combinations with Inorganic Fertiliser and Chemical Weed Control on the Sustainability of Chewing Sugarcane Production at Badeggi Southern Guinea Savanna of Nigeria (National Cereals Research Institute, P.M.B. 8, Niger State, Nigeria." *Middle East Journal of Scientific Research* 4 (4): 282-287

Gaskell, M., R. E. Smith, J. P. Mitchell, S. T. Koike, C. Fouche, T. Hartz, W. R. Horwath, and L. Jackson. 2006. *Soil Fertility Management for Organic Crops*. Oakland, CA: UCAR.

Geering, H. R. 1995. "Field Measurements of Soil Physical Properties." *Australian Society of Soil Science* 187-215. .

GEF. 2003. *What Kind of World? The Challenge of Land Degradation*. Washington, DC: Global Environmental Facility.

Gendebien, A., R. B. Ferguson, J. Brink, H. Horth, M. Sullivan, R. Davis, H. Brunet, et al. 2001. *European Commission- Directorate-General for Environment*. Marlow, Bucks, UK.: Water Research Centre.

Gerba, C. P., and J. E. Smith. 2004. "Sources of Pathogenic Microorganisms and Their Fate During Land Application of Wastes." *Journal of Environmental Quality* 34 (1): 42-48.

Gichangi, E. M., N. K. Karanja, and C. W. Wood. 2006. "Composting Cattle Manure from Zero-Grazing Systems with Agro-Organic Waste to Minimize Nitrogen Losses in Smallholder Farms in Kenya." *Tropical and Subtropical Agro-ecosystems* 6: 57-64.

Giller, K. E., G. Cadisch, and C. Palm. 2002. "The North-South Divide! Organic Wastes or Resources for Nutrient Management?" *Agronomie* 22: 703-709.

Giller, K. E., E. C. Rowe, N. de Ridder, and H. van Keulen. 2006. "Resource Use Dynamics and Interactions in the Tropics: Scaling up in Space and Time." *Agricultural Systems* 88: 8-27.

Gilmour, J. T., C. G. Cogger, L. W. Jacobs, G. K. Evanylo, and D. M. Sullivan. 2003. "Decomposition and Plant-Available Nitrogen in Biosolids: Laboratory Studies, Field Studies, and Computer Simulation." *Journal of Environmental Quality* 32: 1498-1507.

Glendining, M. J., P. R. Poulton, D. S. Powlson, and D. S. Jenkinson. 1997. "Fate of 15n-Labelled Fertiliser Applied to Spring Barley Grown on Soils of Contrasting Nutrient Status." *Plant and soil* 195: 83-98.

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." *Inter J Sustain Dev World Ecol* 6: 45-59.

Gollin, D. 1991. *Status, Trends, and Directions of Animal Agriculture in Sub-Saharan Africa*. Morilton, Arkansas: Winrock International.

Gooch, C., and A. W Wedel. 2010. *Effective Means of Handling Sand-Laden Dairy Manure*. http://www.ansci.cornell.edu/prodairy/index.html.

Gowa, A., B. Bashaasha, and B. Tayebwa. 2001. "Determination of Optimal Levels of Resource Use in Clonal Robusta Coffee Production in Central Uganda." *Eastern Africa Journal of Rural Development* 17: 1-8.

Grant, P. M. 1967. "The Fertility of Sandveld Soil under Continuous Cultivation I. The Effect of Mnaure and Nitrogen on the Nitrogen Status of Soil." *The Rhodesia, Zambia and Malawi Journal of Agricultural Research* 5: 71 - 79.

GRDC. 2008. "Raising the Bar with Better Canola Agronomy." http://www.grdc.com.au/uploads/documents/Raising%20the%20Bar%20with%20Better%20Canola%20Agronomy%20Part%202.pdf.

———. 2009. "The Annual Operational Plan of the Grains Research and Development Corporation (GRDC) for the Financial Year 2009–10."

———. 2010. "Recycled Organic Fertiliser. Grains Research and Development Corporation Fertiliser Fact Sheet, May 2010, Publication."www.dpi.nsw.gov.au/research/centres/croa.

Green Alliance. 2007. "The Nutrient Cycle: Closing the Loop ", ed. H Hislop. London, UK: Green Alliance.

Greene, W. H. 2008. *Econometric Analysis*. 6th ed. Upper Saddle River, NJ: Prentice-Hall.

Greenwood, D. J., T. J. Cleaver, M. K. Turner, J. Hunt, K. B. Niendorf, and S. M. H. Loquens. 1980a. "Comparison of the Effects of Potassium Fertiliser on the Yield, Potassium Content and Quality of 22 Different Vegetable and Agricultural Crops" *Journal of Agricultural Science, Cambridge* 95: 441-456.

———. 1980b. "Comparison of the Effects of Nitrogen Fertiliser on the Yield, Content and Quality of 21 Different Vegetable and Agricultural Crops." *Journal of Agricultural Science, Cambridge* 95: 471-485.

Greenwood, D. J., L. M. J. Verstraeten, A. Draycott, and R. A. Sutherland. 1987. "Response of Winter Wheat to N-Fertiliser: Dynamic Model." *Fertiliser Research* 12: 139-156.

Greenwood, D.J., and A. Draycott. 1989. "Experimental Validation of an N-Response Model for Widely Different Crops." *Ferterliser Research*: 153-174.

Griffin, T. S., E. Giberson, and M. Wiedenheft. 2002. "Yield Response of Long-Term Mixed Grassland Awards and Nutrient Cycling under Different Nutrient Sources and Management Regimes. ." *Grass and Forage Science* 57: 268-278.

Griliches, Z. 1957. "Specification Bias in Estimates of Production Functions." *Journal of Farm Economics* 39 (1): 8-20.

Grimm, S. S., Q. Paris, and W. A. Williams. 1987. "A Von Liebig Model for Water and Nitrogen Crop Response." *Western Journal of Agricultural Economics* 12: 182-192.

Gruhn, P., F. Golleti, and M. Yudelman. 2000. Integrated Nutrient Management, Soil Fertility and Sustainable Agriculture: Current Issues and Future Challenges. Food, Agriculture and Environment Discussion Paper. 32. Washington D.C: International Food Policy Research Institute.

Gunnerson, C. G., and D. C. Stuckey. 1986. *Integrated Resource recovery Anaerobic Digestion Principles and Practices for Biogas Systems. World Bank Technical Paper 49. UNDP Project Management Report Number 5*. Washington, D.C., U.S.A: The World Bank .

Gupta, V. 2011. "Biological and Nutritional Value of Stubble Retention " *Grains Research and Development Corporation (CSIRO) Ecosystem Sciences*.

Haines, J. R.; and L. Staley. 2004. *Risk Assessment Evaluation for Concentrated Animal Feeding Operations;* EPA/600/R-04/042; Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory: Cincinnati, Ohio.

Hansen, E. M., J. Eriksen, and F. P. Vinther. 2007. "Catch Crop Strategy and Nitrate Leaching Following a Grazed Grass-Clover." *Soil Use and Management* 23: 348-358.

Hansen, S., H. E. Jensen, N. E Nielsen, and H. Svendsen. 1991. "Simulation of Nitrogen Dynamics and Biomass Production in Winter Wheat Using the Danish Simulation Model Daisy." *Fertiliser Research* 27: 245-259.

Hansen, S., H. E. Jensen, N. E. Nielsen, and H. Svendsen. 1990. "Daisy: A Soil Plant System Model. Danish Simulation Model for Transformation and Transport of Energy and Matter in the Soil Plant Atmosphere System, 350 Pp."

Hao, X., C. Chang, F. J. Larney, and G. R. Travis. 2001. "Greenhouse Gas Emissions During Cattle Feedlot Manure Composting." *Journal of Environment Quality* 30: 376-386.

Haque, I., M. J. Powell, and K. S. Ehui. 1995. *Improved Crop-Livestock Production Strategies for Sustainable Soil Management in Tropical Africa. In: R.Lal and B.A Steward (Eds). Advances in Soil Science Management Experimental Basis for Sustainability and Environmental Quality*. Tokyo CRC Lewis publishers Boca Raton London, PP 293- 345.

Harris, F. 2002. "Management of Manure in Farming Systems in Semi-Arid West Africa." *Experimental Agriculture* 38 (2): 131-148.

Harris, M. A., and P. Rengasamy. 2004. "Sodium Affected Subsoils, Gypsum, and Green-Manure: Inter-Actions and Implications for Amelioration of Toxic Red Mud Wastes." *Environmental Geology* 45 (8): 1118-1130.

Harris, P. J. C., H. D. Lloyd, A. H. Hofny-Collins, BarrettH. R., and BrowneA. W. 1997. "Organic Agriculture in Sub-Saharan Africa: Farmer Demand and Potential for Development, a Study to Inform Policy. ODA Project R6362a. Henry Doubleday Research Association, Coventry & African Studies Centre, Coventry University, Uk ".

Harter, T., H. Davis, M. C. Mathews, and R. D. Meyer. 2002 "Shallow Groundwater Quality on Dairy Farms with Irrigated Forage Crops." *Journal of Contaminant Hydrology* 55: 287-315.

Hasanein, B. M., F. A. El-Azizy, and H. H. Hatem. 2009. "Evaluation of N Submodel of Ceres-Maize under Egyptian Desert Soil Conditions of North Sinai " *Egyptian Journal of Soil Science* 49: 145-153.

Hasegawa, H., D. C. Bryant, and R. F. Denison. 2000. "Testing Ceres Model Predictions of Crop Growth and N Dynamics, in Cropping Systems with Leguminous Green Manures in a Mediterranean Climate." *Field Crops Research* 67 (3): 239-255.

Hashimoto, A. G., and Y. R. Chen. 1981a. In: Proc. 4th Intl. Symp. On Livestock Wastes, Am. Soc. Agric. Eng., St. Joseph, Michigan, Pp. 129-132.

Havlicek, J., and J. A. Seagraves. 1962. "The Cost of the Wrong Decision as a Guide in Production Research." *Journal of Farm Economics* 44 (1): 157-168.

Havlin, J. L., J. D. Beaton, S. L. Tisdale, and W. L. Nelson. 2005. *Soil Fertility and Nutrient Management: An Introduction to Nutrient Management*. 7th ed. Upper Saddle River, NJ: Pearson/Prentice Hall.

Havlin, J. L., J.D. Beaton, S.L. Tisdale, and W.L. Nelson. 1999. *Soil Fertility and Fertilisers*. 6th ed. Upper Saddle River, N.J. Prentice-Hall inc 499. On N effects of growth.

Haynes, R. J., R. S. Swift, and R. C. Stephen. 1991. "Influence of Mixed Cropping Rotations (Pasture-Arable) on Organic Matter Content Water Stable Aggregation and Clod Porosity in a Group of Soils " *Soil Tillage Res* 19: 77.

Heady, E. 0., and J. T. Pesek. 1954. "A Fertiliser Production Surface." *Journal of Farm Economics* 36: 466-482.

Heady , E. O., L. John, and J. Dillon. 1961. *Chapter 3, Agricultural Pro-Duction Functions*: Iowa State Uni-versity Press.

Heathman, G. C., D. C. Flanagan, M. Larose, and B. W. Zuercher. 2008. "Application of the Soil and Water Assessment Tool and Annualized Agricultural Non-Point Source Models in the St. Joseph River Watershed." *Journal of Soil and Water Conservation* 63 (6): 552-568.

Heard, J., C. Cavers, and G. Adrian. 2006. "Up in Smoke-Nutrient Loss with Straw Burning." *Better Crops* 90 (3): 10-11.

Hazelton, P., and B. Murphy. 2010. *Interpreting Soil Test Results: What Do All the Numbers Mean?* Collingwood VIC, Australia: CSIRO Publishing.

Heinrich, A. 2009."Nitrogen fertiliser value of solid and liquid dairy wastes produced in California's San Joaquin Valley". M.S. diss., University of California, Davis. In *Dissertations & Theses:* Available from http://www.proquest.com (publication number AAT 1468085; accessed October 20, 2011).

Heisey, P. W., and W. Mwangi. 1996. "Fertilizer Use and Maize Production in Sub-Saharan Africa. Cimmyt Economics Working Paper 96-01. Mexico, D.F.: Cimmyt."

Helgason, B. L., F. J. Larney, H. H. Janzen, and B. M. Olson. 2007. "Nitrogen Dynamics in Soil Amended with Composted Cattle Manure." *Canadian Journal of Soil Science* 87: 43-50..

Hemy, C. 1984. *Growing Vegetables in South Africa*. Johannesberg, South Africa: McMillan South Africa, Pty Ltd

Henao, J., and C. Baanante. 2006. *Agricultural Production and Soil Nutrient Mining in Africa: Implications for Resource Conservation and Policy Development*. Muscle Shoals, Alabama 35662, U.S.A: International Center for Soil Fertility and Agricultural Development (IFDC).

Hendawy, S. F. , A. Azza, E. El-Din, E. E. Aziz, and Omer. E. A. 2010. "Productivity and Oil Quality of Thymus Vulgaris L. Under Organic Fertilisation Conditions." *Ozean Journal of Applied Sciences* 3 (2): 201-216.

Henry, C., L. Johnson, R. Koelsch, C. Shapiro, and C. S. Wortmann. 2010. *Animal Manure Management. University of Nebraska-Lincoln Manure Management Team*. http://water.unl.edu/web/manure/manure-value.

Hepperly, P. R., K. Kpomblekou-A, and J. G. Davis. 2010. "Organic Nitrogen Systems in the United States."

Hergert, G. W. 2009. "Fertiliser Prices and Their Availability for 2009. Soils and Nutrient Management " *High plains/Midwest agricultural Journal*

Hession, W. C., R. A. Young, and C. A. Onstad. 1988. Simulation of Site-Specific Sediment Deposition with the AnnAGNPS Model. In *ASAE winter meeting paper No.88-534*.

Higgs, R. L., A. E. Peterson, and W. H. Paulson. 1990. "Crop Rotation: Sustainable and Profitable." *Journal of Soil Water Conservation* 45: 68-70.

Hillel, D. 1982. *Introduction to Soil Physics Academic Press*. New York.

Hirel, B., J. L. Gouis, B. Ney, and A. Gallais. 2007. "The Challenge of Improving Nitrogen Use Efficiency in Crop Plants: Towards a More Central Role for Genetic Variability and Quantitative Genetics within Integrated Approaches." *Journal of Experimental Botany* 58, (9): 2369-2387.

Hocking, P. J., P. J. Randall, and D. DeMarco. 1997. "The Response of Dryland Canola to Nitrogen Fertiliser: Partitioning and Mobilization of Dry Matter and Nitrogen, and Nitrogen Effects on Yield Components." *Field Crops Research* 54 (2-3): 201-220.

Hocking, P. J., and M . Stapper. 2001. "Effects of Sowing Time and Nitrogen Fertiliser on Canola and Wheat, and Nitrogen Fertiliser on Indian Mustard 11. Nitrogen Concentrations, N Accumulation, and N Fertiliser Use Efficiency." *Australian Journal of Agricultural resources* 52: 635-644.

Hodges, T., S. L. Johnson, and B. S. Johnson. 1992. "Simpotato: A Highly Modular Program Structure for an IBSNAT Style Crop Simulation." *Agronomy Journal* 84: 911-915.

Holmes, B. J. 2007. *Sand Laden Manure Handling Alternatives Biological Systems* Madison, 460 Henry Mall Madison, WI 53706 Engineering Department, University of Wisconsin

Holt-Giménez, E. 2008. "The World Food Crisis": What Is Behind It and What We Can Do? Available at .Http://Americas.Irc-Online.Org/Am/5611 ".

