Management Strategies for Improving Manure Nutrient Use Efficiency and Productivity of Subsistent Farmers in Enset-based Farming Systems of Southern Ethiopia

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This is to certify that the thesis prepared by Ferew Kebede Zema, entitled *Management strategies for improving manure nutrient use efficiency and productivity of subsistent farmers in enset-based farming systems of southern Ethiopia* and submitted in partial fulfillment of the requirement for the Degree of Doctor of philosophy in Biology (Botanical Science) complies with the regulation of the University and meet the accepted standard with respect to originality and quality.

Signed by the Examining Committee:

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ABSTRACT

Management Strategies for Improving Manure Nutrient Use Efficiency and Productivity of Subsistent Farmers in Enset-based Farming Systems of Southern Ethiopia

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The overall objective of this study was to evaluate enset clones for nitrogen use efficiency and identify best manure management practices minimizing losses and maximizing nitrogen use efficiency by the crop. The study consisted of i) evaluation of manure nitrogen mineralization and nitrification potential ii) effects of rate of manure nitrogen supply on growth and nitrogen use efficiency of enset clones iii) manure placement effects on growth and nutrient recovery efficiency of enset iv) the effect of traditional methods and duration of manure storage on manure chemical composition and quality.

The results of laboratory incubation study on manure mineralization and nitrification revealed that addition of manure significantly ($P \leq 0.001$) increased the amount of inorganic nitrogen released compared to that of the control soil. Moreover, net mineralization and nitrification of manure organic nitrogen was observed throughout the incubation period. The net rates of mineralization varied between 0.04 to 0.33 mg N kg^{-1} of soil /day with mean value of 0.21 mg N kg^{-1} soil/ day. On the other hand, the net rates of nitrification range from 0.058-0.57 mg kg^{-1} soil/ day with mean nitrification rate value of 0.28 mg kg^{-1} soil/ day.

In relation to the effect of rate of manure nitrogen supply, it was observed that the rate of manure nitrogen supply significantly ($P \leq 0.001$) influenced nitrogen use efficiency of enset clones. In the study, the highest nitrogen use efficiency was obtained at application rate of 300 kg of total manure nitrogen per hectare. Of the enset clones studied, clone *Ado* showed the highest nitrogen use efficiency.

In relation to methods of manure application, a significant ($P \leq 0.001$) manure placement effects on growth and nitrogen recovery efficiency of enset were observed. In the study, placement of manure at 20 cm depth and split application of half above and half at 20 cm depth induced better growth and nitrogen recovery efficiency than to surface application.

On the other hand, the existing traditional practice of manure storage in open air was found to be in efficient. It not only reduces the carbon and nitrogen content of manure but also increases the C/N ratio. The duration of manure storage had also significant influence on chemical composition and manure quality. In general, based on the results of the present study it can be concluded that the growth and yield of enset plants in smallholder farms could substantially be increased with planting nitrogen efficient clones along with improved management practices.

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1. GENERAL INTRODUCTION

1.1. Problem Introduction

Since Ethiopia's tragic drought and famine prone decades of the 1970's and 1980's, researchers have been particularly concerned with finding long-term sustainable solution to the country's food security needs. The majority of extension, development, and research on Ethiopian agriculture, focused upon the cereal-based system of the highlands of northern, central, and eastern Ethiopia to address food security problems. There has been considerably less research on Ethiopia's other major agricultural complex, the enset agricultural system of the highlands of southern Ethiopia (Brandt *et al*., 1997). Despite its role in providing food for about a quarter of Ethiopia's population, the enset agricultural system has been deprived of the research attention it deserves. The enset agriculture still employs an age-old traditional farming system with little or no research input made to improve its productivity. Although enset research began in the 1970's (Solomon Zewdie, 2008), the progress made on the intervening years has been so little that there still exists a wide gap of knowledge in our understanding of the enset system in general and in tackling the specific production constraints in particular. Much information considered base line for other crops has not yet been collected with respect to enset (Brandt *et al.*, 1997). Among others, there is scarcity of information on crop growth and yield response in relation to manure management despite the predominance of manure based cultivation in the area. Information on nutrient use efficiency of the crop is also lacking. In addition, no studies have yet been conducted to evaluate the mineralization and nitrification potential of cattle manure. Information along this line believed to be important not only in understanding the system but also in designing sound nutrient management practices and improving the productivity of the system.

The enset-based system is a low input perennial system, where nutrient input from aboveground litter is minimal. In this system, cattle manure is the principal source of organic matter and nutrient input that is crucial for the sustainable productivity of the system. The use of inorganic fertilizers are limited mainly due to financial inability of most farmers to purchase and supply fertilizer throughout the growth period of the crop. Apart from its low cost and local availability, cattle manure is highly valued by smallholder farmers due to its multiple roles and long-term benefits. Besides supplying all the essential elements that plants require, manure improves the physical, chemical, and biological properties of the soil (Rissie *et al*., 2006).

Although manure remains an important organic resource for smallholder farmers, its production, management and use has never been given the due research attention that it deserves. Due to lack of research information in relation to manure management, the efficiency of manure nutrient use remained low among the traditional sectors of Ethiopia in general and in the enset system in particular (Tesfaye Kumsa, 2002). Among others, poor storage and inappropriate methods of manure application resulting in loss of nutrients has been responsible for low efficiency.

Particularly, nowadays, because of significant increase in human population and reduction in livestock population, the quantity of manure has been declining. Consequently, poor soil fertility and decline in crop yield accompanied with increasing population has threatened the livelihood of the people and long-term sustainability of the system. Hence, there is an immediate need to overcome the problem and ensure the long-term sustainability of the system.

We feel that sustainable productivity in the enset system could be achieved through two main strategies. One way of ensuring sustainable productivity is implementing management practices that aim at reducing nutrient loss from the system. Another option is the cultivation of enset clones with high nutrient use efficiency. The present study, therefore, reports on field and laboratory experiments undertaken to address some of these research gaps. By way of introduction, hereunder, an attempt will be made to introduce the enset based agricultural system followed by description of past research, existing research gaps and the underlying objectives of the present study.

1.2 Role of agriculture in Ethiopian economy

Ethiopia is located in eastern Africa between 3^0 and 15^0 North latitude and 33^0 and 48^0 East longitude with a land area of 1.223 million km^2 and occupies a huge land mass of Africa (FAO, 2003). It is a country of great altitudinal diversity ranging from lowlands as low as 116 meters below sea level to highlands more than 4620 meters above sea levels. Although the country is found in the tropics, owing to the moderating influence of high altitude, the central, south and southwestern highlands generally enjoy a temperate and pleasant climate with average daily temperatures rarely exceeding 20^0C (Admasu Tsegaye, 2002). Most of the highlands have rainfall in the range of 600 to 2700 mm (Balesh Tulema, 2005). However, the sparsely populated lowlands typically have hot climates. The diversity of altitude, climate, soils and other physical features have created a variety of agro ecological zones in Ethiopia. The highlands with altitude range of 1500-3500 meters accommodate 88% of the human population, 75% of the livestock population, and 95% of the total cultivated land (EFAP, 1994).

Ethiopia is predominantly an agrarian country and agricultural production plays an important role in Ethiopian economy. About 80-85 percent of the population is dependent on agriculture for its livelihood. The sector contributes for about 54 % of the gross domestic product (GDP) and about 90 % of foreign currency earnings (Eyasu Elias, 2003; CSA, 2000). The agricultural sector, therefore, forms the basis for the overall socio-economic development of the country. Nevertheless, agricultural production in Ethiopia still remains to be predominantly traditional; employing an age old, poorly developed farming practices. As such, the country's agriculture is still far from playing its strategic role in the overall economic development of the country. Among the major factors behind the poor performance of Ethiopian agriculture are poor soil fertility and low and variable rainfall. Particularly, soil fertility depletion is the principal constraint for increasing crop production in majority of smallholder fields. Several factors such as intensive cultivation, lack of sufficient fallow period for fertility restoration, high soil erosion and lack of adequate nutrient input and poor nutrient management practices have resulted in soil nutrient depletion and crop yield decline. Nutrient balance calculations for countries by Stoorvogel and Smaling (1990) showed that Ethiopia is among the 14 sub-Saharan countries with the highest rates of net nutrient losses. Consequently, there is very little surplus output even during climatically good years and the country consistently faces severe food shortages to feed the rapidly growing population. The subsistent farmers still practice old traditional methods of production with a very low productivity. Today farmers in Ethiopia have difficulties in feeding their households using their traditional techniques of production. Hence, there is a drastic need to improve agricultural productivity.