Hooton, N.; Lee-Smith, D.; Nasinyama, G.; Romney, D.; Atukunda, G.; Azuba, M.; Kaweesa, M.; Lubowa, A.; Muwanga, J.; Njenga, M.; Young, J. 2007. Championing urban farmers in Kampala. Influences on local policy change in Uganda. Process and partnership for pro-poor policy change. ILRI Research Report 2. Nairobi (Kenya): ILRI Hopper, D. W. 1965. "Allocation Efficiency in Traditional Indian Agriculture." *Journal of farm economics* 47 611-624.

Howard, J., J. Jeje, V. Kelly, and D. Boughton. 2000. *Comparing Yields and Profitability in Mader's High- and Low-Input Maize Program*. Maputo, Mozambique: Government of Mozambique, Ministry of Agriculture and Rural Development. Research Report 39.

Huang, S. N., and J. C. Lin. 2001. "Current Status of Organic Materials Recycling in Southern Taiwan."

Huett, D. O. 1986. "Response to Nitrogen and Potassium of Tomatoes Grown in Sand Culture." *Australian Journal of Experimental Agriculture* 26: 133-138.

Huett, D. O., and E . B. Dettmann. 1988. "Effect of Nitrogen on Growth, Fruit Quality and Nutrient Uptake of Tomatoes Grown in Sand Culture." *Australian Journal of Experimental Agriculture* 28: 391-399.

Huett, D. O., and E. B. Dettmann. 1991. "Nitrogen Response Surface Models of Zucchini Squash, Head Lettuce and Potato." *Plant and Soil* 134 (2): 243-254.

Hulugalle, N., S. Ghosh, T. Weaver , L Finlay, H. Daniel, and P. Lockwood. 2009. "Cattle Manure and Composted Gin Trash: Benefits and Costs ".

Idnani, M. A, and S Varadaraj an. 1974. "Indian Council of Agric. Res., Technical Bull. No. 46, New Delhi."

IFDC. 1996. Africa Fertiliser Situation, November 1996, at Muscle Shoals, Alabama.

———. 2003. Input Subsidies and Agricultural Development: Issues and Options for Developing and Transitional Economies. Muscle Shoals, Al: International Fertiliser Development Center. Paper Series P-29

———. 2006. Africa Fertiliser Summit Proceedings, at Abuja, Nigeria June 9-13 2006. IFDC, Florence, Alabama.

———. 2008. "High Fertiliser Prices, Shortages, Cause Worldwide. Social Unrest. Available at Http://Betuco.Be/Compost/Fertilisers%20prices%202008.Pdf."

IITA. 1993. *Sustainable Food Production in Sub-Saharan Africa: Constraints and Opportunities*. Vol. 2. Ibadan, Nigeria.

IITA. 2010. "Made to Measure: Smart Natural Resources Management Approaches " *Research Review for Development . IITA publication* http://r4dreview.org/2010/03/made-to-measure-smart-natural-resources-management-approaches.

Innes, R. 2000. "The Economics of Livestock Waste and Its Regulation." *American Journal of Agricultural Economics* 82: 97-117.

Isbell, R. F. 1996. *The Australian Soil Classification*. Collingwood, Victoria: CSIRO.

Islam, K. R., S. R. Wright, and J. Fisher. 2011. Cover Crop, Composted Chicken and Cattle Manure Effect on Crop Yields, Weed Control and Soil Quality in Soybean-Corn Rotations. Paper read at Proceedings of the Midewest Cover Crops Council at The Ohio State University.

Iwuafor, E. N. O., K. Aihou, J. S. Jaryum, B. Vanlauwe, J. Diels, N. Sanginga, O. Lyasse, J. Deckers, and R. Merckx. 2002. *On-Farm Evaluation of the Contribution of Sole and Mixed Applications of Organic Matter and Urea to Maize Grain Production in the Savanna.In Integrated Plant Nutrient Management in Sub-Saharan Africa*. Edited by J. Vanlauwe, D. N Sanginga and R. Merckx, *From Concept to Practice*. Wallingford, UK: CAB International.

Jackson, D. R., and K. A. Smith. 997. "Animal Manure Slurries as a Source of Nitrogen for Cereals; Effect of Application Time on Efficiency." *Soil Use and Management* 13: 75-81.

Jackson, H. L., and E. J. Mtengeti. 2005. "Assessment of Animal Manure Production, Management and Utilization in Southern Highlands of Tanzania." *Livestock Research for Rural Development* 17 10.http://www.cipav.org.co/lrrd/lrrd17/10/jack17110.htm.

Jahan, M., A. Koocheki, M. Nassiri, and F. Dehghanipur. 2008. The Effects of Different Cattle Manure Levels and Branch Management Methods on Organic Production of Cucubita Pepo L. Paper read at 16th IFOAM Organic World Congress

Jalota, S. K., A. Sood, J. D. Vitale, and R. Srinivasan. 2007. "Simulated Crop Yield Response to Irrigation Water and Economic Analysis: Increasing Irrigated Water Use Efficiency in the Indian Punjab." *Agronomy Journal* 99: 1073-1084.

Janssen, B. H. 1998. "Efficient Use of Nutrients: An Art of Balancing." *Field Crops Research* 56 (1-2): 197-201..

Janvry, A. 1972. "Optimal Levels of Fertilisation under Risk: The Potential for Corn and Wheat Fertilisation under Alternative Price Policies in Argentina." *American Journal of Agricultural Economics* 54 (1): 1-10.

Jayne, T. S., J. Govereh, M. Wanzala, and M. Demeke. 2003. "Fertiliser Market Development: A Comparative Analysis of Ethiopia, Kenya, and Zambia." *Food Policy* 28 (4): 293-316.

Jayne, T. S., V. Kelly, and E. Crawford. 2003. *Fertiliser Consumption Trends in Sub-Saharan Africa. Policy Synthesis. Number 69.* Africa Bureau Office of Sustainable Development and Bureau for Economic Growth, Agriculture, and Trade, and Office of Agriculture Food Security.

Jen-Hshuan, C. 2008. The Combined Use of Chemical and Organic Fertilisers and/or Biofertiliser for Crop Growth and Soil Fertility. Food and Fertiliser Technology Center: Accessed 3rd October, 2011.

Jenkinson, D. S., and D .S. Powlson. 1976. "The Effects of Biocidal Treatments on Metabolism in Soil-V. A Method for Measuring Soil Biomass." *Soil Biology and Biochemistry* 8: 209-213.

Joern, B. C., and P. Hess. 2004. "Manure Nutrient Availability Calculator. Available at Http://Www.Agry.Purdue.Edu/Mmp."

Jeffery, R. C. 1982. "Measurement of Potassium in 0.5 M $NaHCO_3$ Extracts of Soil by Flame Aas", Annual Technical Report No. 2, Agricultural Chemistry Laboratory, Government Chemical Laboratories, Perth WA.

Joghan, A. K., A. Ghalavand, M. Aghaalikhani, M. Gholamhoseini, and A. Dolatabadian. 2010. "Comparison among Different Integrated Nutrition Management for Soil Micro and Macro Elements after Winter Wheat Harvesting and Yield " *Not Sci Biol* 2 (2): 107-111.

Johnson, J., M. Mark Loux, G. Ropp, and J Adams. 2011. *Best Management Practices: Application of Organic Materials on Soils Used for Crop Production*: Ohio State University Extension Department of Horticulture and Crop Science: AGF-211-95.

Johnson, P. R. 1953. "Alternative Functions for Analysing a Fertiliser-Yield Relationship." *Journal of Farm Economics.* 35: 519-29.

Johnston, J. 1972. *Econometrics Methods*: McGraw Hill Book Co.

Jokela, B., S. Bosworth and J. Tricou 1999. Manure Application Methods for Corn Field Studies on Direct Incorporation of Liquid Dairy Manure for Fall, Spring, and Sidedress Application in Corn LMWQ-4. Plant and Soil Sci. Dept., Univ. of Vermont, Burlington, VT. http://pss.uvm.edu/vtcrops/NutrientMgt.html

Jokela, W. E. 1992. "Nitrogen Fertiliser and Dairy Manure Effects on Corn Yield and Soil Nitrate." *Soil Science Society of American Journal* 56: 148-154.

Jokela, W. E., and J. J. Meisinger. 2004. "Liquid Manure: Ammonia Loss and Nitrogen Availability. Http://Www.Farmwest.Com/Index.Cfm?Method=Library.Showpage&Librarypageid=140."

Jones, C. A., and J. Kiniry. 1986. *Ceres-Maize: A Simulation Model of Maize Growth and Development. Texas Am University Press College Station Texas. Texas A and M University Press.*

Jon, D. G., and T. R. Leinbach. 1996. "Focus Groups as Alternative Research Practice: Experience with Transmigrants in Indonesia." *Area* 28 (2): 115-123.

Joshua, W. D., D. L. Michalk, I. H. Curtis, M. Salt, and G. J. Osborne. 1998. "The Potential for Contamination of Soil and Surface Waters from Sewage Sludge (Biosolids) in a Sheep Grazing Study, Australia." *Geoderma* 84 (1-3): 135-156.

Junge, B., R. Abaidoo, D. Chikoye, K. Stahr, and R. Lal. 2008. "Soil Conservation in Nigeria :Past and Present on-Station and on-Farm Initiatives." *Soil and Water Conservation Society, Ankeny, Iowa*.

Just, E. R., D. Zilberman, E. Hchman, and Z. Barshira. 1990. "Input Allocation in Multicrop Systems." *American journal of Agricultural Economics* 72: 200-209.

Kabat, P., B. van der Broek, and R. A. Feddes. 1992. "SWACROP: A Water Management and Crop Production Simulation Function." *LCID Bulletin* 41 (2): 61-84.

Kabeer, N. 1998. Money Cant Buy Me Love'? Re-Evaluating Gender, Credit and Empowerment in Rural Bangladesh. Discussion Paper 363, Institute of Development Studies, Sussex University, Brighton.

Kaizzi, C. K., H. Ssali, A. Nansamba, and L. G. Vlek Paul. 2002. "The Potential, Cost and Benefit of Velvet Bean (Mucuna Pruriens) an Inorganic N Fertilisersin Improving Maize Production under Soils of Different Fertility". IFPRI/ Zef/ NARO Working Paper.

Kalirajan, K. P., and J. C. Flinn. 1983. "The Measurement of Farm Specific Technical Efficiency." *Pakistan Journal of applied economics* 11 (2): 167-180.

Kanbur, R. 2008. *Shadow Pricing:The New Palgrave Dictionary of Economics*. Edited by S. N. Durlauf and L. E. Blume. 2nd ed: Palgrave Macmillan.

Kaneko, N., and E. F. Salamanca. 1999. "Mixed Leaf Litter Effects on Decomposition Rates and Soil Microarthropod Communities in an Oak-Pine Stand in Japan." *Ecological Research* 14 (2): 131-138.

Kanonge, G., H. Nezomba, R. Chikowo, F. Mtambanengwe, and P. Mapfumo. 2009. Assessing the Potential Benefits of Organic and Mineral Fertiliser Combinations on Maize and Legume Productivity under Smallholder Management in Zimbabwe. Paper read at African Crop Science Conference Proceedings.

Kapkiyai, J. J., N. K. Karanja, P. L. Woomer, and J. N. Qureshi. 1999. "Soil Organic Carbon Fractions in a Long-Term Experiment and the Potential for Their Use as a Diagnostic Assays in Highland Farming Systems of Central Kenya." *African Crop Science Journal* 6: 19-28.

Kaplan, J. D., R. C. Johansson, and M. Peters. 2004. "The Manure Hits the Land: Economic and Environmental Implications When Land Application of Nutrients Is Constrained." *American Journal of Agricultural Economics* 86 (,3): 688-700.

Karungi, J., S. Kyamanywa, and B. Ekbom. 2006. "Comparison of the Effect of Market Crop Wastes and Chemical Soil Fertility Amendments on Insect Pests, Natural Enemies and Yield of Brassica Oleracea." *Annals of Applied Biology* 149 (2): 103-109.

Kazemeini, S. A., H. Hamzehzarghani, and M. Edalat. 2010. "The Impact of Nitrogen and Organic Matter on Winter Canola Seed Yield and Yield Components. Crop Production and Plant Breeding Department, College of Agriculture, Shiraz University, Shiraz, Iran." *Australian journal of crop science (AJCS)* 4 (5): 335-342.

Keating, B. A., P. S. Carberry, G. L. Hammer, M. E. Probert, M. J. Robertson, D. Holzworth, N. I. Huth, et al. 2003. "An Overview of APSIM, a Model Designed for Farming Systems Simulation." *European Journal of Agronomy* 18 (3-4): 267-288.

Kelling, K. A., and L. G. Bundy. 2001. Economics of Nitrogen Fertiliser Use with Low Crop Prices. Paper read at Wis. Fert. Aglime and Pest Mgmt.

Kelly, R. M., W. M. Strong, T. A. Jensen, and D. Butler. 2004. "Application of Probability Analysis to Assess Nitrogen Supply to Grain Crops in Northern Australia." *Precision Agriculture* 5 (2): 95-110.

Kemppainnen, E. 1989. "Nutrient Content and Fertiliser Value of Livestock Manure with Special Reference to Cow Manure." *Annales Agriculturae Fenniiae* 28: 163-284.

Keplinger, K. O., and L. M. Hauck. 2006. "The Economics of Manure Utilization: Model and Application." *Journal of Agricultural and Resource Economics* 31 (2): 414-440.

Ketseemang, M. 2006. "Response of Cabbage (*Brassica Oleracea Vacapitata*) to Nitrogen, Phosphorus and Potassium Nutrition." Department of plant production and soil science, Faculty of natural and agricultural sciences, University of Pretoria, Prestoria.

Ketterings, Q. M., G. Albrecht, K. Czymmek, and S. Bossard. 2005. *Nitrogen Credits from Manure Fact Sheet 4*. Ithaca: Cornell University Cooperative Extension.

Keulen H van, H., F. W. T. Penning de Vries, and E. M. Drees. 1992. "A Summary Model for Crop Growth" In *Simulation of Crop Growth and Crop Production* eds F. W. T. Penning de Vries and H. H. van Laar, 87-97. Wageningen: PUDOC

Khan, A. R., C. Chandra, P. Nanda, S. S. Singh, A. K. Ghorai, and S. R. Singh. 2004. "Integrated Nutrient Management for Sustainable Rice Production." *Archives of Agronomy and Soil Science* 50: 161-165.

Khan, A. U. H., M. Iqbal, and K. R. Islam. 2007. "Dairy Manure and Tillage Effects on Soil Fertility and Corn Yields." *Bioresource Technology* 98 (10): 1972-1979..

Khan, P. K., J. Nath, S. N. T. Tanaja, and V. P. Gopal. 1975. "Effect of Organic Manuring on Soil Physical Properties of Sandy Loam Soils of Hissar." *Indian Journal of Soil Science* 23 380-383.

Kiemnec, G. L., T. L. Jackson, Jr. D. D. Hemphill, and V.V. Volk. 1987. "Relative Effectiveness of Sewage Sludge as a Nitrogen Fertiliser for Tall Fescue." *Journal of Environmental Quality* 16 (4): 354-356.

Kimani, S. K., and J. K. Lekasi. 2004. *Managing Manures Throughout Their Production Cycle Enhances Their Usefulness as Fertilisers: In Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa* Edited by A Bationo. Nairobi, Kenya: CIAT-TSBF.

Kimetu, J. M., D. N. Mugendi, C. A. Palm, P. K. Mutuo, C. N. Gachengo, A. Bationo, S. Nandwa, and J. B. Kungu. 2004. "Nitrogen Fertiliser Equivalencies of Organics of Differing Quality and Optimum Combination with Inorganic Nitrogen Source in Central Kenya." *Nutrient Cycling in Agroecosystems* 68 (2): 127-135.

King, K. W., and H. A. Torbert. 2007. "Nitrate and Ammonium Losses from Surface-Applied Organic and Inorganic Fertilisers." *Journal of Agric Science* 145: 385-393.

King, T., J. J. Schoenau, and S. S. Malhi. 2008. Effect of Repeated Additions of Liquid Swine Manure and Solid Cattle Manure on Soil Organic Carbon. Paper read at CSSS/SCSS, Annual meeting at University of northern British Columbia, Prince George , British Columbia , 6-10 July 2008

Kirchhof, G., and F. K. Salako. 2000. "Residual Tillage and Bush-Fallow Effects on Soil Properties and Maize Intercropped with Legumes on a Tropical Alfisol." *Soil Use and Management* 16: 183-188.

Kirchmann, H. 1985. "Losses, Plant Uptake and Utilisation of Manure Nitrogen During a Production Cycle." *Acta Agriculturae Scandinavica (Suppl)* 24: 77.

Kirchmann, H. , and E. Witter. 1992. "Composition of Fresh, Aerobic and Anaerobic Farm Animal Dungs." *Bioresoure Technology* 40: 137-142.

Kislev, Y. 1966. "Overestimates of Returns to Scale in Agriculture. A Case of Synchronized Aggregation." *Journal of Farm Economics* 48: 51-62.

Kitzinger, J. 1995. "Introducing Focus Groups." *British Medical Journal* 311: 299-302.

Klausner, S. D. 1997. "Nutrient Management: Crop Production and Water Quality. Northeast Regional Agricultural Engineering Service, Ithaca, N.Y."

Klausner, S. D., and D. R. Bouldin. 1983. *Soil Fertility, Managing Animal Manure. Part Ii: Field Management*. Ithaca: Cornell University Cooperative Extension.

Klausner, S. D., V. R. Kanneganti, and D. R. Bouldin. 1994. "An Approach for Estimating a Dairy Series for Organic Nitrogen in Animal Manure." *Agronomy Journal* 86: 897-903.

Kölling, A. 2010. *Organic Food and Farming a System Approach to Meet the Sustainability Challenge*: IFOAM EU GROUP.

Kőlling, D. R., H. Menzi, T. F. Kröber, A. Neftel, F. Sutter, P. Lischer, and M. Kreuzer. 2001. "Emissions of Ammonia, Nitrous Oxide and Methane from Different Types of Dairy Manure During Storage as Affected by Dietary Protein Content." *Journal of Agricultural Science* 137: 235-250.

Kumar, D., and Y. S. Shivay. 2008. *Modern Concepts of Agriculture. Integrated Crop Management.*http://nsdl.niscair.res.in/bitstream/123456789/679/1/revised+integrated+Crop+management.pdf

Kumar, S., T. Rojalin, and C. Usha Kiran. 2008. "Evaluation of Ceres-Wheat and Cropsyst Models for Water-Nitrogen Interactions in Wheat Crop." *Agricultural Water Management* 95 (7): 776-786.

Kumari, S. 2011. "Yield Response of Uniculm Wheat (Triticum Aestivum L.) to Early and Late Application of Nitrogen. Flag Leaf Development and Senescence " *Journal of Agricicultural Science* 3 (1).

Kwakye, P. K. 1980. The Effects of Method of Dung Storage and Its Nutrient (NPK) Content and Crop Yield in the North East Savanna Zone of Ghana. Organic Recycling in Africa Paper read at Papers Presented at the FAO/SIDA Workshop on the Use of Organic Materials on Fertilisersin Africa at Rome.

Kwesiga, F., S. Franzel, F. Place, D. Phiri, and C. P. Simwanza. 1999. "Sesbania Sesban Improved Fallows in Eastern Fallows in Eastern Zambia: Their Inception Development and Farmer Enthusiasm." *Agroforestry System* 47: 49-66.

Laar, H. H., J. van Goudriaan, and H. van Keulen. 1992. *Simulation of Crop Growth for Potentialand Water-Limited Production Situations, as Applied to Spring Wheat*. Edited by H. H. Laar, J. Goudriaan. van and van Keulen. H. Vol. 27, *Simulation Reports*.

Laboski, C. A. M., J. B. Peters, and L. G . Bundy. 2006. *Nutrient Application Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin*. Madison: University of Wisconsin Extension.

Laboski, C. A. M., J. E. Sawyer, D. T. Walters, L. G. Bundy, R. G. Hoeft, G. W. Randall, and T. W. Andraski. 2008. "Evaluation of the Illinois Soil Nitrogen Test in the North Central Region of the USA." *Agronomy Journal* 100: 1070-1076.

Lal, .R. 1993a. "Soil Erosion and Conservation in West Africa." In *World Soil Erosion and Conservation*, ed. D . Pimentel, 7-28. Cambridge: Cambridge University Press.

Lal, R.———. 1990. *Soil Erosion in the Tropics: Principles and Management*. New York: McGraw-Hill.

———. 2000. "Restorative Effects of Mucuna Utilis on Soil Organic C Pool of a Severely Degraded Alfisols in Western Nigeria." In *Global Climate Change and Tropical Ecosystems*, eds R. Lal, J. M. Kimble and B. A. Stewart, 147-165. Boca Raton, FL: CRC Press.

Lalor, S. T., J. J. Schröder, E. A. Lantinga, O. Oenema, L Kirwan, and R. P. O. Schulte. 2011. "Nitrogen Fertiliser Replacement Value of Cattle Slurry in Grassland as Affected by Method and Timing of Application." *Journal of Environmental Quality* 40: 362-373

Lander, C. H., D. Moffitt, and A. Klaus. 1998. *Nutrients Available from Livestock Manure, Relative to Crop Growth Requirements Working Paper 98-1. Natural Resources Conservation Service, Resource Assessment and Strategic Planning*. US Department of Agriculture, 15 pp.

Langmeier, M., E. Frossard, M. Kreuzer, P. Ma¨der , D. Dubois , and A. Oberson. 2002. "Nitrogen Fertiliser Value of Cattle Manure Applied on Soils Originating from Organic and Conventional Farming Systems." *Agronomy Journal* 22: 789-800

Larney, F. J., and R. E. Blackshaw. 2003. "Weed Seed Viability in Composted Beef Cattle Feedlot Manure." *Journal of Environment Quality* 32: 1105-1113.

Larney, F. J., D. M. Sullivan, K. E. Buckley, and B. Eghball. 2006. "The Role of Composting in Recycling Manure Nutrients." *Canadian Journal of Soil Science* 86: 597-611.

Leikam, D. F., and R. E. Lamond. 2003. *Estimating Manure Nutrient Availability*. Manhattan: Kansas State University.

Lekasi, J. K, J. C Tanner, S. K Kimani, and P. J. C Harris. 1998. *Manure Management in the Kenya Highlands: Practices and Potential, Pp 1-35. The Henry Doubleday Research Association*. UK: HDRA, Ryton Organic Gardens.

Lekasi, J. K. 2000. "Manure Management in the Kenya Highlands: Collection, Storage and Utilisation to Enhance Fertiliser Quantity and Quality." PhD Thesis, Coventry University, UK.

Lekasi, J. K., J. C Tanner, S. K. Kimani, and P. J. C. Harris. 2001a. *Manure Management in the Kenya Highlands: Practices and Potential*. Kenilworth, UK: HDRA.

Lekasi, J. K., J. C. Tanner, S. K. Kimani, and P. J. C. Harris. 2001b *Managing Manure to Sustain Smallholder Livelihoods in the East African Highlands*. Kenilworth,UK: HDRA.

———. 2003. "Cattle Manure Quality in Maragua District, Central Kenya: Effect of Management Practices and Development of Simple Methods of Assessment." *Agriculture, Ecosystems & Environment* 94 (3): 289-298.

Leleu, O., C. Vuylsteker, J. F. Tetu, D. Degrande, L. Champolivier, and S. Rambour. 2000. "Effect of Two Contrasted N Fertilisations on Rapeseed Growth and Nitrate Metabolism." *Plant Physiol . Biochem* 38: 639-645.

Levington Agriculture. 1997. *A Report for the European Fertiliser Manufacturers Association.* Ipswich UK, 111 pp: Levington Agriculture Ltd.

Li, J. T., L. Zhong, F. Wang, and Q. G. Zhao. 2011. "Effect of Poultry Litter and Livestock Manure on Soil Physical and Biological Indicators in a Rice-Wheat Rotation System." *Journal of Plant, Soil and Environment* 57 (8): 351-356.

Lithourgidis, A. S., T Matsi, N. Barbayiannis, and C. A. Dordas. 2007. "Effect of Liquid Cattle Manure on Corn Yield, Composition, and Soil Properties." *Agronomy Journal* 99: 1041-1047.

Liu, M., F. Hu, X. Chen, Q. Huang, J. Jiao, B. Zhang, and H. Li. 2009. "Organic Amendments with Reduced Chemical Fertiliser Promote Soil Microbial Development and Nutrient Availability in a Subtropical Paddy Field: The Influence of Quantity, Type and Application Time of Organic Amendments." *Applied Soil Ecology* 42 (2): 166-175.

Llewelyn, R. V., and A. M. Featherstone. 1997. "A Comparison of Crop Production Functions Using Simulated Data for Irrigated Corn in Western Kansas." *Agricultural Systems* 54 (4): 521-538.

Luebbe, M. K., G. E. Erickson, T. J. Klopfenstein, and M. A. Greenquist. 2008. "Greenquist, Aerobic Composting or Anaerobic Stockpiling of Feedlot Manure, Nebraska Beef Cattle Reports (2008), Available at Http://Digitalcommons.Unl.Edu/Animalscinbcr/25. (Retrieved 9.10.2011)

Lund, Z. F., B. D. Doss, and F. E. Lowry. 1975. "Dairy Cattle Manure-Its Effect on Yield and Quality of Coastal Bermudagrass." *Journal of Environmental Quality* 4 (3): 358.

Lupwayi, N. Z., M. Girma, and I. Haque. 2000. "Plant Nutrient Contents of Cattle Manures from Small-Scale Farms and Experimental Stations in the Ethiopian Highlands." *Agriculture, Ecosystems and Environment* 78 (1): 57-63.

Lupwayi, N. Z., and I. Haque. 1999. "Leucaena Hedgerow Intercropping and Cattle Manure Application in the Ethiopian Highlands III. Nutrient Balances." *Biology and fertility of soils* 28 (2): 204-211.

Ma, B. L., L. M. Dwyer, and E. G . Gregorich. 1999b. "Soil Nitrogen Amendment Effects on Seasonal Nitrogen Mineralisation and Nitrogen Cycling in Maize Production." *Agronomy Journal* 91: 1003-1009.

MAAIF. 1999. *Ministry of Agriculture, Animal Industries and Fisheries, (MAAIF)*. Kampala.

———. 2002. *Plan for Modernization of Agriculture: Eradicating Poverty in Uganda-Government Strategy and Operational Frame Work*. Kampala, Uganda: Ministry of Agriculture, Animal Industries and Fisheries.

MacDonald, J. M., M. O. Ribaudo, M. J. Livingston, J Beckman, and W. Y. Huang. 2009. *Manure Use for Fertiliser and for Energy*. Economic Research Service, U.S. Department of Agriculture. http://www.ers.usda.gov/Publications/AP/AP037/AP037.pdf.

MacLeod, N. D., C. K. McDonald, S. N. Lisson, and R. Rahman. 2007. Modelling for Scenario Analysis for Improved Smallholder Farming Systems in Indonesia. Paper read at MODSIM07: Land, Water and Environmental Management: Integrated Systems for Sustainability, Proceedings.

MAFF. 2000. *Ministry of Agriculture Fisheries and Food (2000) Fertiliser Recommendations for Agricultural and Horticultural Crops. Reference Book 209*. 7th ed. London: HMSO.

Mahajan, A., R. D. Gupta, and R. Sharma. 2008. "Bio-Fertilisers- a Way to Sustainable Agriculture." *Agrobios Newsletter* 6 (9): 36-37.

Makinde, E. A., J. O. Saka, and J. O. Makinde. 2007. "Economic Evaluation of Soil Fertility Management Options on Cassava-Based Cropping Systems in the Rain Forest Ecological Zone of South Western Nigeria." *African Journal of Agricultural Research* 2 (1): 007-013.

Mallory, E. B., T. S. Griffin, and G. A. Porter. 2010. "Seasonal Nitrogen Availability from Current and Past Applications of Manure." *Nutrient Cycling in Agroecosystems* 88 (3): 351-360.

Mannering, J.V., and D.R. Griffith. 1981. Value of crop rotation under various tillage systems. Agronomy Guide AY-230. Coop. Ext. Serv., Purdue University.West Lafayette, IN.

Mapfumo, P., and K. E. Giller. 2001. *Soil Fertility Management Strategies and Practices by Small Holder Farmers in Semi Arid Areas of Zimbabwe*. P.O. BOX 776 Bulawayo Zimbabwe pp 53: International Crops Research Institute for the Semi Arid Tropics (ICRISAT).

MARC. 2008. *Manure Application Rate Calculator Software for Manitoba, Manitoba Agriculture, Food and Rural Initiatives*. http://www.gov.mb.ca/agriculture/livestock/marc/index.html.

Markewich, H. A., A. N. Pell, D. M. Mbugua, D. J. R. Cherney, H. M. van Es, J. Lehmann, and J. B. Robertson. 2010. "Effects of Storage Methods on Chemical Composition of Manure and Manure Decomposition in Soil in Small-Scale Kenyan Systems." *Agriculture, Ecosystems & Environment* 139 (1-2): 134-141.

Marletto, V., F. Ventura, G. Fontana, and F. Tomei. 2007. "Wheat Growth Simulation and Yield Prediction with Seasonal Forecasts and a Numerical Model " *Journal of Agricultural and Forest Meteorology* 147: 71-79.

Marquer, S. 2010. *Fertiliser Price Liberalization Stalls. Available at www.Zawya.Com*.

Martins, O., and T. Dewes. 1992. "Loss of Nitrogenous Compounds During Compositing of Animal Waste." *Bioresource Technology* 42: 103-111.

Mason, M. G., and R. F. Brennan. 1998. " 'Comparison of Growth Response and Nitrogen Uptake by Canola and Wheat Following Application of Nitrogen Fertiliser'." *Journal of Plant Nutrition* 21 (7): 1483 -1499.

Matata, P. Z., O.C. Ajay, P. A. Oduol, and A. Agumya. 2010. "Socio-Economic Factors Influencing Adoption of Improved Fallow Practices among Smallholder Farmers in Western Tanzania." *African Journal of Agricultural Research* 5 (8): 818-823.

Mathers, A. C., B. A. Stewart, and J. D. Thomas. 1977. "Manure Effects on Water Intake and Runoff Quality from Irrigated Grain Sorghum Plots." *Journal of Soil Science Society of America* 41: 782-785.

Matsi, T., A. S. Lithourgidis, and A. A. Gagianas. 2003. "Effects of Injected Liquid Cattle Manure on Growth and Yield of Winter Wheat and Soil Characteristics." *Agronomy Journal* 95: 592-596.

Matthfius, E., W. Mirschel, H. Kretschmer, H. K. Künkel, and I. Klank. 1986. "The Winter Wheat Crop Model Tritsim of the Agroecosystem Agrosim-W Tag.- Ber., Akad. Landwirtschaftswiss. Ddr, Berlin (1986) 242, S. 43-74."

Maxwell, D. G. 1995. "Labour, Land, Food and Farming: A Household Analysis of Urban Agriculture in Kampala, Uganda. Ph.D.Thesis." University of Wisconsin, Madison, USA.

Mazza, C. P., S. J. Cunningham, and E. Z. Harrison. 2010. Using Organic Matter in the Garden. Department of Horticulture, Cornell University. Accessed 28th October 2011

McCalla, T. M., J. R. Peterson and C. Lue-Hing. 1977. "Properties of Agricultural and Municipal Wastes. ASA,CSSA, SSSA " In *Soils for Management of Organic Wastes and Waste Waters*, 11-41. Madison, Wis: ASA, CSSA, SSSA.