1.3 Enset-based farming systems

There are four different farming systems in Ethiopia namely: pastoralism, seed-farming complex, shifting cultivation, and the enset-planting complex of the south and southwestern Ethiopia. Of these, the enset farming system is believed to be indigenous to Ethiopia and mainly practiced in the highlands of southern and southwestern parts of the country. Given the restricted geographic distribution of domesticated enset and the degree of complexity and variability in contemporary enset agricultural systems, agronomists and biogeographers have long considered the Ethiopian highlands to be the primary center for the origin of enset agriculture (Brandt *et al.*, 1997). Although evidence is lacking to locate the exact place of origin, Smeds (1955) speculated that the highlands along western edge of the Rift Valley, particularly the present Wolaita, Kambata-Gurage regions, could be the original centers of enset cultivation. Anthropologists, archeologists, historians and other scholars have also developed theories and models that argue about the domestication of enset in Ethiopia to have begin as early as 10,000 years ago (Brandt, 1996). Stiehler (1948), as cited in Brandt *et al*. (1997), one of the first scholars to consider the origin of enset, believed the indigenous hunter/gatherers of southern Ethiopia were the first to cultivate enset. He also proposed that enset agriculture was later introduced to northern Ethiopian highlands by Cushitic speaking peoples, only to be replaced by crops such as wheat, barley, and tef.

It has been estimated that around 10-20 million people depend on enset as staple and co-staple food (Asnakech Woldetensaye, 1997; Tilahun Amede and Mulugeta Diro; 2005; Tadesse Kippie, 2001). The enset growing regions are the most densely populated areas in the country. The population density in some of the major enset producing areas could reach 250-350 persons per square km (Seifu Gebremariam, 1996).

Within the enset agricultural systems, four major enset sub-systems have been recognized mainly based on the extent to which people depend upon the plant as staple crop (Westphal, 1975). One of such subsystem is where enset is the staple food and main crop (e.g., the Sidama and Gurage people). Another enset subsystem uses enset as a co-staple food with cereals and tuber crops. The Gamo, Hadiya, Wolayta, and Ari, among others, depend upon enset as a co-staple crop. The third enset subsystem relies upon cereals as the most important crops, with enset and root crops of secondary importance. Such groups as the Oromo farmers of southwestern Ethiopia exemplify this system, where both the hoe and plow are used to grow cereals. In this subsystem, enset is grown largely for security reasons (e.g., if in case cereal crops fail) and eaten in the form of kocho and amicho. The fourth enset subsystem is where root crops are of prime dietary importance, cereals are of secondary importance, and enset is of minor importance. Groups such as the Sheko in southwestern Ethiopia practice hoe-based shifting cultivations, in which yams and taro are the most important crops, while enset and cereals are of minor importance.

1.4 Description of the enset crop

1.4.1. Morphology

Enset is a banana like crop. Both enset and banana have an underground corm, a bundle of leaf sheaths that form the pseudostem, and large leaves. Enset, however, is usually larger than banana, with the largest plants up to 10 meters tall and with a pseudostem up to one meter in diameter. The leaves of enset are more erect, broad, and long, than those of banana. Banana plants normally form suckers or clusters of plants at the base, but enset does not.

The stem of enset has three parts. The upper-most portion is the pseudostem, which is made of a system of tightly clasping leaf bases or leaf sheaths. Depending on the variety and ecological condition of its cultivation, the pseudostem height ranges from 2 to 5 m. The pseudostem and leaf midribs color vary considerably; some are purple to dark red but most are light green with variegated brown patches (Taye Bezuneh, 1996). Leaves are borne on the pseudostem almost from the same point and on short petioles and are about 5 meters long and 0.75 to 1.5 m wide. The underground portion of the plant consists of a corm, which is 0.70 to 1.8 m long with a circumference of 1.5 to 2.5 meters at maturity.

A short section of stem near the soil line, between the pseudostem and corm, is the true botanical stem. Enset has a fibrous rooting system that grows out from the corm. At maturity, a single flower head emerges, which forms multiple flowers, fruit, and seeds. The entire head, which may be nearly one meter in length, hangs downward from a stalk in the center of the plant. Many of the small, banana-like fruits (enset is sometimes called false banana) on each flower head produce several irregularly shaped black seeds, each about one centimeter across. Most wild plants are produced from seed, and have more than one parent. Most domesticated plants, however, are propagated from suckers, and are clones of their one parent. Most plants are harvested before or at early stages of flower formation, (Fig 1.1 shows morphology of enset).

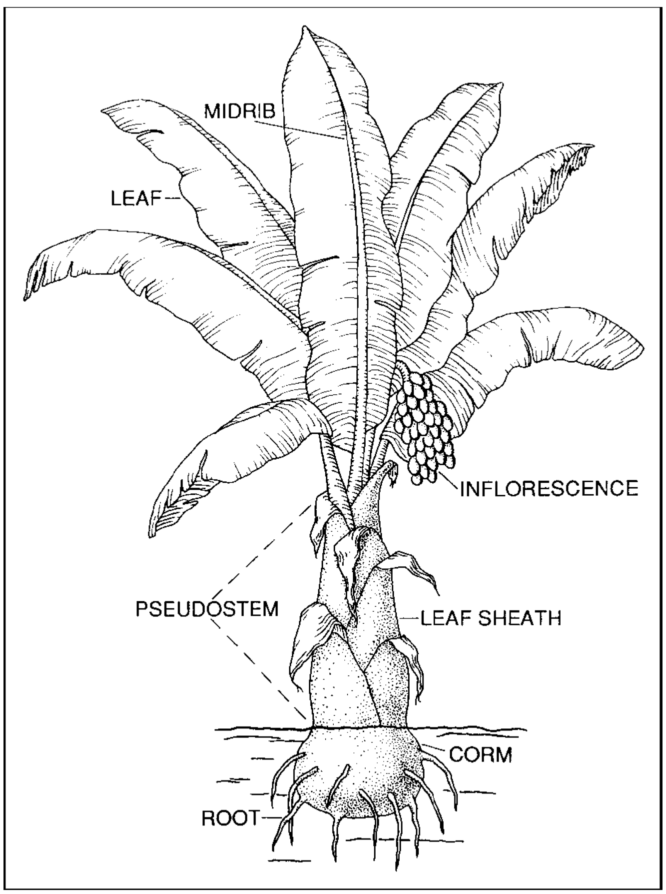


Figure 1. 1: Parts of mature enset plant (Source: Brandt *et al*., 1997)

1.4.2 Taxonomy of enset

Enset belongs to the order Zingiberales, the family *Musaceae* and the genus *Ensete*. Banana and enset belong to the same family Musaceae but banana belongs to the genus Musa. Although further research still needs to be done on the taxonomy and distribution of enset species, current data reveal that the genus *Ensete* contains about eight distinct species distributed over much of Asia and Africa (Beker and Simmonds, 1953). Among these, *Eneste gillettii* De Wild is native to western Africa from Sierra Leone, Nigeria, Cameroon to Angola, and it is relatively more adapted to drier locations than other species of Ensete. *Ensete homblei* Beq. ex De Wild is more like Canna and banana and distributed in Congo, democratic republic of Congo and Zambia. *Ensete perrieri* is largely distributed on the islands of Madagascar. *Ensete superbum* Roxb is native to India, *Ensete gluacum* Roxb is distributed over a wide range from Bruma to the Philippines and Java (Indonesia), and *Ensete ventricosum* is generally adapted to moist areas through central and eastern Africa. Taye Bezuneh *et al*. (1967) reported that among the species occurring in tropical Africa, *Ensete ventricosum* is widely cultivated only in Ethiopia for food and fiber.

1.4.3 Ecology of enset

Domesticated enset is cultivated at altitudes ranging from 1,500 to 3,100 meters above sea level. However, it grows best at elevations between 2,000 and 2,750 meters above sea level. Most enset growing areas receive annual rainfall of about 1,100 to 1,500 millimeters (Westphal, 1975). The average temperature of enset growing areas is between 10 and 21 ^{o}C with relative humidity of 63 to 80 per cent (Asnaketch Woldetensae, 1997). Temperature plays a significant role in the growth rate of enset. Accordingly, at the altitudinal ranges of 1500-2300 meters (woyna dega) with mean annual temperature of 15-20^{0}C, enset grows fast and reaches full maturity in 5 to 7 years. On the other hand, in the high altitudes of 2300-3100 meters (Dega areas), where mean temperature drops to 10-15^{0}C, it takes 8-10 years and sometimes up to 16 years (Tesfaye Abebe, 2005). Enset grows well on most of the soil types if they are sufficiently fertile and well drained. Cattle manure is the principal source of nutrients and soil organic matter. The ideal soils of enset growing areas are moderately acidic to slightly alkaline (p^H 5.5 to 7.3) and contain two to three per cent organic matter (Kelsa Kena, 1996).