McCormick, R. A., D. W. Nelson, A.L. Sutton and D. M. Huber. 1983. "Effect of Nitrapyrin on Nitrogen Transformations in Soil Treated with Liquid Swine Manure." *Agronomy Journal* 75: 947-950.

McIntire, J., D. Bourzat, and P. L. Pingali. 1992. *Crop-Livestock Interaction in Sub-Saharan Africa*. Washington D.C: The World Bank

McIntosh, P. 1993. *White Privilege: Unpacking the Invisible Knapsack*.

Mckenzie, N., D. Jacquier, R.. Isbell, and K. Brown. 2004. *Australian Soils and Landscapes: An Illustrated Compendium*. Collingwood VIC 3066 Australia: CSIRO Publishing.

McQuaker, N. R., D. F. Brown, and P. D.Kluckner. 1979. "Digestion of Environmental Samples for Analysis by Inductively Coupled Plasma-Atomic Emission Spectrometry." *Analytical Chemistry* 51: 1082-4.

MDG Africa Steering Group. 2008. *Achieving the Millennium Development Goals in Africa*. New York: United Nations.

Meek, B., L. Graham, and T. Donovan. 1982. "Long-Term Effects of Manure on Soil Nitrogen, Phosphorus, Potassium, Sodium, Organic Matter and Water Infiltration Rate " *Journal of Soil Science Society of America* 46: 1014-1019.

Mehdi, S. M., M. Sarfraz, S. T. Abbas, G. Shabbir, and J. Akhtar. 2011. "Integrated Nutrient Management for Rice-Wheat Cropping System in a Recently Reclaimed Soil." *Soil Environment* 30 (1): 36-44.

Mehlich, A . 1984. "Mehlich 3 Soil Test Extractant: A Modification of Mehlich 2." *Communications in Soil Science and Plant Analysis* 15: 1409-1416.

Mehlich, A. 1965. "Mineral Nutrient Content of Manures and Mulching Materials with Particular Reference to Calcium, Magnesium and Potassium." *Kenya Coffee* 30: 157-161.

Mekki, B. B. 2003. Yield and Chemical Composition of Rapeseed (*Brassica Napus* L.) Varieties in Response to Nitrogen Fertilisation. Paper read at Proceeding of the 11th International Rapeseed Congress 6-10 July, at The Royal Veterinary and Agric. Univ., Copenhagen, Denmark.

Mendham, N. J., and P. A. Salisbury. 1995. "Physiology-Crop Development, Growth and Yield." In *Production and Utilization of Brassica Oilseeds* eds D. S. Kimber and D. I. McGregor. London: CAB International, Oxford.

Mengel, K., and E. K. Kirby. 2001. *Principles of Plant Nutrition*. 5th ed. Bern, Switzerland International Potash Institute.

Metson, A. J. 1956. *Nz Soil Bureau Bulletin*. Vol. 12.

MFPED. 2000. *Uganda Participatory Poverty Assessment (UPPAP) 2000*. Kampala: Ministry of Finance Planning and Economic development

———. 2002. "Ministry of Finance, Planning and Economic Development: Background to the Budget 2001-2002."

———. 2004. *Uganda Government: Poverty Eradication Action Plan (2004/5–2007/8)* Kampala: Ministry of Finance, Planning and Economic Development.

———. 2007. *Ministry of Finance Planning and Economic Development . Background to the Uganda Budget 2007–2008*. Kampala: MFPED.

———. 2008. *Government of Uganda 2008, 2007, 2006, Development Cooperation, 2005/06 Report*. Kampala Uganda: Ministry of Finance Planning and Economic Development.

———. 2010. *Ministry of Finance Planning and Economic Development . Background to the Uganda Budget 2009–2010*. Kampala: MFPED.

Mikkelsen, R. L. 2007. "Managing Potasium for Organic Crop Production." *HortTechnology* 17: 455-460.

Mikkelsen, R. L., and T. K. Hartztter. 2008. "Nitrogen Sources for Organic Crop Production " *Better Crops* 92 (4).

Miller, P. R., S. V. Angadi, G. L. Androsoff, B. G. McConkey, C. L. McDonald, S. A. Brandt, H. W. Cutforth, M. H. Entz, and K. M. Volkmar. 2003. "Comparing Brassica Oilseed Crop Productivity under Contrasting N Fertility Regimes in the Semiarid Northern Great Plains." *Canadian Journal of Plant Science* 83: 489-497.

Mills, H., and Jr Jones, J. B. 1996. *Plant Analysis Handbook II*. Athens, Ga: Micro Macro Publishing, Inc. pp 422.

Milton, N. 2011. "Bacteria Transform Ammonium to Nitrate in Soil." *Soils are Alive' newsletter Volume 2 Number 1:*

Min, D. H., K. R. Islam, L. R. Vough, and R. R. Weil. 2003. "Dairy Manure Effects on Soil Quality Properties and Carbon Sequestration in Alfalfa-Orchardgrass Systems" *Communications in Soil Science and Plant Analysis* 34 (5-6): 781-799.

Misiko, M., P. Tittonell, K. Giller, and P. Richards. 2011. "Strengthening Understanding and Perceptions of Mineral Fertiliser Use among Smallholder Farmers: Evidence from Collective Trials in Western Kenya." *Agriculture and Human Values* 28 (1): 27-38

Mokolobate, M. S., and R. J. Haynes. 2002. "Comparative Liming Effect of Four Organic Residues Applied to an Acid Soil." *Biology and fertility of soils* 35 (2): 79-85.

Mooleki, S. P., J. J. Schoenau, J. L. Charles, and G. Wen. 2004. "Effect of Rate, Frequency and Incorporation of Feedlot Cattle Manure on Soil Nitrogen Availability, Crop Performance and Nitrogen Use Efficiency in East-Central Saskatchewan." *Canadian Journal of Soil Science* 84 (2): 199-210.

Moral, R., C. Paredes, M. A. Bustamante, F. Marhuenda-Egea, and M. P. Bernal. 2009. "Utilisation of Manure Composts by High-Value Crops: Safety and Environmental Challenges." *Bioresource Technology* 100 (22): 5454-5460.

Morgan, D. L. 1996."Focus Groups." *Annual Review of Sociology* 22: 129-52.

Morgan, R. P. C. 1995. "Soil Erosion and Soil Conservation." Essex: Longman.

Morris, M., V. Kelley, R. Kopicki, and D. Byerlee. 2007. *Fertiliser Use in African Agriculture: Lessons Learned and Good Practice Guidelines*. Washington, 45-61: World Bank.

Morris, R. K., S. R. Smith, D. M. Bellett-Travers, and J. N. B. Bell. 2003. Reproducibility of the Nitrogen Response and Residual Fertiliser Value of Conventional and Enhanced-Treated Biosolids. Paper read at Proceedings of the Joint CIWEM and Aqua Enviro Technology Transfer 8th European Biosolids and Organic Residuals Conference, 24-26 November at Wakefield, UK.

Mosier, A. R., J. K. Syers, and J. R. Freney. 2004. "Nitrogen Fertiliser: An Essential Component of Increased Food, Feed and Fibre Production." In *Agriculture and the Nitrogen Cycle: Assessing the Impacts of Fertilser Use*, eds A. R. Mosier, J. K. Syers and J. R. Freney.

Motavalli, P. P., K. A. Kelling, and J. C. Converse. 1989. " First-Year Nutrient Availability from Injected Dairy Manure." *Journal of Environmental Quality* 18: 180 - 185.

Mpairwe, D., D. Mutetikka, G. H. Kiwuwa, S. Mugerwa, B. Owoyesigire, E. Zziwa, and D Peden. 2009. "Options to Improve Livestock-Water Productivity (LWP) in the Cattle Corridor within the White Nile Sub-Basin in Uganda.

Mtambanengwe, F., and P. Mapfumo. 2006. "Effects of Organic Resource Quality on Soil Profile N Dynamics and Maize Yields on Sandy Soils in Zimbabwe." *Plant and Soil* 281 (1): 173-191.

———. 2006. "Effects of Organic Resource Quality on Soil Profile N Dynamics and Maize Yields on Sandy Soils in Zimbabwe." *Plant and Soil* 281: 173–191.

Mucheru-Muna, M., D. Mugendi, J. Kung'u, J. Mugwe, and A. Bationo. 2007. "Effects of Organic and Mineral Fertiliser Inputs on Maize Yield and Soil Chemical Properties in a Maize Cropping System in Meru South District, Kenya." *Agroforestry Systems* 69 (3): 189-197..

Mugendi, D., M. Mucheru-Muna, Pypers. P., J. Mugwe, Kung'u. J., Vanlauwe. B., and R. Merckx. 2010. Maize Productivity as Influenced by Organic Inputs and Mineral Fertiliser in a Nitisol Soil in Meru South District. Paper read at Proceedings of the 19th World Congress of Soil Science, Soil Solutions for a Changing World, 1 - 6 August at Brisbane, Australia.

Mueller-Harvey, I., A . S. R. Juo, and A. Wild. 1985. "Soil Organic C, N, S and P after Clearance in Nigeria: Mineralisation Rates and Spatial Variability." *Journal of Soil Science* 36 585-591.

Mugerwa, S., D. Mpairwe, E. N. Sabiiti, D. Mutetikka, G. H. Kiwuwa, E. Zziwa, and D. Peden. 2008. Effect of Cattle Manure and Reseeding on Pasture Productivity. Paper read at the CPWF Second International Forum on Water and Food, at Addis Ababa, Ethiopia, November 10-14.

Mugisa, T. K. 2002. "Integration of Forage Legumes into Per-Urban Maize and Elephant Grass Systems in Kampala-Jinja Milk Shed: MSc. Thesis." Makerere University, Kampala.

Mugwira, L. M., and H. K. Murwira. 1997. "Use of Cattle Manure to Improve Soil Fertility in Zimbabwe: Past, Current and Future Research Needs. Soil Fertility Network for Maize-Based Cropping Systems in Malawi and Zimbabwe." *Working paper* No. 2

Muhereza, I. 2005. "Socio Economic Evaluation of Cattle Manure Application in Peri-Urban Smallholder Farming Systems." Msc Thesis, Makerere University, Kampala, Uganda.

Mulugeta, A., M. Purdon, Y. Seboka, J. Biggs, S. Karekezi, W. Kithyoma, O. Onguru, and M. Kamoche. 2009. "Harnessing Carbon Finance to Promote Sustainable Forestry, Agro-Forestry and Bio-Energy. Bio-Carbon Opportunities in Eastern & Southern Africa."

Mulumba, D. 2005. "Gender Relations, Livelihood Security and Reproductive Health among Women Refugees in Uganda the Case of Sudanese Women in Rhino Camp and Kiryandongo Refugee Settlements." Ph.D. Thesis, Rural Development Sociology Group, Disaster Studies, Wageningen University.

Mulumba, D. 2008. Gender Perspective on the PRDP in North and North Eastern Uganda. In *Paper presented to Deniva workshop*. Lira, Uganda.

Mundus, S., R. Menezes, A. Neergaard, and M. Garrido. 2008. "Maize Growth and Soil Nitrogen Availability after Fertilisation with Cattle Manure and/or Gliricidia in Semi-Arid Ne Brazil." *Nutrient Cycling in Agroecosystems* 82 (1): 61-73.

Munoz, G. R., K. A. Kelling, J. M. Powell, and P. E. Speth. 2004. "Comparison of Estimates of First-Year Dairy Manure Nitrogen Availability or Recovery Using Nitrogen-15 and Other Techniques." *Journal of Environment Quality* 33: 719-727.

Mureithi, J. G., R. S. Jayler, and W. Thorpe. 1996. "Effects of the Application of Dairy Cattle Slurry and Intercropping with Cowpea on the Performance of Maize in Coastal Low Land Kenya." *African Crop Science Journal* 4 (3): 315 -324.

Muriithi, L. M. M., and J. Irungu. 2004. "Effect of Integrated Use of Inorganic Fertiliser and Organic Manures on Bacterial Wilt Incidence (BWI) and Tuber Yield in Potato Production Systems on Hill Slopes of Central Kenya." *Journal of Mountain Science* 1 (1): 81-88.

Murphy, J., and J. D. Riley. 1962. "A Modified Single Solution Method for the Determination of Phosphate in Natural Waters." *Analytica Chimica Acta* 27: 31-36.

Murwira, H. K. 1995. "Ammonia Losses from Zimbabwean Cattle Manure before and after Incorporation into Soil." *Journal of Tropical Agriculture* 72: 269-273.

Murwira, H. K., and H. Kirchmann. 1993. "Nitrogen Dynamics and Maize Growth in a Zimbabwean Sandy Soil under Manure Fertilisation." *Communications in Soil Science and Plant Analysis* 24: 2343-2359.

Murwira, H. K., M. J. Swift, and P..G. H. Frost. 1995. Manure as a Key Resource in Sustainable Agriculture Pp.131-49. In: Powell, J.M., Fernanddez-Rivera, T.O., Williams, T.O and Renard, C. (Eds.). Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of Sub-Saharan Africa. Paper read at Proceeding of International Conference, International Livestock Center for Africa (ILCA), at Addis Ababa, Ethiopia, 22-26 November 1993.

Mutuo, P. K., A. E. Marandu, R. Rabeson, M. Mwale, S. S. Snapp, and C. A. Palm. 1999. *Nitrogen Fertiliser Equivalencies Based on Organic Input Quality and Optimum Combinations of Organic and Inorganic N Sources: Network Trial Results from East and Southern Africa. In Swnm Report on the Combating Nutrient Depletion* Tropical Soil Biology and Fertility Institute of CIAT.

Mutuo, P. K., J. P. Mukalama, and J. Agunda. 2000. *On-Farm Testing of Organic and Inorganic Phosphorus Source on Maize in Western Kenya. In the Biology and Fertility of Tropical Soils*. Nairobi: TSBF Report, 22pp.

Muyonga, J. H., D. Nabakabya, D. N. Nakimbugwe, and D. Masinde. 2008. *Efforts to Promote Amaranth Production and Consumption in Uganda to Fight Malnutrition*. Edited by G. L. Robertson and J. R. Lupien, *Chapter 8 from Using Food Science and Technology to Improve Nutrition and Promote National Development*: International Union of Food Science & Technology.

Mwebaze, S. M. N. 1999. *Country Pasture/ Forage Resources Profiles and Agro-Ecological Zones of Uganda*. Entebbe, Uganda: Department of Animal Production and Marketing MWLE. 2001. *National Land Use Policy Paper 2001*. Kampala, Uganda: Ministry of Water, Lands and Environment

MWEDM. 2011. *Review of Rainfall Performance for the Past Season (June to August) and Seasonal Climate Outlook for September to December 2011*. Entebbe: Ministry of Water and Environment, Deprtment of Meteorology. http://www.meteo-uganda.net Accessed 2nd October 2011

Myers, R. J . K. 1984. "A Simple Model for Estimating the Nitrogen Fertiliser Requirement of a Cereal Crop." *Fertiliser Research* 5: 95-108.

Myint, A. K., T. Yamakawa, Y. Kajihara, and T. Zenmyo. 2010. "Application of Different Organic and Mineral Fertilisers on the Growth, Yield and Nutrient Accumulation of Rice in a Japanese Ordinary Paddy Field." *Science World Journal* 5 (2).1-8 http://www.scienceworldjournal.org/article/view/6242/4333.

N'dayegamiye, A, and D. Côté. 1989. "Effect of Long-Term Pig Slurry and Solid Cattle Manure Application on Soil Chemical and Biological Properties." *Canadian Journal of Soil Science* 69: 39-47.

N'Dayegamiye, A. 2009. "Soil Properties and Crop Yields in Response to Mixed Paper Mill Sludges, Dairy Cattle Manure, and Inorganic Fertiliser Application." *Agronomy Journal* 101 (4): 826-835.