Enset is not tolerant to freezing. Frost damage on upper leaves is commonly observed above 2800 meters above sea level, and serious stunting is seen above 3,000 meters. For a certain range below 1500 meters, the constraint to enset plant growth probably is more related to available water (Endale Tabogie, 1997). Enset is not affected by occasional heavy rainfall. This resilience is attributed to the plant's stiff leaves, which resist large raindrops. In fact, one of the main attributes of enset is that it protects the soil from erosive rainfall. The main danger of heavy rains to enset is that roots and the corm do not tolerate water logging for long periods. For that reason, enset is usually grown in soils that do not have high water tables and are well-drained (Brandt *et al*., 1997). Enset requires considerable amount of mineral nutrients to maintain yields. Nitrogen, phosphorus, and potassium are the major nutrients required in large quantities (Eyasu Elias, 2003).

1.4.4. Economic importance of enset

Enset is a multipurpose crop. All parts of the plant are economically important. The corm, the pseudostem and the stalk of the inflorescence of enset are the most important sources of food. Enset is used as food in three forms: Kocho, Bulla and Amicho. Kocho is a fermented product obtained from the corm, the pseudostem and inflorescence stalk; Bulla is made by dehydrating the juice collected during the decortication of the pseudostem and grating of the corm. Amicho is a boiled enset corm. The most important characteristic feature of enset is its productivity of food per unit area and its storability for long periods without spoilage (Seifu Gebremariam, 1996). Nutritionally, enset products are rich in carbohydrates but low in proteins and fats (ENI, 1981). The protein content of enset products are estimated to be 12 g per kg of dry processed enset compared to cereals (100 g kg^{-1} of dry maize) (ENI, 1981). Due to poor protein and fat content, enset food products are not consumed by their own, except during periods of extreme famine or by poor households who do not have the means to vary their diet (Pankhurst, 1996). Enset food is mostly consumed together with other crops such as cabbage, beans etc, and animal products such as milk, meat, yoghurt etc. Because of these basic reasons, enset is always grown alongside with other crops and livestock. The enset production, thus, provides the opportunity and the need for diversification of agricultural production (Pankhurst, 1996).

In addition to food, enset has many other uses. The fiber extracted during processing is used locally for making strings, ropes and other products. Enset fiber has an excellent structure and its strength is only next to *Musa textailes*, a world-class fiber crop (Kefale Alemu and Sandford, 1991). Data on the fiber yield of enset are virtually lacking. Based on the limited data available, the estimated fiber yield could vary from 600-800 kg ha^{-1} (Taye Bezuneh, 1984). Increased production of the fiber could lead to realization of cottage industries, if the present methods of processing and fiber extraction are improved. Fresh enset leaves are used as bread and food wrappers, serving plates and pit liners to store kocho for fermentation and future use. During enset harvesting enset leaves are also used to line the ground, where processing takes place. Dried leaf sheaths are used as wrappers for butter, kocho and other items to transport to local markets. Especially in the dry season when grasses are scarce, enset is an important cattle feed. The dried petiole and midribs of enset are used as a source of fuel. Particular clones of enset are also used medicinally for both humans and livestock to cure bone fracture, broken bones, child birth problems (i.e., assisting to discharge the placenta), diarrhea, birth control (as an abortifacient), jaundice, back-ache and heart diseases (Worku Nida, 1996). Besides these, enset plays a very important environmental role. Enset's perennial canopy of leaves and the abundant accumulation of litter protect the soil from erosion and runoff. Because enset production improves soils, particularly with adequate manure, many enset fields have been in continuous production for decades, if not centuries. However, currently significant increases in human population and decreases in animals and manure is causing reduction in crop yields and soil fertility, thereby reducing the long-term sustainability of the enset system. Increased use of fertilizer may not compensate for the manure loss because of the multiple roles that manure plays in improving soils biologically, chemically and physically.

1.4.5. Clones of enset

In enset system, local farmers recognize different clones. However, exhaustive inventory of clones at various locations is not available (Teketel Makiso, 1996). Recently, Admasu Tsegaye and Striuk (2003) reported 52, 55, and 59 different types of clones from Sidama, Wolaita and Hadiya, respectively. On the other hand, Bezuayehu Tesfaye (2002) reported 86 locally recognized clones from Sidama region. A number of factors, including household economic status, cultural background, and agro ecology influence the number of enset clones on a given farm (Admasu Tsegaye and Struik, 2003). It is indicated that wealthier households tends to have greater clonal variation, as well as, a great number of clones in general. This is mainly because of their larger landholding size, greater social networking for obtaining more varieties, larger income to purchase other varieties and better all round management practices (Brandt *et al*., 1997). In enset growing regions, planting many different clones in the backyard is a sign of high status within the community. Farmer's prefer a specific clone type to fit their specific household needs. The selection criteria for household use include quantity and quality of food products, maturation period, disease and drought tolerance, forage and fiber quality, and medicinal value (Admasu Tsegaye and Struik, 2003). Since one clone can never fulfill all criteria, farmers tend to maintain a wide range of enset types on their own farm.

1.4.6. Livestock in enset system

Regardless of elevation, ethnic groups, or degree of dependence on enset in dietary intake, livestock play a critical role in enset system in maintaining soil fertility (and thus agricultural sustainability). In traditional (low input) farming systems like enset, animal production is strongly dependent on local crop production, while crop production is strongly dependent on the amount of animal manure produced and of the amount and availability of nutrients therein. As such, crop production and animal production are intimately related in such systems. Besides manure supply for soil fertility maintenance, livestock act as a source of milk and meat for supplementing protein poor enset diets, a source of wealth that can be sold to provide cash in times of need and provide traction for plowing and transportation of agricultural products to local markets. Additionally, livestock are also kept as an indicator of wealth and sources of prestige among rural households.

In enset farming system, cattle manure is the principal source of organic matter and nutrient input and is crucial for the productivity of the system. The use of inorganic fertilizers is limited for enset crop because of its high cost and limited availability. Thus, cattle manure is a locally available low cost substitute for the majority of resource poor farmers. Apart from its low cost and local availability, cattle manure is highly valued by farmers because of its multiple roles and long-term benefits. Because of its importance in maintaining long-term soil productivity besides meeting timely requirement of nutrients, manure is regarded essential for sustainable productivity of the enset system. Manure is an excellent source of plant nutrients such as nitrogen, phosphorus and potassium as well as the secondary nutrients that plants require (Risse *et al*., 2006). In addition, manure application can have significant influence on physical, chemical, and biological properties of the soil. Most of the effects are due to an increase in soil organic matter resulting from application of manure. Soil organic matter is known to affect a number of soil chemical properties such as the cation exchange capacity and the soil buffering capacity that enable manure treated soils to retain nutrients and other chemicals for longer periods of time (Risse *et al*., 2006).

However, nowadays, because of significant increase in human population and decreases in livestock, reduction in soil fertility is one of the major constraints of enset production. Farmers are unable to obtain the expected amount of yield out of the crop using traditional systems. Brandt *et al*. (1997) noted that because of low productivity and high rates of mortality, the livestock production in enset growing region is under significant stress. Current data indicate that the most severe constraint is lack of adequate forage for livestock. A decrease in the amount of land allocated for grazing per village, and transformation of some common grazing land to crop production have contributed to this decline in forage resources.

1.4.7. Agronomy and production management of enset

Compared to most crops, particularly annuals, the production of enset involves many more steps. The major activities include sucker propagation, transplanting, weeding, manuring, harvesting and processing.

1.4.7.1. Propagation and cultivation methods

Enset is generally propagated vegetatively. However, in some areas (highland part of Gardula) propagation is done both vegetatively and by seed (Taye Bezuneh, 1984). The seed germination of enset is erratic generally low and may take several weeks (Taye Bezuneh, 1996). However, mechanical scarification or cracking of the seed is known to improve the imbibition of water. Soaking enset seeds for 24 hrs after mechanical scarification is known to improve germination of the seed by 60-80% (Taye Bezuneh, 1996).

In establishing an enset farm, farmers usually use vegetatively propagated seedlings. Vegetative propagation is done by use of suckers that sprout from the corm of the plant after it has been buried. To initiate suckering, mother plant of 2-4 years is dugout and pseudostems cut some 10 to 20 cm above the corm. The apical meristem (situated at the top of the corm) is removed to eliminate the apical dominance. Then, the corm that is cut half way or into quarter is planted into a shallow hole dug at a fertile spot. After 4 to 12 weeks, suckers begin to emerge more or less in rings. Propagation of suckers is carried out in December or January (as in Kambata and Gurage) or March (as in Sidamo). The age of suckers before separation from the mother corm and transplantation to another site, depend on the altitude. In altitudes between 1600 and 3000 meters it takes one and one and half years; above 3000 meters two or more years (Westphal, 1975). Once the suckers are ready for transplanting, they will be separated from the degenerating corm and the small leaves and roots are trimmed and transplanted to a different plot usually with narrow spacing. Although the fundamental reason for repeated transplantation is not adequately known, depending on cultural practices, the suckers are transplanted one to four times (Seifu Gebremariam, 1996; Admasu Tsegaye, 2002). In Sidama suckers are transplanted only once. While transplanting cycles of 2-3 are common among the people of Gurage and Siltae where as a cycle of 4 is common in Hadiya. Enset can, however, grow well without being transplanted that the spacing is wide enough (Mulugeta Diro and Endale Tabogie, 1994).