Naik, B. K. 1965. "Production Function for a Sample of Famers in Akodia Village”." *Indian Journal of Agricultural Economics* 20 (3).

Nair, P. K. R., R. J. Buresh, D. N. Mugendi, and C. R. Lalt. 1999. *Nutrient Cycling in Tropic Agroforestry Systems: Myths and Science . Agroforstry in Sustainable Agriculture Systems*. Edited by Buck L. E., J. P. Lassoie and E.C.M. Fernandes. Boca Raton: CRC Press.

Nandwa, S. M. 1995. "Synchronization of Nitrogen Mineralisation with N Uptake through Maize Stover Placements and N Fertilisation under Continuous Maize Monocropping Systems in Kenya, Ph.D.Thesis." University of Exter, UK.

Naramabuye, F. X ., and R. J. Haynes. 2006. "Short-Term Effects of Three Animal Manures on Soil Ph and Al Solubility " *Australian Journal of Soil Research* 44 (5): 515-521.

Naramabuye, F. X., R. J. Haynes, and A. T. Modi. 2008. "Cattle Manure and Grass Residues as Liming Materials in a Semi-Subsistence Farming System." *Agriculture, Ecosystems & Environment* 124 (1-2): 136-141.

Ncube, B., J. P. Dimes, S. J. Twomlow , W. Mupangwa , and K. E. Giller. 2006. "Raising the Productivity of Smallholder Farms under Semi-Arid Conditions by Use of Small Doses of Manure and Nitrogen: A Case of Participatory Research." *Nutr Cycl Agroecosyst*.

NDSU. 2010. "Composting Animal Manures: A Guide to the Process and Management of Animal Manure Compost." *North Dakota State University, Extension Service*.

Neeteson, J. J., and W. P. Wadman. 1987. "Assessment of Economically Optimum Application Rate of Fertiliser: N on the Basis of Response Curves." *Ferterliser Research* 12: 37-52.

Negassa , W., H. Gebrekidan, and D. K. Friesen. 2005. "Integrated Use of Farmyard Manure and NP Fertilisersfor Maize on Farmers’ Fields." *Journal of Agriculture and Rural Development in the Tropics and Subtropics* 106 (2): 131-141.

Nelson, N. O., and R. R. Janke. 2007. "Phosphorous Sources and Management in Organic Production Systems." *HortTechnology* 442-454.

NEMA. 1996. *State of the Environment*

———. 2001. *Uganda State of the Environment Report 2000 Version 2*. Kampala, Uganda: National Environment Management Authority, Ministry of Natural Resources, Government of Uganda.

———. 2007. *National Environment Management Authority, 2006/07, State of Environment Report for Uganda*. Kampala: National Environment Management Authority (NEMA), pp 357.

Ngambeki, D. S., and P. R. Rubaihayo. 1993. An Economic Analysis of Banana Production in Uganda. Paper read at paper presented at the first crop science conference for Eastern and Southern Africa, 14-18 June 1993, at Kmapla, Uganda.

Ngoze, S., S. Riha, J. Lehmann, L. Verchot, J. Kinyangi, D. M. Mbugua, and A. N. Pell. 2008. "Nutrient Constraints to Tropical Agroecosystem Productivity in Long-Term Degrading Soils." *Global Change Biology* 14 (12): 2810-2822.

Nhamo, N., H. K. Murwira, and K. E. Giller. 2004. *The Relationship between Nitrogen Mineralisation Patterns and Quality Indices of Cattle Manures from Different Smallholder Farms in Zimbabwe*. Edited by A. Bationo, *Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa*. Nairobi, Kenya: CIAT-TSBF.

Nicholson, F. A., B. J. Chambers, and P. M. R. Dampney. 2003. "Nitrogen Value of Poultry Litter Applications to Root Crops and Following Cereal Crops." *Journal of Agricultural Science, Cambridge* 140: 53-64.

Nicholson, F.A.; Chambers, B.J.; Smith, K.A. and Harrison, R. (1999). Spring applied organic manures as a source of nitrogen for cereal crops; experiments using field-scale equipment. *Journal of Agricultural Science, Cambridge* 133 (4), 353-363.

Nicholson, F. A., B. J. Chambers, and K. A. Smith. 1996. "Nutrient Composition of Poultry Manures in England and Wales." *Bioresource Technology* 58: 279-284.

Nicholson, F. A., S. Humphries, S. G. Anthony, C. Procter, D. Chadwick, S. R. Smith, P. Gibbs, and B. J. Chambers. 2008. "A Software Tool for Determining the Agricultural Landbank for Recycling Organic Materials (ALOWANCE). Report to Ramiran Conference 2008. http://www.ramiran.net/doc08/RAMIRAN_2008/Nicholson.pdf

Nicholson, F. A., K. A. Smith, B. J. Chambers, and E. I. Lord. 2000. Prediction of Farm Manure Nitrogen Availability and Losses Following Land Application (MANNER). Paper read at Proceedings of the 8th International Symposium on Animal, Agriculture and Food Processing Wastes, at Des Moines, Iowa.

Nielsen, A, and V. Chanhsomphou. 2006. *Needs and Potential for Rural Youth Development in Lao PDR*. Bangkok: Food and Agriculture Organisation of the United Nations Regional Office for Asia and the Pacific.

Nkonya, E., C. K. Kaizzi, and J. Pender. 2005. "Determinants of Nutrient Balances in a Maize Farming System in Eastern Uganda " *Agricultural Systems* 85 (2): 155-182.

Nkonya, E., J. Pender, K. C. Kaizzi, E. Kato, S. Mugarura, H. Ssali, and J. Muwonge. 2008. *Linkages between Land Management, Land Degradation, and Poverty in Sub Saharan Africa. The Case of Uganda*. Washington, D.C. USA: International Food Policy Research Institute (IFPRI).

Nkonya, E., J. Pender, D. Sserunkuuma, and P. Jagger. 2002. Development Pathways and Land Management in Uganda: In Policies for Sustainable Land Management in the East African Highlands. Paper read at Paper presented at the Conference on Policies for Land Management in the East African Highlands, United Nations Economic Commission for Africa (ECA), at Addis Ababa, Ethiopia.

North Carolina, Agricultural Extension Service. 1973a. "Dairy Waste Management Alternatives." *North Carolina Agric. Ext. Service Circ. no. 568.*

Nsubuga, H.S. K. 1992. "Pasture in the Feeding of Dairy Cattle in Uganda, with Particular Reference to Zero Grazing. In:A.Hjort Af Ornas and T.Hjort Af Ornas (Eds.). International Union of Anthropological Sciences." *Journal of Nomadic peoples* 31: 85-90.

Nyamangara, J., J. Gotosa, and S. E. Mpofu. 2001. "Cattle Manure Effects on Structural Stability and Water Retention Capacity of a Granitic Sandy Soil in Zimbabwe." *Soil Tillage Research* 62: 157-162.

Nyamangara, J., F. Mtambanengwe, and C. Musvoto. 2009. "Carbon and Nitrogen Mineralisation from Selected Organic Resources Available to Smallholder Farmers for Soil Fertility Improvement in Zimbabwe." *African Journal of Agricultural Research* 4: 870 - 877.

Nyamangara, J., M. I. Piha, and K. E. Giller. 2003. "Effect of Combined Cattle Mnaure and Mineral Nitrogen on Maize N Uptake and Grain Yield." *African Crop Science Journal* 11 (4): 289-300.

Nyende, P., and R. J. Delve. 2004. "Farmer Participatory Evaluation of Legume Cover Crop and Biomass Transfer Technologies for Soil Fertility Improvement Using Farmer Criteria, Preference Ranking and Logit Regression Analysis.". *Experimental agriculture* 40 (1): 77-88.

Nyiraneza, J., M. H. Chantigny, and A. N'Dayegamiye. 2009. "Dairy Cattle Manure Improves Soil Productivity in Low Residue Rotation Systems." *Agronomy Journal* 101 (1): 207.

Nziguheba, G., R. Merckx, C. A. Palm, and P. K. Mutuo. 2002b. "Combining Tithonia Diversifolia and Fertilisersfor Maize Production in a Phosphorus Deficient Soil in Kenya." *Agroforestry Systems* 55: 165-174.

Nziguheba, G., and P. K. Mutuo. 2000. *Integration of Tithonia Diversifolia and Inorganic Fertiliser for Maize Production. The Biology and Fertility of Tropical Soils*. Nairobi: TSBF Report, pp. 23.

Nziguheba, G., C Palm, A., T. Berhe, G. Denning, A. Dicko, O. Diouf, W. Diru, et al. 2010. *The African Green Revolution: Results from the Millennium Villages Project*.

Nzuma, J. K., and H. K. Murwira. 2000. *Improving the Management of Manure in Zimbabwe. Managing Africa's Soils No 15*. London International Institute for Environment and Development, Drylands programme.

Oenema, J., H. van Keulen, R. L. M. Schils, and H. F. M. Aarts. 2011. "Participatory Farm Management Adaptations to Reduce Environmental Impact on Commercial Pilot Dairy Farms in the Netherlands." *NJAS - Wageningen Journal of Life Sciences* 58 (1-2): 39-48.

Ofori, C. S. 1980. The Use of Organic Materials in Increasing Crop Production in Africa.Paper read at FAO/SIDA workshop on the use of organic materials as fertilisersin Africa, FAO, Organic recycling in Africa: In FAO soils bulletin No. 43, Rome 5-14th Dec 1977, at Bue, Camerron.

Ojeniyi, S. O., M. A. Awodun, and S. A. Odedina. 2007. "Effect of Animal Manure Amended Spent Grain and Cocoa Husk on Nutrient Status, Growth and Yied of Tomato." *Middle-East Journal of Scientific Research* 2 (1): 33-36.

Okidi, J., A and Mugambe, G. K. 2002: An Overview of Chronic Poverty and Development Policy in Uganda

Okwira, P. O. 1999. "Poverty in Uganda: A Multivariate Analysis" Research Series No. 22. Economic Policy Research Centre, Kampala Uganda."

Okwuagwu, M. I., M. E. Allehi, and I.O. Osemwota. 2003. The Effects of Organic and Inorganic Manure on Soil Properties and Yield of Okra in Nigeria. Paper read at African Crop Science conference proceedings.

Olayinka, A., and V. Ailenubhi. 2001. "Influence of Combined Application of Cowdung and Inorganic Nitrogen on Microbial Respiration and Nitrogen Transformation in an Alfisol." *Nigerian Journal of Soil Research* 2: 15-20.

Olson, J. M., and L. Berry. 2003. "Land Degradation in Uganda: Its Extent and Impact ".

Olson, R. A. 1987. *The Use of Fertilisers and Soil Amendments*. Edited by M. G. Wolman and F. G. A Fournier.

Olufolaji, A. O., and A. O. Tayo. 1980. "Growth, Development and Mineral Content of Three Cultivars of Amaranth." *Journal of Science and Horticulture* 13: 181-189

Omiat, G., and G. Diiro. 2005. "Rationalization and Harmonization of Fertiliser Policies, Laws, Regulations and Procedures in Uganda." Study Report Prepared for the Eastern and Central Africa Programme for Agricultural Policy Analysis (ECAPAPA) of the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). Department of Agricultural Economics and Agribusiness, Makerere University Kampala.

Omotayo, O. E., and K. S. Chukwuka. 2009. "Soil Fertility Restoration Techniques in Sub-Saharan Africa Using Organic Resources." *African Journal of Agricultural Research* 4 (3): 144-150.

Onduru, D. D., J. M. Diop, E. der Werf, and A. de Jager. 2002. "Participatory on-Farm Comparative Assessment of Organic and Conventional Farmers' Practices in Kenya." *Biological Agriculture and Horticulture Journal* 19: 295-314.

Onduru, D. D., P. Snijders, F. N. Muchena, B. Wouters, A. De Jager, L. Gachimbi, and G. N. Gachini. 2008. "Manure and Soil Fertility Management in Sub-Humid and Semi-Arid Farming Systems of Sub-Saharan Africa: Experiences from Kenya." *International Journal of Agricultural Research* 3 (3): 166-187.

Orazem, F., and J. P. Doll. 1984. *Production Economics: Theory with Applications*. 2nd ed. New York: John Wiley and sons.

Osborne, L. D., and Z. Rengel. 2002b. "Growth and P Uptake by Wheat Genotypes Supplied with Phytate as the Only P Source." *Australian Journal of Agricultural Research* 53: 845–850. Ouédraogo, E., A Mando, M., and N. P. Zombré. 2001. "Use of Compost to Improve Soil Properties and Crop Productivity under Low Input Agricultural System in West Africa." *Agriculture Ecosystems and Environment* 84: 259-266.

Pali, P. N., R. J. Delve, E. Nkonya, and B. Bashaasha. 2005. Using Linear Programming to Optimize the Use of Biomass Transfer and Improved Fallow Species in Eastern Uganda.

Pali, P. N. 2003. "The Profitability and Acceptance of Alternative Soil Improvement Practices in Tororo District. Unpublished Msc Thesis." Makerere University, Kampala, Uganda.

Pali, P. N., R. Delve, and R. Miiro 2003. "Determinants of the Adoption Potential of Selected Green Manure and Legume Species in Eastern Uganda." *African Crop Science Journal*.

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 *Replenishing Soil Fertility in Africa*, eds J. P. Buresh , A. Sanchez and F. Calhoun. Madison, Wisconsin: Soil Science Society of America.

Palma, M. A., R. Ortiz, C. Alvarez-Dardet, and M. T. Ruiz. 2009. "Policy Determinants Affecting the Hunger Millennium Development Goal." *Soc. Sci. Med* 68: 1788-1792.

Palmar, H. C., G. L. Maliwal, R. R. Kaswala, and M. L. Patel. 1999. "Effect of Irrigation, Nitrogen and Spacing on Yield of Cabbage." *Indian Journal of Horticulture* 56 (3): 256-258.

Panda, S. C. 2008. *Soil Conservation and Fertility Management*. Jodhpur. India: Agrobios (India).

Pansu, M., L. Thuries, M. C. Larre-Larrouy, and P. Bottner. 2003. "Predicting N Transformations from Organic Inputs in Soil in Relation to Incubation Time and Biochemical Composition." *Soil Biology & biochemistry* 35: 353-363.

Paris, Q. 1992. "The Von Liebig Hypothesis." *Am. J. Agricultural Econ* 74: 1019-1028.

Paul, J. W., and E. G. Beauchamp. 1994. "Short-Term Nitrogen Dynamics in Soil Amended with Fresh and Composted Cattle Manures." *Canadian Journal of Soil Science* 74: 147-155.

Payne, R. W., S. A. Harding, D. A. Murray, D. M. Soutar, D. B. Baird, A. I. Glaser, Welham, A. R. Gilmour, R. B. Thompson, and R. Webster. 2011. *Introduction to Genstat for Windows 14th Edition*: VSN International, 5 The Waterhouse, Waterhouse Street, Hemel Hempstead, Hertfordshire HP1 1ES, UK.

Peil, M. 1995. *Socio Science Research Methods. A Handbook for Africa.2nd Revised Edition*. Nairobi: East African Education Publishers Ltd.

Pender, J. 2002. *Overview of Findings and Implications. In Policies for Sustainable Land Management in the East African Highlands*. Edited by S Benin, J Pender and S Ehui. Washington, D.C. and Nairobi, Kenya: International Food Policy Research Institute and International Livestock Research Institute.

Pender, J., and J Ndjeunga. 2008. *Impacts of Sustainable Land Management Programs on Land Management and Poverty in Niger*. Vol. 1 and 2. Washington, D.C World Bank.

Pender, J., E. Nkonya, P. Jagger, D. Sserunkuuma, and H Ssali. 2004. "Strategies to Increase Agricultural Productivity and Reduce Land Degradation: Evidence from Uganda." *Agricultural Economics* 31 (2/3): 181-195.

Pesek, J. T. 1966. Effects of Economic Criteria on Experimental Design in Plant Science Research, in Production Economics in Agricultural Research. Paper read at Proceedings of a conference held at University of Illinois, March 8-10,1966.

Peterson, T. A., and G. E. Varvel. 1989a. "Crop Yield as Affected by Rotation and Nitrogen Rate. I. Soybean." *Agronomy Journal* 81: 727-731.

Pettygrove, G. S., A. L. Heinrich, and D. M. Crohn. 2009. *Manure Nitrogen Mineralisation*. University of California Cooperative Extension Manure Technical Bulletin Series. http://manuremanagement.ucdavis.edu.

Pidwirny, M. 2006. "The Nitrogen Cycle". *Fundamentals of Physical Geography, 2nd Edition*. Retrieved 21st December 2010 from http://www.physicalgeography.net/fundamentals/9s.html

Pierzynski, G. M., J. T. Sims, and G. F. Vance. 2005. *Soils and Environmental Quality*. Boca Raton, Florida: CRC Press, Taylor and Francis Group.

Pingali, P. L., Y. Bigot, and H. Binswanger. 1987. *Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa*. Washington D C: World Bank.

Pittaway, P., V. Slizankewiecz, and M. Spence. 2001. *Waste Reuse Strategies for Rural Development and Sustainability*. Toowoomba QLD: NHT Project No. 979304, Part B, National Centre for Engineering in Agriculture.

Place, F., P. Hebinck, and M. Omosa. 2003. Chronic Poverty in Rural Western Kenya: Its Identification and Implications for Agricultural Development. In *Staying Poor: Chronic Poverty and Development Policy*

PLANET. 2006. "Planet Nutrient Management. Available at Http://Www.Planet4farmers.Co.Uk/."

Pocknee, S., and M. E. Sumner. 1997 "Cation and Nitrogen Contents of Organic Matter Determine Its Liming Potential." *Soil Science Society of American Journal* 61: 86-92.

Potts, R. C., and P. H. Hewitt. 1973. "The Distribution of Intestinal Bacteria and Cellulase Activity in the Harvester Termite Trinervitermes Trinervoides (Nasutitermitinae)." *Insectes Sociaux* 20 (3): 215-220.

Poulain, J. F. 1980. "Crop Residues in Traditional Cropping Systems of West Africa. Effects on the Mineral Balance and Level of Organic Matter in Soils and Proposals for Their Better Management." In *Organic Recycling in Africa, FAO Soils Bulletin* 38-71. FAO.

Poulton, C., J. Kydd, and A. Dorward. 2006. *Increasing fertiliser use in Africa: What have we learned*

Washington, DC: The International Bank for Reconstruction and Development.

Powell, J.M., F. N. Ikpe, and Z. C. Somda. 1999. "Crop Yield and the Fate of Nitrogen and Phosphorus Following Application of Plant Material and Feces to Soil." *Nutrient Cycling in Agroecosystems* 54: 215-226.

Powell, J. M., K. A. Kelling, Gabriela. R. MuÃ±oz, and P. R. Cusick. 2005. "Evaluation of Dairy Manure Nitrogen-15 Enrichment Methods on Short-Term Crop and Soil Nitrogen Budgets." *Agron. J.* 97 (1): 333-337.

Powell, J. M., R. A. Pearson, and P. H. Hiernaux. 1994. "Crop-Livestock Interactions in the West African Drylands." *Agronomy Journal* 96: 469-483.

Powell, J. M., and M. P. Russelle. 2009. "Dairy Heifer Management Impacts Manure N Collection and Cycling through Crops in Wisconsin, USA." *Agriculture, Ecosystems and Environment Environment* 131 (3-4): 170-177.

Powell, J. M., and T. O. Williams. 1995. An Overview of Mixed Farming Systems in Sub-Saharan Africa. Livestock and Sustainable Nutrient Cycling. Mixed Farming Systems of Sub-Saharan Africa. Paper read at proceedings of an International Conference 22nd-26th November, 1993, at Addis Ababa, Ethiopia.

Powell, J. M., and Z. Wu. 1999. "Nitrogen-15 Labeling of Dairy Feces and Urine for Nutrient Cycling Studies." *Agronomy Journal* 91: 814-818.

Powell, J., and T.O. Williams. 1993. *Livestock Nutrient Cycling and Sustainable Agriculture in the West African Sahel London*. 11 ed: Gate Keeper.

Powell, M. and F. Ikpe. 1992. Nutrient recycling through livestock “Fertilizer factories”. Information Center for Low-External-Input and Sustainable Agriculture (ILEIA), Netherlands. Newsletter, 1993, Volume 8, No. 3.

Pratt, P. F. 1982. Fertiliser Value of Manure. In *The Agricultural Waste Conference*. Mixico city, Mexico.

Preece, J. E., and P. E. Read. 2005. *The Biology of Horticulture: An Introductory Text Book*. Hoboken, New Jersy John Wiley & Sons, Inco.

Quansah, G. W. 2010. "Effect of Organic and Inorganic Fertilisersand Their Combinations on the Growth and Yield of Maize in the Semi-Deciduous Forest Zone of Ghana." Kwame Nkrumah UniversityofScienceand Technology, Kumasi, Ghana.

Rafsnider, G. T., A. Driouchi, B. V. Tew, and D. W. Reid. 1983. "Theory and Application of Risk Analysis in an Agricultural Development Setting: A Moroccan Case Study." *European Review of Agricultural Economics* 20 (4): 471-489.

Rajabapaia, P., K. V. Ramanayya, S. R. Mohan, and A. K. N. Reddy. 1979. In *Proc. Indian Acad. Sc. III:357-363. Rankin, R.S. (1948) Sewage Works J. 20:478*.

Rajinth 2011. What is a suitable minimum number of respondents for a targeted Market Research Survey? http://www.linkedin.com/groups/What-is-minimum-amount-respondents-82105.S.50970626

Rajsic, P. , and A. Weersink. 2008. "Do Farmers Waste Fertiliser? A Comparison of Ex Post Optimal Nitrogen Rates and Ex Ante Recommendations by Model, Site and Year." *Agricultural Systems* 97: 56-67.

Ramsey, B., and A. Callinan. 1994. "Effects of Nitrogen Fertiliser on Canola Production in North Central Victoria." *Australian Journal of Experimental Agriculture* 34: 789-796.

Randall, G. W., T. K. Iragavarapu, and M. A. Schmitt 2000. "Nutrient Losses in Subsurface Drainage Water from Dairy Manure and Urea Applied for Corn." *Journal of Environmental quality* 29: 1244-1252.

Randolph, T. F., E. Schelling, D. Grace, C. F. Nicholson, J. L. Leroy, D. C. Cole, M. W. Demment, A. Omore, J. Zinsstag, and M. Ruel. 2007. "Invited Review: Role of Livestock in Human Nutrition and Health for Poverty Reduction in Developing Countries." *Journal of Animal Science* 85: 2788-2800.

Rathke, G. W., O. Christen, and W. Diepenbrock. 2005. "Effects of Nitrogen Source and Rate on Productivity and Quality of Winter Oilseed Rape (Brassica Napus L.) Grown in Different Crop Rotations." *Field Crops Research* 94 (2-3): 103-113.

Rayment, G. E , and F. R. Higginson. 1992b. *Nitrogen. In "Australian Laboratory Handbook of Soil and Water Chemical Methods". (Inkata Press, Melbourne) 41-43. (Method 7A2)*.

Rayment, G. E., and F. R. Higginson. 1992a *Soil pH. In "Australian Laboratory Handbook of Soil and Water Chemical Methods"* Vol. 17-18 (Method 4A1). Melbourne Inkata Press.

Reijs, J. W., M. P. W. Sonneveld, P. Sørensen, R. L. M. Schils, J. C. J. Groot, and E. A. Lantinga. 2007. "Effects of Different Diets on Utilization of Nitrogen from Cattle Slurry Applied to Grassland on a Sandy Soil in the Netherlands." *Agriculture, Ecosystems and Environment* 118: 65-79.

Rekhi, R.S., D. K. Benbi, and S. Bhajan. 2000. " Effect of Fertilisers and Organic Manures on Crop Yields and Soil Properties in Rice-Wheat Cropping System. Page 1-6 in Long-Term Soil Fertility Experiments in Rice-Wheat Cropping Systems. (Abrol, I.P.,Bronson, K. F., Duxbury, J. M. And Gupta, R. K. Eds.). Rice-Wheat Consortium Paper Series 6. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains.

Reuter, D. J., and J. B. Robinson. 1997. *Plant Analysis: An Interpretation Manual* Collingwood, Vic: CSIRO Publishing.

Ribaudo, M. 2003. *Managing Manure: New Clean Water Act Regulations Create Imperative for Livestock Producers. Amber Waves 1(1)*. Washington, DC: US department of Agriculture Economic research service.

Riedell, W. E., J. L. Pikul, A. A. Jaradat, and T. E. Schumacher. 2009. "Crop Rotation and Nitrogen Input Effects on Soil Fertility, Maize Mineral Nutrition, Yield, and Seed Composition." *Agronomy Journal* 101 (4): 870-879.

Rigby, H. 2008. "Quantifying the Agronomic Value of Biosolids and Biowastes." A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy, Chemistry Imperial College, London, UK.

Rijtema, P. E., and J. G. Kroes. 1991. "Some Results of Nitrogen Simulations with the Model Animo." *Nutrient Cycling in Agroecosystems* 27 (2): 189-198.

Robinson, M. B., and P. J. Polglase. 2000. "Volatilization of Nitrogen from Dewatered Biosolids." *Journal of Environmental Quality* 29 (4): 1351-1355.

Rogers, S. W., and J. R. Haines. 2006. *Detecting and Mitigating the Environmental Impact of Fecal Pathogens Originating from Confined Animal Feeding Operations*. Cincinnati, Ohio: Review; EPA/600/R-06/021; U.S. Environmental Protection Agency, Land Remediation and Pollution Control Division, National Risk Management Research Laboratory.

Rommelse, R. 2000. "Economic Assessment of Biomass Transfer and Improvement Trials in Western Kenya. Natural Resource Problems, Priorities and Programme Working. Paper 2001- 3. International Centre for Research in Agroforestry, Nairobi and Kenya."

Romney, D. L., P. J. Thorne, and D. R. Thomas. 1994. "Some Animal-Related Factors Influencing the Cycling of Nitrogen in Mixed Farming Systems in Sub-Saharan Africa." *Agriculture Ecosystem and Environment* 49: 163-172.

Rosen, C. J., and P. M. Bierman. 2005. *Using Manure and Compost as Nutrient Sources for Fruit and Vegetable Crops* 2nd ed: Department of Soil, Water, and Climate University of Minnesota

Roy, H. R. 2001. Fertiliser Feeds the World. Paper read at Fertiliser Industry Federation of Australia, Inc., Conference "Fertilisers in Focus" 28-29 May 2001.

Rufino, M. C. 2008. "Quantifying the Contribution of Crop livestock Integration to African Farming. Phd Thesis." Wageningen University, the Netherlands.

Rufino, M. C., E. C. Rowe, R. J. Delve, and K. E. Giller. 2006. "Nitrogen Cycling Efficiencies through Resource-Poor African Crop-Livestock Systems." *Agriculture, Ecosystems and Environment* 112 (4): 261-282.

Rufino, M. C., P. Tittonell, M. T. van Wijk, A. Castellanos-Navarrete, R. J. Delve, N. de Ridder, and K. E. Giller. 2007. "Manure as a Key Resource within Smallholder Farming Systems: Analysing Farm-Scale Nutrient Cycling Efficiencies with the Nuances Framework." *Livestock Science* 112 (3): 273-287.

Russell, E. W. 1988. *Soil Condition and Plant Growth*. Ed. A.Wild. 1th ed. Longman Scientific and Technical (1988), pp. 991

Ryan, J. G., and R. K. Perrin. 1974. "Fertiliser Response Information and Income Gains: The Case of Potatoes in Peru." *American Journal of Agricultural Economics* 56: 337-43.

Rynk, R. 1992. *On-Farm Composting Handbook. Publ. Nraer-54*. Ithaca, NY: Northeast Regional Agric. Eng. Service.

Sabiiti, E. N., F. B. Bareeba, E. S. Sporndly, J. S. Tenywa, S. Ledin, E. Ottabong, S. Kyamanywa, B. Ekbom, J. Mugisha, and L. Drake. 2004. "Urban Market Garbage: A Hidden Resource for Sustainable Urban/Peri Urban Agriculture and the Environment in Uganda." *The Uganda Joumal* 50: 102-109.

Sahota, G. S. 1968. "Efficiency of Resource Allocation in Indian Agriculture." *American Journal of Agricultural Economics* 50: 584-605.

Salako, F. K., G. Kirchhof, and G. Tian. 2006. "Management of a Previously Eroded Tropical Alfisol with Herbaceous Legumes: Soil Loss and Physical Properties under Mound Tillage." *Soil and Tillage Research* 89: 182-195.

Salami, A., A. B. Kamara, and Z. Brixiova. 2010. *Smallholder Agriculture in East Africa: Trends, Constraints and Opportunities, Working Papers Series NO 105* Tunis, Tunisia: African Development Bank.

Salunkhe, D. K., B. B. Desai, and N. R. Bhat. 1987. *Vegetable and Flower Seed Production*. New Delhi: Agricole Publishing Academy

Samuelson, W., and S. Marks. 2003. *Managerial Economics* Fourth ed: Wiley.

Sanchez, P. 1999. "Improved Fallows Come of Age in the Tropics." *Agroforestry Systems* 47 (1): 3-12.

Sanchez, P. A., K. D. Shephered, M. J. Soule, F. M. Place, A. U. Mokwunye, R. J. Buresh, F. R. Kwesiga, A-M Izac, N., C. G. Ndiritu, and P. L. Woomer. 1997. *Soil Fertility Replenishment in Africa: An Investment in Natural Resource Capital.* Edited by R.J Buresh, P. A Sanchez and F Calhoun. Vol. 51, *Replenishing Soil Fertility in Africa*. Madison: Soil Science Society of America and ICRAF, Special publication 51.

Sanginga, N., and P. L. Woomer. 2009. *Integrated Soil Fertility Management in Africa: Priciples, Practices and Developmental Process.Tropical Soil Biology Institute of the International Centre for Tropical Agriculture*. Nairobi, pp 263.

Sansoucy, R. 1997. *Livestock-a Driving Force for Food Security And Sustainable Development. In: Current Issues in International Rural Development. No. 13/14 Idrc*. Swedish University of Agricultural Sciences.

Sant'Anna, R. 1994. "Soil Tillage in Africa: Needs and Challenges "In *FAO Soils Bulletin*.

Schlecht, E., A. Buerkert, E. Tielkes, and A . Bationo. 2006. "A Critical Analyses of Challenges and Opportunities for Soil Fertility Restoration in Sudano-Sahelian West Africa." *Nutrient Cyc.Agroecosyst* 76 (2-3): 109-136.

Schoenau, J. J., B. A. Assefa, M. C. J. Grevers, J. J. Charles, P. Mooleki, P. Qian, and T. Zeleke. 2002. *Manure Management to Improve Soil Quality*: Dept. of Soil Science, College of Agriculture, University of Saskatchewan.

Schoenau, J. J., P. Mooleki, B. A. Assefa, M. C. J. Grevers, P. Qian, and G. Hultgreen. 2002. Benefits to Soil from Livestock Manure: Manure Management in Direct Seeding Systems. Paper read at Proceedings of Direct Seeding "Optimizing Production Systems" 14th Annual Conference of the Saskatchewan Soil Conservation Association, Febuary 13 &14, at Regina, SK.

Schreinemachers, P., T. Berger, and J. B. Aune. 2007. "Simulating Soil Fertility and Poverty Dynamics in Uganda: A Bio-Economic Multi-Agent Systems Approach." *Journal of Ecological Economics* 64 (2): 387- 401.