Field management of enset also involves regular weeding and application of manure. Weeding is done by hand using local tools. Another management activity in enset cultivation is application of manure. The quantity of manure applied varies with plant age and manure availability (Asnakech Woldetensae, 1997). Farmers usually practice heavy application of manure during the wettest months (June to August). Manure first broadcast on the surface and incorporated into the soil later during the period of weeding.

1.4.7.2. Harvesting and processing of enset

The optimum harvesting time for enset is shortly after flowering. At this stage, it has maximum storage of food in the pseudostem (Kefale Alemu and Sandford, 1991). Age of flowering depends upon climatic condition, clone and management. Hence, the flowering time varies from 3 to 15 years but is optimally around 6 or 7 years. However, in some cases enset is harvested in its premature stage especially when there is lack of food. Kelbessa Urega *et al*., (1996) have reported the effects of premature harvest. According to their studies, enset harvested too young will have reduced starch content. In majority of ethnic groups, harvesting is done between November and January, and mostly carried out by women. There is a clear gender division in enset cultivation practice. Men are involved in propagating, planting, and transplanting activities. On the other hand, women are involved in manuring, hand-weeding, thinning, and colonal selection. In addition, the laborious work of harvesting and processing is left to women. At harvest, leaves and older leaf sheaths are first removed from the designated plants. Following this, the internal leaf sheaths are separated from the pseudostem down the true stem. Then, the leaf sheaths peeled and cut into pieces of about one meter length and split lengthwise in order to shorten the leaf sheaths to a workable size. The leaf sheaths are then decorticated using a locally made bamboo scraper while the leaf sheath is held on an incline (at 45 to 80 degrees from the ground) against a wooden plank. The working area used for decortication is covered with enset leaves. At the same time, the corm is grated separately using a locally made wooden tool with a short serrated edge. The scraped pseudostem and corm tissue are mixed and then squeezed to extract more starchy fluid before they are placed in a pre-prepared pit lined with enset leaves. Turning, mixing, rinsing, and chopping continue over a period until the mixture partially ferments, when it is then referred to as *kocho.* The total period for this fermentation to occur ranges from 15 to 20 days. Then the fermented *kocho* is stored in pits that are lined with enset leaves.

1.4.7.3. Yield of enset

Among enset based foods, ‘kocho’ pre-dominates other enset food products (i.e., Bulla and Amicho) in its quantity of production. Consequently, quantification of enset yield mostly considers the yield of ‘kocho’. Reports on the yield of ‘kocho’ are variable. Yield of enset varies with the landraces used and with the climate. According to the nationwide survey on enset production (CSA, 1997), the average yield of kocho and bulla per mature enset plant is 30.2 and 1.0 kilograms respectively. Taye Bezuneh (1984) reported a maximum yield of 11.9 tonne ha^{-1} $year^{-1}$. Admasu Tsegaye (2002) reported a maximum yield of 26.26 tonne ha^{-1} $year^{-1}$ for a plant spacing of 2.83 m^2. Shank and Cherinet Eritro (1996) have reported kocho yield of mature enset to vary from 19.7 to 84.6 kilograms per plant, with the average of 44.2 kilograms at 50% moisture.

1.5. Past research, research gaps, and justification of the study

In densely populated areas of southern Ethiopia, enset is regarded as a food security crop. The presence of enset in the farming system contributes significantly to the stability of the food supply by several mechanisms. The primary strategic importance of enset in food security is that enset helps prevent famine by surviving drought when other food crops fail. Once enset plants are established in areas of sufficient rainfall, they are able to tolerate occasional years of very low rainfall or a short rainy season (Brandt *et al*., 1997). Secondly, it gives higher yield per unit area than other crops and thus supporting the densely populated areas in the country. According to Kefale Alemu and Sandford (1996), enset yields 1.3 to 3.5 times much more food energy per hectare per year compared to maize grown under similar management conditions. Thus, for households facing a shortage of land, the higher energy productivity of enset relative to cereals makes enset an important food security crop. Third, enset foods can be stored for long-term uses. The ability to store processed enset products for long periods with little storage loss provides households with a mechanism to smooth consumption during food shortage periods. Fourth, enset plants can be harvested at any time and any stage of growth, allowing households to weather out period of food shortage.

Despite all these desirable attributes, the enset farming system received very little research attention as compared to that given to cereal based system. Although, enset research began in the early 1970’s, earlier research undertakings on enset were related to clone characterization, documentation and few field trials that mainly focused on methods of sucker propagation, transplanting and spacing. They were generally less coordinated and poorly funded. Gradually, however, the awareness on the importance of enset for food security and environmental sustainability has increased and recently, several important studies on the various aspects of the enset crop and/or farming system have been undertaken. The research areas mainly include biodiversity/conservation, agronomy, ecophysiology, microbiology, genetics, and biotechnology. In relation to biodiversity/conservation, Almaz Negash (2001) reported on the diversity and conservation of enset in relation to household food and livelihood security in Kaffa region southern Ethiopia. Similarly, Yemane Tsehay and Fasil Kibebew (2006) studied diversity and cultural use of Enset in Bonga. In vitro conservation and propagation protocols were also developed for enset to allow conservation and rapid propagation of disease free germplasm (Almaz Negash, 2001; Genet Birmeta and Welander, 2004). Dagmawit Chombe and Endashaw Bekele (2011) also investigated the genetic diversity among populations of cultivated enset using inter simple sequence repeats (ISSRS) marker and reported the existence of high genetic diversity within the study populations. Bezuayehu Tesfaye (2002) investigated the clonal diversity of enset and reported 86 locally recognized clones in Sidama. Bezuayehu Tesfaye (2002) also investigated in vivo regeneration of enset as well as developed a protocol for the cloning of enset in vitro. The study indicated that tissue culture of enset provides new opportunity to control and spread of bacterial wilt disease, which is now threatening enset production. In relation to enset agronomy, (Admasu Tsegaye, 2002) reported on indigenous production, genetic diversity and crop ecology of enset. In his study, indigenous production methods and farm-based biodiversity of enset were analyzed in three enset growing regions in southern Ethiopia. He also estimated the yield potential of some enset clones using crop physiological and weather parameters. More recently, in relation to enset ecophysiology, Solomon Zewdie

(2008) investigated the influence of water stress on growth and physiological performance of enset and fine root dynamics of enset in relation to its contribution to carbon and nitrogen economy.

Apart from these, there exists a wide gap of knowledge on mineral nutrition of the crop. Information with regard to crop growth performance, biomass production, and nutrient use efficiency as influenced by manure management practices. Although manure is the principal source of organic matter and nutrient input that is crucial for the sustainable productivity of enset system; it remained far from scientific investigation. There are no research data available as a base to use for advising farmers on the rates of manure that should be applied to enset. Similarly, there is no information on the effect of manure placement on crop's growth, biomass production and nutrient use efficiency. In addition, studies addressing the mineralization of manure nitrogen and the effect of traditional methods and duration of manure storage on manure chemical composition are scanty. Determination of the effect of rate and method of manure application as well as understanding the level of change in nutrient composition from the time of production to the time of application of manure is crucial in developing sound manure management practices for its efficient use.

Particularly, nowadays, because of significant increase in human population and decreases in livestock, low soil fertility is one of the major constraints of enset production. This situation is worsened by the financial inability of most resource poor farmers to purchase inorganic fertilizers. This accompanied with lack of external knowledge input made to improve input management and use has contributed to decline in the productivity of the system to support household needs (Tilahun Amede and

Mulugeta Diro, 2005). As a result, the system became vulnerable to frequent food crises since the last 2-3 decades, the population became food aid dependent at least 3 months per year (Tadesse Kippie, 2001; Tilahun Amede and Mulugeta Diro, 2005). Thus, there is a need for reversing the situation and improving the productivity of the system in more sustainable way.

It is believed that the sustainability of enset system could be achieved through two main strategies. One way of ensuring sustainable productivity is implementing nutrient management practices that aim at reducing nutrient losses from the system. Another way is the cultivation of enset clones with higher nutrient use efficiency. These practices generally reduce production costs, optimize the use efficiency of limited input, and minimize environmental damage.