Schröder, J. J., D. Uenk, and G. J. Hilhorst. 2007. "Long-Term Nitrogen Fertiliser Replacement Value of Cattle Manures Applied to Cut Grassland." *Plant Soil* 299: 83-99.

Searle, P. L. 1984 "The Berthelot or Indophenol Reaction and Its Use in the Analytical Chemistry of Nitrogen." *A review. Analyst* 109: 549-68.

Seastedt, T. R. 1984. "The Role of Microarthropods in Decomposition and Mineralisation Processes." *Annual Review of Entomology* 29: 25-46.

Semuli, K. L. H. 2005. "Nitrogen Requirements for Cabbage Transplants and Crop Response to Spacing and Nitrogen-Top Dressing. M. Inst. Agrar. Desertation. University of Pretoria, Pretoria, South Africa."

Seneviratne, G. 2000. "Litter Quality and Nitrogen Release in Tropical Agriculture: A Synthesis." *Biology and Fertility of Soils* 31: 60-64.

Seran, T. H., S. Srikrishnah, and M. M. Z. Ahamed. 2010. "Effect of Different Levels of Inorganic Fertilisers and Compost as Basal Application on the Growth and Yield of Onion (Allium Cepa L.)." *The Journal of Agricultural Sciences* 5 (2): 64-70.

Sewell, J. I. 1975. "Animal Waste Management Facilities and Systems." *Agricultural Experiment Station Bulletin 548, University of Tennessee, Knoxville, TN.*

Shaik, S., G. A. Helmers, and M. R. Langemeier. 2002. "Direct and Indirect Shadow Price and Cost Estimates of Nitrogen Pollution Abatement." *Journal of Agricultural and Resource Economics, Western Agricultural Economics Association* 27 (2): 420-432.

Shamudzarira, Z., and M. J. Robertson. 2002. "Simulating Response of Maize to Nitrogen Fertiliser in Semi-Arid Zimbabwe." *Experimental Agriculture* 38 (1): 79-96.

Sharpley, A. N., and B. Moyer. 2000. "Forms of Phosphorus in Manures and Composts and Their Dissolution During Rainfall." *Journal of Environmental Quality* 29: 1462-1469.

Sharpley, A. N., and J. R. Williams. 1990. "Garden with Insight V1.0 . Introduction to EPIC Model Documentation ".

Sheldrick, W., J. Keith Syers, and John Lingard. 2003. "Contribution of Livestock Excreta to Nutrient Balances." *Nutrient Cycling in Agroecosystems* 66 (2): 119-131

Shepherd, K., E. Ohlsson, J. Okalebo, and J. Ndufa. 1995. "Potential Impact of Agroforestry on Soil Nutrient Balances at the Farm Scale in the East African Highlands." *Nutrient Cycling in Agroecosystems* 44 (2): 87-99.

Shisanya, C. A., M. W. Mucheru, D. N. Mugendi, and J. B. Kung'u. 2009. "Effect of Organic and Inorganic Nutrient Sources on Soil Mineral Nitrogen and Maize Yields in Central Highlands of Kenya." *Soil and Tillage Research* 103 (2): 239-246.

Sieling, K., H. Schröder, M. Finck, and H. Hanus. 1998. "Yield, N Uptake, and Apparent N-Use Efficiency of Winter Wheat and Winter Barley Grown in Different Cropping Systems." *Journal of Agricultural Science* 131: 375-387.

Sinclair, A. H., A. M. Litterick, P. M. R. Dampney, and J. P. Newell Price. 2010. Planet Scotland Software for Nutrient Management Planning and NvZ Compliance on Farms in Scotland. Paper read at Proceedings Crop Protection in Northern Britain

Singh, Karam 1978. "Optimum Land Use Pattern and Resource Allocation in a Growing Economy." *Indian Journal of Agricultural Economics* 33 (1): 44-58.

Sims, J.T. (1986) Nitrogen transformations in a poultry manure amended soil: temperature and moisture effects. *Journal of Environmental Quality* 15 (1): 59-63.

Smaling, E. M .A., M. Toure, N. Ridder, N. Sanginga, and H. Breman. 2006. Fertiliser Use and the Environment in Africa: Friend or Foes? In *Background Paper Prepared for African Fertiliser Summit*. Abuja, Nigeria.

Smaling, E. M. A., S. M. Nandwa, and B. H. Jansen. 1997. "Soil Fertility in Africa is at Stake. In: Buresh R. J Sánchez P.A, Calhoun F (Eds) Replenishing Soil Fertility in Africa. Special Publication No. 51." *ASA and SSSA, Madison, WI* 46-61

Smith, K. A., and B. J. Chambers. 1995. Muck: From Waste to Resource. Utilisation: The Impacts and Implications. Paper read at Proceedings of theMUCK'95 Conference. Agricultural Engineer, Summer 1995.

Smith, K. A., B. J. Chambers and R. Jackson. 1994. Utilisation of Slurry and Solid Manures in an Arable Cropping Rotation. In Animal Waste management Paper read at Proceedings of the Seventh Technical Consultation of the ESCORENA Network on Animal Waste Utilisation, REUR Technical Series 34, FAO Rome, pp157-163.

Smith, K. A., R. J. Unwin, and J. H. Williams. 1984. Experiments on the Fertiliser Value of Animal Waste Slurries. Long Term Effects of Sewage Sludge and Farm Slurries Applications. Paper read at Proceedings of a round-table seminar organized by the Commission of the European Communities, Directorate-General Science, Research and Development, Environmental Research Programme, 25-27 September Pisa, Italy.

Smith, S. R., and D. M. Bellett-Travers. 2001. Field Trials to Develop Fertiliser Advice for Enhanced Treated and Conventional Biosolids. Paper read at Proceedings of the CIWEM/Aqua Enviro Consultancy Services 6th European Biosolids and Organic Residuals Conference, 12-14 November, at Wakefield, UK.

Smith, S. R., and P. Hadley. 1988. "A Comparison of the Effects of Organic and Inorganic Nitrogen Fertilisers on the Growth Response of Summer Cabbage (Brassica Oleracea Var. Capitata Cv Hispi F1)." *Journal of Horticultural Science* 63: 615-620.

Smith, S. R., R Morris, D.M Bellett-Travers, and J. N. B Bell. 2003. Managing the Phosphate Supply from Sewage Sludge Amended Agricultural Soil. Paper read at Proceedings of the Joint CIWEM and Aqua Enviro Technology Transfer 8th European Biosolids and Organic Residuals Conference, 24-26 November, at Wakefield, UK.

Smith, S. R., R. K. Morris, D. M. Bellett-Travers, M. Ferrie, C. L. Rowlands, and N. Bell. 2002b. Implications of the Nitrates Directive and the Provision of Fertiliser Advice for the Efficient Agricultural Use of Conventional and Enhanced-Treated Biosolids Products. Paper read at Proceedings of the Joint CIWEM and Aqua Enviro Technology Transfer 7th European Biosolids and Organic Residuals Conference, 8-20 November, Wakefield, UK.

Snapp, S. S., P. L. Mafongoya, and S. Waddington. 1998. "Organic Matter Technologies for Integrated Nutrient Management in Smallholder Cropping Systems of Southern Africa." *Agriculture, Ecosystems & Environment* 71 (1-3): 185-200.

Snijders, P., O. Davies, B Wouters, L. Gachimbi, J. Zake, P. Ebanyat, K. Ergano, M. Abduke, and H. van . Keulen. 2009. *Cattle Manure Management in East Africa: Review of Manure Quality and Nutrient Losses and Scenarios for Cattle and Manure Management*. Lelystad: Wageningen UR Livestock Research. http://library.wur.nl/WebQuery/clc/1918677.

Snijders, P. J. M., A. B. Orodho, and A. P. Wouters. 1992. *Effect of Manure Application Methods on Yield and Quality of Napier Grass*. Naivasha, Kenya: Kenya Agricultural Research Institute.

Snijders, P., D. Onduru, J. Zake, and B Wouters. 2008. "Livestock Model Explanation (Livestock and Integrated Soil Nutrient Management Tool). Http://Www.Lei.Dlo.Nl/Inmasp/Files/1cd8aea6ae03d0785a522215e90bdc25.Pdf Accessed 12th October 2011."

Sommerfeldt, T. G., and C. Chang. 1985. "Changes in Soil Properties under Annual Applications of Feedlot Manure and Different Tillage Practices." *Soil Society of American Journal* 49: 983-987.

Sommerfeldt, T. G., C. Chang, and T. Entz. 1988. "Long-Term Annual Manure Applications Increase Soil Organic Matter and Nitrogen, and Decrease Carbon to Nitrogen Ratio." *Soil Science Society of American Journal* 52: 1668-1672.

Spicer, S. 2002. "Fertilisers, Manure, or Biosolids? The Benefits and Risks of Fertilisers and Soil Amendments." *Water Environment and Technology* 14 (7): 32.

Ssembalirwa, E. 2008. *Urban Agriculture in Kampala City, Uganda*. Kampala: Local Government

Sserunkuuma, D., J. Pender, and E. Nkonya. 2001. *Land Management in Uganda: Characterization of Problems and Hypothesis about Causes and Strategies for Improvement*. Washington, D.C. Mimeo.: International Food Policy Research Institute, Environment and Production Technology Division.

Ssewanyana, S. N., and J. A Okidi. 2007b. *Poverty Estimates from the Uganda National House Survey 111, 2005/2006*. Kampala, Uganda: Economic Policy research Centre, Makerere University.

Ssonko, R. N., E. Njue, J. M. Ssebuliba, and A. de Jager. 2005. *Pro-Poor Horticulture in East Africa and South Asia: The Horticultural Sector in Uganda*. www.lei.dlo.nl/uk/content/.

Stace, H. C. T., G. D. Hubble, R. Brewer, K. H. Northcote, J. R. Sleeman, M. J. Mulchay, and E. G. & Hallsworth. 1968.

Stanford, G., and E. Epstein. 1974. "Nitrogen Mineralisation-Water Relations in Soils." *Soil Science Society of America Journal* 38: 103-107.

Stephenson, A. H., T. A. McCaskey, and B. G. Ruffin. 1990. "A Survey of Broiler Litter Composition and Potential Value as a Nutrient Resource." *Biological Wastes* 34: 1-9.

Stewart, W. M., D. W. Didds, A. E. Johnson, and T. J. Smyth. 2005. "The Contribution of Commercial Feretlisers Nutrients to Food Production." *Agronomy Journal* 97: 1-6.

Sticksel, E. F., F. X. Maidl, F. Retzer, J. Dennert, and G. Fischbeck. 2000. "Efficiency of Grain Production of Winter Wheat as Affected by N Fertilisation under Particular Consideration of Single Culm Sink Size." *European Journa Agronomy* 13: 287-294.

Stockdale, E. A., M. A. Shepherd, S. Fortune, and S. P. Cuttle. 2002. "Soil Fertility in Organic Farming Systems -Fundamentally Different? ." *Soil Use and Management* 18: 301-308.

Stone, A. G., S. J. Scheuerell, and H. M. Darby. 2004. "Suppression of Soil borne Diseases in Field Agricultural Systems: Organic Matter Management, Cover Cropping, and Other Cultural Practices." In *Soil Organic Matter in Sustainable Agriculture*, eds F Magdoff and R. W Ray.

Stoorvogel, J. J., E. M. A. Smaling, and B. H. Janssen. 1993. "Calculating Soil Nutrient Balances in Africa at Different Scales." *Nutrient Cycling in Agroecosystems* 35 (3): 227-235.

Stowell, R. R., and W. G. Bickert. 1995. "Storing and Handling Sand-Laden Dairy Manure." In *Extension Bulletin E-2561*. East Lansing, MI: Michigan State University

Sullivan, D. M. 2008. "Estimating Plant-Available Nitrogen from Manure." eds B. Jokela, D. Moberg, D. Horneck, J. Harrison, L. Ko, N. Andrews, R. Flynn, S. Bittman, S. Pettygrove and T. W. Downing.

Sullivan, D. M., S. C. Fransen, A. I. Bary, and C. G. Cogger. 1998. "Fertiliser Nitrogen Replacement Value of Food Residuals Composted with Yard Trimmings, Paper or Wood Wastes." *Compost Science and Utilization* 6 (1): 6 - 18.

Sullivan, P. 2003. "Overview of Cover Crops and Green Manures. Retrieved November 2, 2010 from Http://Attra.Ncat.Org/Attra-Pub/Covercrop.Html."

Sutton, A. L., D. D. Jones, B. C. Joern, and D. M. Huber. 1999. "Animal Manure as a Plant Nutrient Resource."

Sutton, A. L., D. W. Nelson, D. T. Kelly, and D. L. Hill. 1986. "Comparison of Solid Vs. Liquid Dairy Manure Applications on Corn Yield and Soil Composition." *Environmental Quality* 15: 370-375.

Swanson, E. R. 1963. "The Static Theory of the Firm and Three Laws of Plant Growth." *Journal of Soil Science* 95 (5): 338-343.

Tarawali, S. A, J. D. H Keatinge, J M Powell, P Hiernaux, O Lyasse, and N Sanginga. 2004. "Integrated Natural Resource Management in West African Crop-Livestock Systems." In *Sustainable Crop-Livestock Production for Improved Livelihoods and Natural Resource Management in West Africa*, 349-370. Ibadan, Nigeria: International Institute of Tropical Agriculture (IITA).

Tembo, G., B. W. Brorsen, F. M. Epplin, and E. Tostão. 2008. "Crop Input Response Functions with Stochastic Plateaus." *American Journal of Agricultural Economics* 90: 424-434.

ten Berge, H. F. M., J. C. M. Withagen, F. J. de Ruiter, M. J. W. Jansen, and H. G. van der Meer. 2000. *Nitrogen Responses in Grass and Selected Field Crops. Quad-Mod Parameterisation and Extensions for Stone-Application*, *Report 24 Plant Research International, Pp 42*.

Thakur, T., and P. Kumar. 1984. "A Comparative Study of Economic Efficiency of Different Irrigation Systems in Western Ular Pradesh." *Indian Journal of Agricultural Economics* 39 (3).

Thamodaran, R., B. Shashanka, and E. O. Heady. 1982. "An Economic Analysis of Water Management Systems in Southern Tamü Nadu-Production Function and Progrmming Approach." *Indian Journal of Agricultural Economics* 37 (1).

Thangata, P. H., and J. R. R. Alavalapati. 2003. "Agroforestry Adoption in Southern Malawi: The Case of Mixed Intercropping of Gliricidia Sepium and Maize." *Agricultural Systems* 78 (1): 57-71.

Thompson, A. 1981. *Economics of the Firm, Theory and Practice*. 3rd ed: Prentice Hall, Englewood Cliffs. ISBN 0-13-231423-1

Tiffen, M. , and M. Mortimore. 1992. "Environment, Population Growth and Productivity in Kenya." *Development Policy Review* 10 (4): 359-388.

Tisdale, S. L., J. L. Halvin, J. D. Beaton, and W. L. Nelson. 1999. "Soil Fertility and Fertilisers: An Introduction to Nutrient Management. 6th Edition, New Jersey: Prentice-Hall."

Tisdale, S. L., W. R. Nelson, J. D. Beaton, and J. L. Havlin. 1993. *Soil Fertility and Fertilisers*. 5 ed. Upper Saddle River, NJ: Prentice Hall.

Tittonell, P., S. Zingore, M .T. van Wijk, M. Corbeels, and K. E . Giller. 2007. "Nutrient Use Efficiencies and Crop Responses to N, P and Manure Applications in Zimbabwean Soils: Exploring Management Strategies across Soil Fertility Gradients." *Field Crops Res* 100: 348-368.

Tumutegyerize, K., T. Hyuha, and E. N. Sabiiti. 1999. "Factors Affecting Dairy Production in the Peri-Urban Areas of Kampala." *Uganda Journal of Agricultural Sciences* 4: 7-11.