Among the major nutrients in manure, nitrogen is typically the nutrient of most concern because it is the most yield-limiting nutrient in crop production and yet it is the most susceptible to losses from soil-crop system. The nitrogen fertilizer applied to soil-crop system, in contrast to most other nutrients, is highly soluble and may be lost or made unavailable through the process of leaching, denitification, volatilization, and immobilization. The loss of nitrogen not only reduce the nutrient value of manure but also may exert harmful effect on the environment through the emission of toxic gases to the atmosphere and contamination of ground water by leaching of nitrate. Any use of nitrogen fertilizer therefore requires specific management to optimize its efficiency. Several factors related to the management of fertilizer nitrogen influence efficient use by the crop including rate of application, time of application and methods of placement. Therefore, efforts to improve nitrogen use efficiency should also include determination of optimum nitrogen rates and managing nitrogen to avoid losses, using appropriate placement, and timing methods. Manure application rates are usually determined based on crop's nitrogen requirements. This is because nitrogen is the nutrient that is required in larger quantity relative to others.

Nitrogen use efficiency of a crop is also a function of its genetic constitution and the environment. Genotypic differences in nitrogen uptake and/or utilization were found in wheat (Cox *et al*., 1985), corn (Moll *et al*., 1982) and oil rape (Kessel and Becker, 1999). A genotype can be termed nitrogen efficient either when realizing a high yield under condition of low nitrogen supply (Graham, 1984) or when converting applied nitrogen fertilizer efficiently into yield under condition of nitrogen supply (Sattelmacher *et al*., 1994). Genotypic variation in nitrogen efficiency could generally be attributed to high nitrogen uptake and/or high nitrogen utilization (Sattelmacher *et al.*, 1994). Effective selection of genotypes for nitrogen efficiency necessitates testing at different nitrogen levels. Testing only under optimal conditions of crop production may mask the difference among the genotypes for nitrogen use efficiency (Gueye, 2002).

Nitrogen use efficiency in crop species can be expressed by three major ways. These are nitrogen agronomic efficiency, nitrogen recovery efficiency and nitrogen physiological efficiency. Agronomic efficiency is the amount of economic/biological yield produced per unit of nitrogen applied. Most fertilizer studies focus on this parameter. On the other hand, the nitrogen uptake efficiency is the total amount of nitrogen absorbed (including that is present in the root, often disregarded) per kg of applied nitrogen. This is ecophysiological parameter often called recovery efficiency. Physiological nitrogen use efficiency, on the other hand, defined as the biological yield/economic yield produced per unit of nitrogen absorbed. It represents the ability of a plant to transform a given amount of acquired fertilizer nitrogen into biomass or yield (Ladha *et al*., 2005).

Various indices are commonly used to assess the efficiency of applied nitrogen (Cassman *et al.*, 2002). In field studies, these indices are either calculated based on difference in crop yield and total nitrogen uptake between fertilized plots and unfertilized control (the difference method), or by using isotopic methods, which uses ^{15}N-labeled fertilizers to estimate crop and soil recovery of applied nitrogen. Both indices are most useful for understanding the factors governing nitrogen uptake and fertilizer efficiency, to compare short-term nitrogen use efficiency in different environments, and to evaluate different nitrogen management strategies (Dobermann, 2005). The difference method is simple and cost-efficient, which makes it particularly suitable for on farm research (Dobermann, 2005). Compared to the difference method, no 0-nitrogen plot (control plot) is required for estimating nitrogen use efficiency using ^{15}N-isotopic method, but costs tend to be higher and a generally higher level of sampling and measurement quality is required. This limits the use of isotopic method in on farm studies.

Munoz *et al.* (2004) compared the difference method and ^{15}N recovery methods in determining the recovery of manure nitrogen. They found no significant difference between the methods.

As mentioned earlier, so far, information on the effect of rate of manure application on growth, biomass yield, and nutrient efficiency of enset is scarce despite the predominance of manure-based cultivation. Nor have there been particular studies, addressing the effectiveness of different methods of manure storage and application methods on crop nutrient uptake and utilization. Moreover, no studies have yet been conducted to evaluate the mineralization and nitrification potential of manure. The study stems from this understanding and was conducted to address the following objectives.

1.6. Research hypothesis

The following four hypothesis were formulated for the study

1. Manure organic nitrogen has a substantial potential for mineralization

2 The rate of manure nitrogen supply influences the growth, biomass production, nitrogen efficiency of enset plants and the responses could differ among the enset clones.

3 The method of manure placement influences growth, biomass production, and nitrogen efficiency of enset plants

4 Method and duration of manure storage influences the chemical composition and manure quality

1.7. Objectives of the study

1.7.1. General Objective

The overall objective of this thesis was to evaluate enset clones for nitrogen uptake, use efficiency, and identify best manure management practices minimizing losses and maximizing nitrogen use efficiency by the crop.

1.7.2. Specific objectives

The work had the specific objectives:

1) To evaluate the mineralization and nitrification potential and patterns of nitrogen release of cattle manure from smallholder farms of the study area using laboratory incubation

2) To determine the effect of rate of manure nitrogen supply on growth, biomass production and nitrogen use efficiency of some selected enset clones

3) To evaluate the effect of manure placement on growth, biomass production and nitrogen recovery efficiency of enset crop

4) To evaluate the effect of method and duration of storage on manure chemical composition and quality

2. MATERIALS AND METHODS

2.1. Description of study area

Field study was conducted in the Hagereselam district of the Sidama administrative zone in the Southern Nations, Nationalities and Peoples Regional State. Hagereselam is situated at $6^0$03'N latitude and $38^0$31'E longitude about 365 km southeast of Addis Ababa and the district is categorized under Sidama-Gedeo highland Enset and barely livelihood zone and the area is known for its high quality enset production and export (SNNPRS, 2005).

The topography of the area is hilly, with slope approximately ranging from 5-60%. The district has an elevation ranging from 2100-3200 m a.s.l. and annual mean temperature range 10-18^0 C. Annual rainfall ranges from 1100-1400 mm. The rainfall pattern in the area is bi-modal, allowing two cropping seasons a year (i.e., the long and the short rains). The long rainy season ranging from July to September and a short rainy season between March to May. The human population density is high (about 350 people/km^2) and farm sizes are consequently small (average 0.5 ha). Farming is characterized by mixed crop-livestock systems. Cattle, sheep, and horses are the major types of livestock kept by households. Enset, barely, wheat, peas, and maize are the main food products. Shallots (locally called *kitel shinkurt*); loose cabbage (*yabesha gomen*) and garlic are the major cash crops of the area. Local agricultural labor is not common in this livelihood zone, but poor households seeking cash migrate to neighboring coffee producing areas during the September-January harvest period. Different soil types exist in Sidama. The most common soils in enset home gardens are e*utric nitosoles*, p*ellic vertisols*, o*rthic* a*crisols*, c*hromic luvisols* and e*uctric fuvisols* (Tesfaye Abebe, 2005).

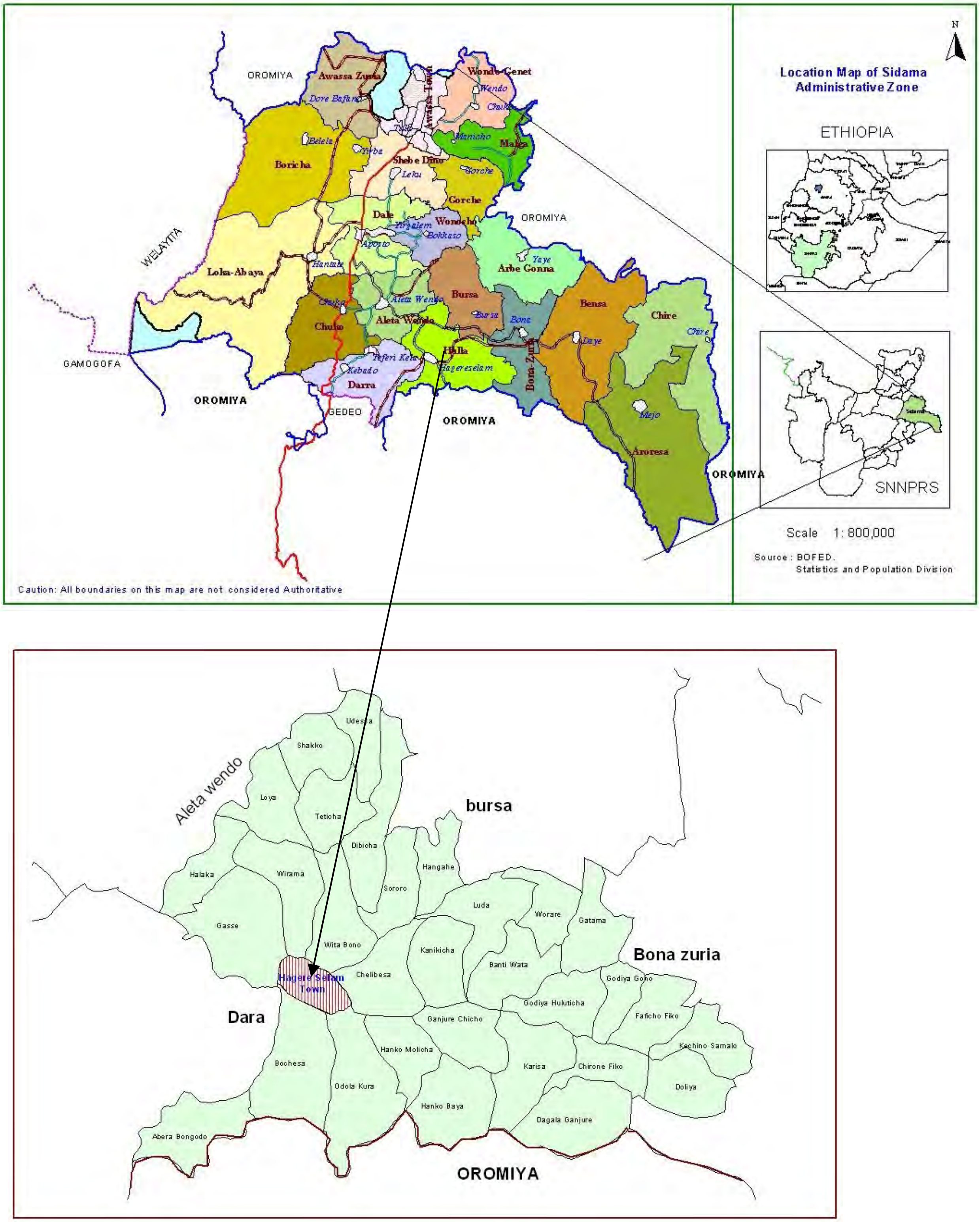


Figure 2. 1: Map showing the study site

2.2. Weather data collection

During the study period, the daily maximum, and minimum temperatures for the experimental sites were recorded (Fig 2.2) using a field installed thermo hygrometer and monthly rainfall was obtained from a metrological sub-station located in Hagereselam town.

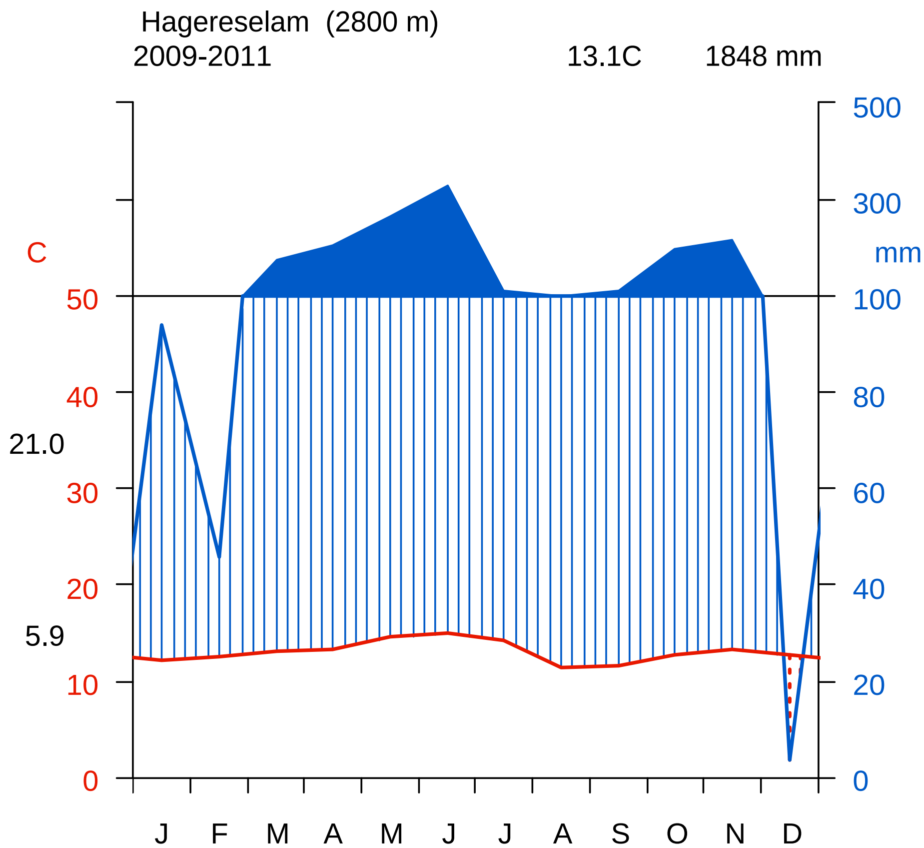


Figure 2. 2: Klimadiagram of the study area. Wet periods are hatched black (for precipitation above 100 mm)

2.3. Description of laboratory and field experiments

The thesis consists of four separate studies undertaken both in the study area and in the Eco-physiology laboratory at Addis Ababa University between January 2009 and February 2012. The first study dealt with in vitro mineralization study of manure organic nitrogen. The investigation was undertaken in the Ecology and Ecophysiology laboratory at Addis Ababa University. The second study dealt with the influence of varying rates of manure nitrogen supply on growth, biomass production, and nitrogen use efficiency of some selected enset clones. The fieldwork was carried out on experimental plot established at Hagereselam district at an altitude of 2800 masl from August 2009 to January 2011. The third experiment investigated manure placement effects on growth, biomass production and distribution, nutrient uptake and use efficiency of enset. The study was carried from August 2010 to September 2011. The fourth and the last experiment dealt with the influence of traditional method and duration of storage on manure chemical composition and quality. The study was conducted on a farmer's field at Hagereselam from December 2011 to February 2012.

2.3.1. Study on mineralization and nitrification of cattle manure

2.3.1.1. Soil sample collection

The soil sample used for the incubation study was collected from Hagereselam district from pre-selected site for the establishment of the field experiments. The site had no cropping and manuring history for the past 10 years. The soil was sampled from surface layer (0 to 15 cm) using an auger from random spots along "W" transects across the field. Soil samples from each location were then mixed to form a composite sample and transported to the laboratory. The composite sample was air-dried and sieved (2-mm mesh) to eliminate coarse rock and plant material and thoroughly mixed to ensure uniformity. Sample was then stored in a dry place at room temperature until incubation to minimize disturbance of the microbial population. From this composite soil sample, a sub-sample was taken for the determination of selected physicochemical parameters. Texture was determined by hydrometer method. Organic carbon was determined using the Walkley-Black rapid titration method. The percent soil organic matter in soil was calculated by multiplying the percent organic carbon by a factor of 1.72, following the standard practice that organic matter is composed of 58% carbon (Brady, 1985). Total nitrogen was analyzed by Kjeldahl method (Yerima, 1992). Available phosphorus in the soil was determined following Bray I method as described in Juo (1978). Soil pH (1:2 soil: water mixtures) was determined by using a pH meter equipped with glass electrode. Bulk density was determined by using a soil corer and measuring the weight of dry soil of a unit volume to a depth of 15-cm. Water holding capacity was determined using perforated can. Soil moisture was determined gravimetrically by drying samples for 48 hrs at 70^0 C. The gravimetric soil moisture content was, then, measured according to the following equation

M= WCWS-WCDS/WCDS-WC x 100 (where M= gravimetric soil moisture content; WCWS = weight of can plus wet soil (g); WCDS= weight of can plus dry soil (g); WC= weight of can)

2.3.1.2. Manure sample collection and analysis

Cattle manure used for the study was obtained from ten randomly selected households at Hagereselam district of the Sidama zone. Fresh manure samples from overnight dropping were collected from each household and at the end of collection, samples were thoroughly mixed and a composite sample of required quantity was brought to Addis Ababa University. In the laboratory, the manure sample was air-dried and ground to pass 2 mm mesh based on Abassi *et al.* (2007). Some selected properties of manure such as total and inorganic nitrogen, organic carbon, pH and phosphorus, were determined following standard procedures. Inorganic nitrogen was determined by steam distillation in filtered samples extracted by using 2M KCl (Keeney and Nelson, 1982). Organic nitrogen was calculated by subtracting inorganic nitrogen from total nitrogen determined. Total nitrogen and organic carbon were determined following the methods described in section 2.3.1.1 above. Phosphorus was determined using colorimetric method following the procedure outlined in Peters *et al.* (2002). Manure pH was determined from 1:2 manure/water mixture using pH meter.

2.3.1.3. Methods of incubation

For estimation of nitrogen mineralization rate in manure samples, the aerobic incubation method of Stanford and Smith (1972) was used. In the study, two treatments (manure treated and control) and eight incubation times replicated three times to examine a total of 48 experimental units at the start of the experiment. About 100 g of air-dried soil sample was placed in a plastic container. To each container, then, quantity of manure to supply 200 mg of organic Nkg^{-1} of soil was added and thoroughly mixed with the soil to trap any volatilized ammonia. The soil without manure was also used as a control. The weight of each container was then recorded and the moisture content of the samples was adjusted to 60% of field capacity and their weight was recorded. The containers were covered with perforated Parafilms to allow oxygen exchange within the container. Each container was then incubated at 25^{0} C. Through out the incubation period, the soil moisture content was maintained at 60 % field capacity regularly by weighing of the container (every 3 days) and adding the required amount of distilled water whenever a loss of weight was observed. During this process, care was taken not to disturb the soil through either stirring or shaking.