Tyner, F. H., and L. G. Tweeten. 1966. "Optimum Resource Allocation in Us Agriculture." *Journal of farm economics* 48: 613-631.

UBOS. 2006. *National Household Survey Report 2006. Uganda Bureau of Statistics*. Kampala, Uganda.

———. 2006. *The Uganda National Household Survey 2005/2006, Report on the Socio-Economic Survey, Statistics Department, MFPED; the Uganda Household Survey (UNHS) 1999/2000*. Kampala.

Uganda Department of Meteorology. 2009. The Rainfall outlook for March to May 2009 Rainfall Season. Ministry of Water and Environment

UN Water. 2006. *Uganda National Water Development Report, Ministry of Water Lands and Environment Uganda, United Nations Water Division*. Kampala, Uganda.

UN Millennium Project. 2005b. "Halving Hunger: It Can Be Done. Earthscan, London."

UNDP/ESMAP. 1996. *Energy for Sustainable Development: A Study of Woody Biomass Derived Energy Supplies in Uganda*. Wiltshire, United Kingdom: United Nations Development Programs.

UNHS. 2003. *Uganda National Household Survey 2002/2003.Socio-Economic/Monitoring Survey*.

Upton, M. 1979. *Farm Management in Africa*: Oxford University press.

U.S. Bureau of Labor, Statistics. 2009. *Manure Use for Fertilizer and for Energy : A Report to Congress*. United States Department of Agriculture. http://stats.bls.gov/ppi/#data

USDA-Agricultural-Research-Service. 2006. *Fy-2005 Annual Report Manure and Byproduct Utilization*. http://www.sustainabletable.org/issues/waste/#fn1.

USEPA. 2004. *Risk Management Evaluation for Concentrated Animal Feeding Operations*. US Environmental Protection Agency. USEPA National Risk Management Laboratory report.

Uzoma, K. C., M. Inoue, H. Andry, H. Fujimaki, A. Zahoor, and E. Nishihara. 2011. "Effect of Cow Manure Biochar on Maize Productivity under Sandy Soil Condition." *Journal of soil use and management* 27 (2): 205-212

Vadas, P. A. 2011. "A New Model for Dung Decomposition and Phosphorus Transformations and Loss in Runoff." *Soil Research* 49 (4): 367-375.

Vagen, T. G., R. Lal, and B. R. Singh. 2005. "Soil Carbon Sequestration in Sub-Saharan Africa: A Review." *Land Degr. Dev* 16: 53-71.

Vallejo, A., L. J. Garcia-Torres, J. A. Diez, A. Arce, and S. Lopez-Fernandez. 2005. "Comparison of Nitrogen Losses ($NO\text{-}_{3,}$ NO_2, No) from Surface Applied, Injected or Amended (Dcd) Pig Slurry of an Irrigated Soil in a Mediterranean Climate." *Plant and Soil* 272: 313-325.

Van-Oosterom, E. J., P. S. Carberry, and R. C. Muchow. 2001. "Critical and Minimum N Contents for Development and Growth of Grain Sorghum." *Field Crops Res* 70: 55-73.

Van den Bosch, H., J Gitari, N., V. N. Ogaro, S. Maobe, and J. Vlaming. 1998. "Monitoring Nutrient Flows and Economic Performance in African Farming Systems (NUTMON). 111. Monitoring Nutrient Flows and Balances in Three Districts in Kenya." *Agriculture Ecosystems & Environment* 71 (1-3): 63-80.

Van der Vossen, H. A. M. 2005. "A Critical Analysis of the Agronomic and Economic Sustainability of Organic Coffee Production." *Experimental Agriculture (Cambridge University Press)* 41: 449-473

Van Duren, I. C., and D. M. Pegtel. 2000. "Nutrient Limitations in Wet, Drained and Rewetted Fen Meadows: Evaluation of Methods and Results." *Plant and Soil* 220: 35-47.

Van Faassen, H. G., and H. Vandijk. 1987. *Manure as a Source of Nitrogen and Phosphorus in Soils. In: Animal Manure on Grassland and Fodder Crops* Edited by H. G. vanMeer. Dordrecht: MartinusNijhoff Publishers, pp 27-45.

Van Hiep, N., and T. R . Preston. 2006. Effect of Cattle Manure and Biodigester Effluent Levels on Growth and Composition of Water Spinach. *Livestock Research for Rural Development.* Volume 18, Article #48. Retrieved October 5, 2011, from Http://Www.Lrrd.Org/Lrrd18/4/Hiep18048.Htm ".

Van Kessel, J. S., and J. Reeves. 2002. "Nitrogen Mineralisation Potential of Dairy Manures and Its Relationship to Composition." *Biology and fertility of soils* 36 (2): 118-123.

van Keulen, H. , and N. G. Seligman. 1987. "Simulation of Water Use, Nitrogen Nutrition and Growth of a Spring Wheat Crop. Pudoc, Wageningen, the Netherlands."

van Straaten, P. . 2002. *Rocks for Crops: Agrominerals of Sub-Saharan Africa. ICRAF, Nairobi, Kenya*. Edited by S Robertson. Scarborough, Canada: Fidelity National Information Solutions Canada.

Vanlauwe, B., J. Diels, K Aihou, E. N. O. Iwuafor, O. Lyasse, N.O. Sanginga, and R. Merckx. 2002. "Direct Interactions between N Fertiliser and Organic Matter: Evidence from Trials with 15N-Labelled Fertiliser. In Integrated Plant Nutrient Management in Sub-Saharan Africa: From Concept to Practice." eds B Vanlauwe, J Diels, N Sanginga and R Merckx, 173–184. CAB International, Wallingford, UK.

Vanlauwe, B., and K. E. Giller. 2006. "Popular Myths around Soil Fertility Management in Sub-Saharanafrica." *Agriculture, Ecosystems and Environment* 116: 34-46.

Vanlauwe, B., P. Tittonell, and J. Mukalama. 2007. "Within-Farm Soil Fertility Gradients Affect Response of Maize to Fertiliser Application in Western Kenya." In *Advances in Integrated Soil Fertility Management in Sub-Saharan Africa: Challenges and Opportunities*, eds A. Bationo, B. Waswa, J. Kihara and J. Kimetu. Dordrecht,Netherlands: Springer

Vanotti, M. B., and L. G. Bundy. 1994. "Corn Nitrogen Recommendations Based on Yield Response Data." Journal of Production Agriculture 7: 249-256

Vereecken, H., M. Vanclooster, and M. Swerts. 1989. A Model for the Estimation of Nitrogen Leaching with Regional Applicability. Paper read at Proceedings at the International Congress 'Fertiliser and the Environment', August 27-30, at Leuven, Belgium.

Vetter, H., and G. Steffens. 1988. *Joint Meeting of FAO Bodies*. Liebefeld, Switzerland.

Von Wiren, N., S. Gazzarrin, and W. B. Frommer. 1997. "Regulation of Mineral Nitrgen Uptake in Plants." *Plant and Soil* 196: 191-199.

Waata, F., B. Jama, and R. J. Delve. 2002 "Integrated Soil Productivity Initiative through Research and Education (INSPIRE). A Collaborative Effort to Improve Livelihoods in Tororo District, Uganda. Africa 2000 Network. Tororo, Uganda."

Wabudeya, B. M. 1996. "Factors Affecting the Adoption of Zero-Grazing among Mbale District Small-Scale Diary Farmers. Msc Thesis." Makerere University, Kampala.

Walaga, C., J. Zake, and F. Nagawa. 2002. "Integrated Nutrient Management to Attain Sustainable Productivity Increases in East Africa Farming Systems.(INMASP). Wakiso Sub-County, Agriculture Sector Baseline Study Report, Wakiso District, Uganda.2002. Environmental Alert P.O. Box 1259, Kampala."

Walker, R. L., I. G. Burns, and J. Moorby. 2001. "Responses of Plant Growth Rate to Nitrogen Supply: A Comparison of Relative Addition and N Interruption Treatments." *Journal of Experimental Botany* 52: 309-307.

Walkley, A. 1947. "A Critical Examination of a Rapid Method for Determining Organic Carbon in Soils. Effect of Variations in Digestion Conditions and of Inorganic Constituents " *Soil Science* 63: 251-64.

Wallace, M. B., and W.I. Knausenberger. 1997. "Inorganic Fertiliser Use in Africa: Environmental and Economic Dimensions. Environmental and Natural Resources Policy and Training Project, Applied Research, Technical Assistance and Training. Winrock International Environmental Alliance, Arlington, Va, USA.".

Walton, G. H., M. Mendham, M. J. Robertson, and T. Potter. 1999. "Phenology, Physiology and Agronomy. Chapter 3. In: Canola in Australia: The First Thirty Years." eds P Salisbury, T Potter, G McDonald and A.G Green, 9-14.

Wambi, M. 2009. "Food Security Requires Increased Fertiliser Use." http://ipsnews.net/news.asp?idnews=46016.

Weil, R. R., and F. Magdoff. 2004. "Significance of Soil Organic Matter to Soil Quality and Health." In *Soil Organic Matter in Sustainable Agriculture*, eds F Magdoff and R. R . Weil, 1-58. Boca Raton. FL: CRC Press.

Wesseling, J. G., P. Kabat, B. van den Broek, and R. A. Feddes. 1989. . "Simulation Function of Water Balance of a Cropped Soil with Different Types of Boundary Conditions Including the Possibility of Drainage and Irrigation and the Calculation of Crop Yield (Swacrop). Instruction for Input." *WSC for Integrated Land, Soil and Water Research*.

Whalen, J. K., and C. Chang. 2001. " Phosphorus Accumulation in Cultivated Soils from Long-Term Annual Applications of Cattle Feedlot Manure." *Journal of Environment Quality* 30: 229–237.

Whalen, J. K., C. Chang, G. W. Clayton, and J. P. Carefoot. 2000. "Cattle Manure Amendments Can Increase the pH of Acid Soils." *Soil Science Society of America Journal* 64: 962-966.

Whitbread, A. M., M. J. Robertson, P. S. Carberry, and J. P. Dimes. 2010. "How Farming Systems Simulation Can Aid the Development of More Sustainable Smallholder Farming Systems in Southern Africa." *European Journal of Agronomy* 32 (1): 51-58.

White, R. E. 2006. "Principles and Practice of Soil Science: The Soil as a Natural Resource."In *Maintenance of Soil Productivity* 241. Malden, USA: Blackwell Science Ltd.

Whitehead, D. C. 1995. *Grassland Nitrogen* Oxon, UK: CAB International.

Wilkinson, K., E. Tee, and V. Hood. 2000. Adequately Benchmarked Compost Quality?. Paper read at Proceedings of the Compost 2000, Down Under Conference, 14-15 November 2000, at Melbourne,Vic.

Woodruff, D. R. 1992. "'Wheatman' a Decision Support System for Wheat Management in Subtropical Australia." *Australian Journal of Agriculture Research* 43: 1483-99.

World Bank. 2011. "World Development Indicators Database, World Bank, 1 July 2011 (Http://Siteresources.Worldbank.Org/Datastatistics/Resources/Gnipc.Pdf."

World-Resources-Institute. 2011. "Fertiliser Use by Country." http://www.NationMaster.com/red/graph/agr_fer_use-agriculture-fertiliser-use&b_printable=1

World Bank. 2009. "World Development Indicators Database, World Bank." http://siteresources.worldbank.org/DATASTATISTICS/Resources/GNIPC.pdf.

World Bank 2000. World Development Report 2000/2001: Attacking Poverty, World Bank, Washington, D.C.

Wortmann, C. S., and C. K. Kaizzi. 1998. "Nutrient Balances and Expected Effects of Alternative Practices in Farming Systems of Uganda." *Journal of Agriculture Ecosystems and Environment* 71: 115-129.

Wysocki, D., N. Sirovatka, and S. Ott. 2005. *Growth and Nutrient Uptake of Winter Canola at Pendleton, Oregon. Special Report 1061*. Oregon State University.

Xiong, W., I. Holman, D. Conway, E. Lin, and Y. Li. 2008. "A Crop Model Cross Calibration for Use in Regional Climate Impacts Studies." *Ecological Modelling* 213 (3-4): 365-380.

Yadav, R. L., V. K. Singh, B. S. Dwivedi, and A. K. Shukla. 2003. "Wheat Productivity and N Use-Efficiency as Influenced by Inclusion of Cowpea as Grain Legume in a Rice-Wheat System." *Journal of Agricultural Science* 141: 213-220.

Yang, Sheng-Mao., S. Malhi, Jian-Rong. Song, You-Cai. Xiong, Wei-Yun. Yue, Li. Lu, Jian-Guo. Wang, and Tian-Wen. Guo. 2006. "Crop Yield, Nitrogen Uptake and Nitrate-Nitrogen Accumulation in Soil as Affected by 23 Annual Applications of Fertiliser and Manure in the Rainfed Region of Northwestern China." *Nutrient Cycling in Agroecosystems* 76 (1): 81-94.

Zake, J., J. S Tenywa, and F. Kabi. 2005. Enhancement of Manure Utilization in Smallholder Cattle Management Systems for Crop Production in Central Uganda. In *7th* African Crop Science Conference Proceedings, Vol. 7. pp. 1067-1071 Zake, J. S., C. Nkwine, and M. K. Magunda. 1999. Integrated Soil Management for Sustainable Agriculture and Food Security in Southern and East Africa. Paper read at Proceedings of the Expert Consultation, at Harare, Zimbabwe.

Zake, J. S., C. Nkwine, and M. K. Magunda. 1999. Integrated Soil Management for Sustainable Agriculture and Food Security in Southern and East Africa. Paper read at Proceedings of the Expert Consultation, at Harare, Zimbabwe

Zake, J., J. S. Tenywa, and F. Kabi. 2010. "Improvement of Manure Management for Crop Production in Central Uganda." *Journal of Sustainable Agriculture* 34 (6): 595-617.

Zebarth, B. J., J. W. Paul, O. Schmidt, and R. McDougall. 1996. "Influence of the Time and Rate of Liquid-Manure Application on Yield and Nitrogen Utilization of Silage Corn in South Coastal British Columbia." *Canadian Journal of Soil Science* 76: 153-164.

Zehnder, C. M., and A. DiCostanzo. 1997. *Estimating Feedlot Nutrients Budgets and Managing Manure Output. 1997 Minnesota Cattle Feeder Report B-450*. Department of Animal Science University of Minnesota, St. Paul

Zhang, H., D. Smeal, and J. Tomko. 1998. "Nitrogen Fertilisation Value of Feedlot Manure for Irrigated Corn Production." *Journal of Plant Nutrition* 21: 287-296.

Zingore, A. 2011. "Maize Productivity and Response to Fertiliser Use as Affected by Soil Fertility Variability, Manure Application, and Cropping System." *Better Crops* 95 (1).

Zingore, S., H. K. Murwira, R. J. Delve, and K. E. Giller. 2007. "Influence of Nutrient Management Strategies on Variability of Soil Fertility, Crop Yields and Nutrient Balances on Smallholder Farms in Zimbabwe." *Agriculture, Ecosystems & Environment* 119 (1-2): 112-126.

Zyskowski, R. F., A. Fletcher, and H. Brown. 2010. Modelling Nitrogen Uptake and Its Distribution in Kale Paper read at Proceedings of 15th Agronomy Conference. Food Security from Sustainable Agriculture, 15-18 November 2010, at Lincoln, New Zealand.

Zyskowski, R. F., D. R. Wilson, and S. Maley. 2004. A Cohort Model for Simulating Forage Brassica Crops with Variable Plant Size. New Directions for a Diverse Planet. Paper read at Proceedings of the 4th International Crop Science Congress 26 September -1 October 2004, at Brisbane, Australia.

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Appendices

For details of the appendices, see attached CD.