2.3.1.4. Analysis of soil-manure mixture

Analysis of soil-manure mixture for total mineral N (TMN), NO_3-N and NH_4-N was carried out at 0, 15, 30, 45, 60, 90, 120 and 150 days after incubation. At each sampling, two sub samples 20 g each were taken from each treatment. The first sub sample was used for the determination of soil moisture content, while the other was extracted using 100 ml of 2M KCl (ratio 1:5) (Keeney and Nelson, 1982). Blank samples were also included. The samples were shaken on a mechanical shaker for 1 hr and the suspension was filtered through Whatman number 42 filter paper.

2.3.1.5. Inorganic nitrogen determination

For the determination of NH_4^+, aliquot from the extract (20 ml) was transferred into a distillation tube and 0.2 g of MgO was added through a dry powder funnel having long stem that reached down the bottom of the tube. The mixture was then distilled, and the distillate was collected in 20 ml of 2% boric acid and titrated against 0.01N H_2SO_4 solution until the color changed from green to pink. For determination of TMN, aliquot from the extract (20 ml) was transferred into distillation tube and 0.2 g MgO and 0.2 g of Deverda's alloy (reducing agent) was added into the distillation tube. It was distilled and the distillate was collected in another flask containing 20 ml of 2% H_3BO_3 containing mixed indicator solution. The distillate was titrated with 0.01 N H_2SO_4 until the color changed from green to pink.

2.3.1.6. Quantification of nitrogen

After titration, the total mineral nitrogen (TMN) and NH_4-N contents of the control and treatment soil samples were calculated using the formula

NH_4-N (mg/Kg) = [a-b/SxV1] x V x N x 0.014 x 10^6

TMN (mg/Kg) = [a-b/S x V1] x V x N x 0.014 x 10^6

Where

a= Volume of H_2SO_4 required for titration of sample (ml)

b= Volume of H_2SO_4 required for titration of the blank (ml)

S=Soil sample weight

V1=Volume of the aliquot distilled (ml);

V= Volume of the extract (ml);

N= Normality of acid used for titration

0.014-miliequivalent weight of N

10^6-conversion factor of the obtained value to mg/kg basis (1kg=10^6mg)

NO_3-N was estimated as the difference between TMN and NH_4-N.

Organic nitrogen in manure mineralized at each sampling time (t) was calculated according to Griffin *et al*. (2005).

1. Norg (mg/kg of soil) = [NO_3 + NH_4]t – (NO_3 + NH_4]0 in manure - [NO_3 + NH_4]t – (NO_3 + NH_4]0 in control soil

2. Net nitrification (mg/Kg soil) = {[NO_3] t-[NO_3]0} manure soil-

{[NO_3]t-[NO_3]0} in control soil

3. The percentage of inorganic N released from an applied N source at time t was calculated as % N released = (N released at time t /N0 applied) x 100

Where, N_0 is the organic nitrogen applied through manure

2.3.2. Effect of rate of manure nitrogen supply on growth, biomass production and nitrogen use efficiency of some selected enset clones

2.3.2.1. Site selection and soil characterization

Following a reconnaissance survey, a site that had not been under cultivation for the last 10 years and representing the major soil type of the study area was chosen. Then, to characterize the soil of the selected site, a composite soil sample was taken from 0-30 cm and 30-60 cm depth from different locations by walking the field in zigzag pattern. Then, about a kg of soil from each sampling depth was taken and then processed and analyzed for determination of soil physical and chemical characteristics. Soil pH was determined in 1:2 soil water mixtures with a standard glass electrode. Soil texture was determined using hydrometer method after dispersing the soils with solutions of sodium carbonate and sodium hexa-metaphosphate. Soil organic carbon was determined according to the Walkley and Black method and total nitrogen was determined following the Kjeldahl procedure. Available phosphorus was determined using Bray I method (Jou, 1978).

2.3.2.2. Manure sampling and analysis

Manure samples (Fresh solid manure) used for the experiment were collected from different households in Hagereselam district and prior to application the entire manure samples were chopped and thoroughly mixed by hand and composite samples were brought to Addis Ababa University for chemical analysis. The manure samples were transported to laboratory and immediately analyzed for the determination of its chemical composition. Total nitrogen was determined using kjeldhal method (fresh wet basis), organic nitrogen was determined using walkley-Black method. Phosphorus was determined using colorimetric method following the procedure outlined in Peters *et al.* (2002). pH was determined from 1:2 manure/ water mixture using pH meter.

2.3.2.3. Selection of enset clones

Two enset clone types, locally called *Ado* and *Ganticha* were selected for the experiment. The two clones were selected based on farmers' preference for their food quality and yield. The suckers were obtained from farmers pre-established plots through purchase. From each clone type, one-year-old suckers of equal size were selected by measuring the pseudostem girth and height. Prior to transplanting all the selected suckers of each clone type were cut at height of 35 cm to remove the leaves (following the traditional practice) to minimize any variation in height that might be created during establishment.

2.3.2.4. Experimental Design and Treatments

The experimental treatment consisted of two enset clones (*Ado* and *Ganticha*) and five manure rates, 0, 150, 300, 450, and 600 kg of total manure nitrogen/ha based on laboratory analysis result. The experiment was arranged in complete randomized block design with four replications. The experimental plots were 6m by 4 m with separation distance of 2 m between adjacent plots and 4 m between blocks. In addition, plots were separated by ditches to prevent cross contamination of manure nutrients between adjacent plots. The quantity of manure required to supply total nitrogen was weighed and uniformly applied to each treatment plot and incorporated to a depth approximately 15 cm within the day of application. The quantity of manure required was calculated using the formula Quantity manure = (Target rate/ Total nitrogen/kg of manure) x $24m^2/10,000m^2$ (Table 2.1)

Following manure application, suckers from selected clone types were transplanted into manured plot with spacing 1.5 m by 2 m. Manual weed control and watering were carried out on regular basis throughout the experiment. The weeds and all plant residues generated were left on the plot throughout the experiment. In the experiment, the phosphorus nutrition was optimized at a rate of 100 kg ha^{-1}/year based on recommended rate for enset by Yohannis Uloro and Mengel, (1996). The phosphorus deficit in the manure was compensated using Triple Super Phosphate (TSP) (Table 2.2). Availability factor 0.5 was used to estimate the amount of phosphorus that would be available from manure for the 1st year following manure application as per recommended for soils very low and to low phosphorus test values (Leikem and Lamond, 2003).

Table2. 1: Total nitrogen and corresponding quantity of manure applied to experimental plot

N level	Total N/ha	Total N/plot ($24m^2$)	Quantity manure/ha	Quantity manure/plot
N0	0	0	0	0
N1	150	120g	32.5 ton	78 kg
N2	300	240g	65 ton	156 kg
N3	450	360g	97.5 ton	234 kg
N4	600	480g	130 ton	312 kg

Table2. 2: Amount of TSP (Triple Super Phosphate) fertilizer added to compensate for phosphorus deficit in the manure (TSP = 20% P)

N level	Total N/ha	Quantity of manure/plot	P-available/year from manure	Deficit (0.24kg/plot area)	TSP added
N0	0	0	0	-0.24 Kg	1.2 Kg
N1	150	78 Kg	0.078 Kg	-0.162 Kg	0.81 Kg
N2	300	156 Kg	0.156 Kg	-0.084 Kg	0.42 Kg
N3	450	234 Kg	0.234 Kg	-0.006 Kg	0.03 Kg
N4	600	312 Kg	0.312 Kg	+0.072 Kg	None

2.3.2.5. Growth and morphological parameters

Four enset plants per treatment/plot were randomly picked and tagged at the beginning of the experiment for monitoring the time course of morphological and growth parameters. Growth and morphological parameters were monitored every month starting from 60 days after transplanting until the end of the experiment (360 days). Plant height, pseudostem girth, the number of green leaves present, and leaf area were recorded every month. Plant height (cm) was measured from the ground to the tip of the lamina of a recently expanded leaf. Pseudostem girth (cm) was measured at the widest point along the lower length of the pseudostem. The green leaf number were counted and the leaf area was assessed by measuring the length and width of individual leaves and calculating the area using the formula developed by Turner (1972) for the banana plant, which has a very similar morphology.

$$LA = (0.83 \times l \times w)/Pn$$

Where, l = length of lamina in meters, w = maximum width of lamina in m and *Pn* = number of leaves per individual plant, and 0.83 is the shape factor.

Leaf area index (LAI, m^2/m^2) was calculated for the same plants and for the same period by dividing the total area of each plant (LA) by the ground area occupied by each plant ($3m^2$) using the formula.

$$LAI = Pn \times LA/Ag$$

Where, Ag is ($3m^2$) the ground area (the ground area occupied by each plant) computed from the spacing (1.5m x 2m) between individual plants.

2.3.2.6. Photosynthesis

Photosynthetic measurement was taken from recently expanded leaves using an open system Li-Cor 6400 portable photosynthetic system (Li-COR Biosciences, Lincoln, Nebraska, USA) under ambient light and CO_2 levels.

2.3.2.7. Determination of leaf chlorophyll

The leaf chlorophyll content was determined by the SPAD-502 portable chlorophyll meter (Minolta Co. Tokyo, Japan). The measurements were taken from recently expanded leaves. Six readings from different spots (two from base, two from middle, and two from tip) of each leaf were recorded in 12 randomly selected plants of each treatment. SPAD readings were carried out in the morning between 8:00 and 11:00 am.

2.3.2.8. Plant Biomass Estimation

At the end of the experiment, four plants per treatment from each clone type were harvested for total biomass determination. Samples were sorted into leaves, pseudostem, corm and roots. Total fresh weight of each plant part was determined with a portable balance in the field. Then, individual parts were chopped into pieces and mixed thoroughly and sub sampled using quartering method. The sub sample fresh weight was recorded. In the laboratory, sub samples of each plant part were oven dried at 70^0 C until constant weight, and the total dry weight of the plant was determined from dry weight of sample plants using the formula.

TDW= TFW x SDW/SFW (GNMAS, 2008)

Where, TDW= Total dry weight, TFW=Total fresh weight, SDW= Sub sample dry weight, SFW= Sub sample fresh weight.

The biomass yield/plant converted to kg ha^{-1} basis as follows

Biomass yield/plant x number of plants/plot area x 10,000 m^2 (Brandit *et al*., 1997).

2.3.2.9. Determination of Harvest Index (HI)

A combined pseudostem and corm dry matter yield as a fraction of total plant dry weight was used to estimate harvest index (HI) (based on Admasu Tsegaye and Struick, 2003).

2.3.2.10. Determination of total nitrogen

Representative plant parts from each treatment were oven dried at 70^0C for 48 hours. Subsequently, the samples were ground to pass a 0.5 mm sieve and stored in vials until analysis. For the determination of total nitrogen, 0.3 g of sample was weighed in sensitive balance and the digestion was initiated by transferring the weighed plant sample in to the digestion tube and adding 7 ml of concentrated sulfuric acid, 2 g of salt mixture (made of a mixture of 30 g K_2SO_4, 3 g of $CuSO_4$ and 0.3 g of selenium powder) and 3 ml of H_2O_2 as outlined in Yerima (1992). Similarly, the blank digest (without plant sample) was passed through all the steps like that of the samples to compensate for any contribution from the reagents used. Then, the tubes were placed in the heating digestion block and digested for about 2 hours. Then the samples digested were distilled with 40 % sodium hydroxide and received in 20 ml of 2 % boric acid containing bromocresol green-methyl red mixed indicator solution and titrated against 0.1 N H_2SO_4 until the green color of the distillate changed to pink. Then, the percent (%) of nitrogen present in the plant samples was calculated as follows:

$$\%N = \frac{(T-B) \times N \times 0.014 \times 100}{\text{Weight of sample in gram}}$$

Where, T- Titration volume of the sample
B- Titration volume from the blank
N- Normality of the acid

2.3.2.11. Determination of nitrogen uptake

The nitrogen uptake by aboveground biomass (pseudostem and leaves) and belowground biomass (corm and root) for all treatments was determined by multiplying biomass yield (kg/ha) of each plant part by respective tissue nitrogen concentration (GNMAS, 2008)

$$\text{Nitrogen uptake (kg/ha)} = \frac{\text{Biomass yield (kg/ha)} \times \text{\% Total nitrogen}}{100}$$

2.3.2.12. Measurement of manure nitrogen use efficiency

a) Agronomic nitrogen use Efficiency (ANE) (kg yield increase per kg N applied) is the amount of biomass yield produced per kg of applied nutrient (N) (GNMAS, 2008).

$$AE_N = \frac{Y_N - Y_0}{F_N}$$

b) Nitrogen uptake efficiency (ARE_N) (kg increase in N uptake per kg N applied) is the total amount of nitrogen absorbed per kg of nitrogen applied. This is eco-physiological parameter, also referred to as recovery efficiency

$$ARE_N = \frac{U_N - U_0}{F_N}$$

c) Plant nitrogen use efficiency

This is the total dry matter produced per unit of nitrogen absorbed. This is physiological parameter, also called physiological efficiency (PEN), is defined.

$$PEN\ (\text{kg yield/kg N}) = \frac{Y_N - Y_0}{U_N - U_0}$$

Where, F_N = Total manure N applied (kg/ha)

Y_N = Biomass yield with applied N (kg/ha)

Y_0 = Biomass yield in control plot (kg/ha)

U_N = Total plant N uptake (kg/ha) in a plot that received manure N

U_0 = Total plant N uptake (kg/ha) in control plot

2.3.2.13. Soil analysis at harvest

Soil samples were taken from 4-5 spots of each treatment plot at the time of harvest at depth increments of 0-30 cm, 30-60 cm, and 60-90 cm, for the determination of the concentration of inorganic nitrogen. The soil samples were transported to the laboratory in icebox and stored in deep freezer until laboratory analysis was initiated. The concentration of total mineral nitrogen (TMN) and NH_4-N were determined in samples extracted with 200 ml of 2M potassium chloride (KCl) solution. The extraction was done by shaking 40 g of soil sample for 1 hr with 200 ml of 2 M KCl followed by filtration through Whatman number 42 filter paper. At the same time, an exactly equal amount of soil (40 g) oven dried at 70^0 C for 48 hrs to determine its moisture content. The mineral nitrogen contents of the extracts were determined using the steam distillation and titration method of Keeney and Nelson (1982). Aliquots (40 ml) of the extract were added via pipette into a distillation flask, and steam distillation was carried out after adding 0.2 g magnesium oxide (MgO) and 0.2g Deverda's alloy in the case of total mineral nitrogen and by adding only 0.2 g MgO in the case of NH_4-N. The distillate was then collected in 20 ml of boric acid containing bromocresol green/methyl red indicators and titrated against 0.01 N H_2SO_4. After titration, the total mineral nitrogen (TMN) and NH_4-N contents of the soil samples were calculated by the formula:

NH4-N (mg/Kg) = [a-b/SxV1] x V x N x 0.014 x 10^6

TMN (mg/Kg) = [a-b/S x V1] x V x N x 0.014 x 10^6

Where

a= Volume of H_2SO_4 required for titration of sample (ml)

b= Volume of H_2SO_4 required for titration of the blank (ml)

S=Soil sample weight

V1=Volume of the aliquot distilled (ml);

V= Volume of the extract (ml);

N= Normality of acid used for titration

0.014-miliequivalent weight of N

10^6-conversion factor of the obtained value to mg/kg basis (1kg=10^6 mg)

Nitrate nitrogen (NO_3-N) was calculated by subtracting NH_4-N from total mineral N. Any NO_2 present would have been included in the NO_3-N fraction.

Soil mineral N was converted from mg N/kg soil to KgN/ha using the following formula Adopted from Omokenye *et al*. (2011).

Kg N/ha = mg N/kg soil X bulk density X number of 10 cm segments in a 0-30, 30-60 and 60-90 cm soil profiles

The bulk density for each sampling depth was determined using soil core method. A cylindrical sampler (can) having 10 cm diameter and 10 cm height was used. A volume of soil taken by driving the can into the soil was oven dried and weighed. The volume of the soil was then calculated from the volume of the sampler (can) that was determined using the formula $V = p \times r^2 \times h$ (p=3.14, r = radius of the can, h=height of the can)

$$\text{Bulk density} = \frac{\text{weight of dry soil}}{\text{Volume of soil}}$$

2.3.3. Manure placement effects on growth, biomass production and nitrogen uptake

2.3.3.1. Experimental layout

In this experiment, three manure placement methods were investigated using soil filled in large polythene bags **(**height: 90 cm, diameter: 60 cm). The first method consisted of top-dressing whereby all the manure applied at the top of the soil (Treatment 1). The second treatment consist of below soil surface-dressing whereby the manure was placed at 20 cm below soil surface of the pot and covered with the soil substrate (Treatment 2). The third method consists of half top-dressing and half at 20 cm below soil surface (Treatment 3). The fourth treatment consists of a control with no manure added to the substrate (Treatment 4) (Fig 2.3).

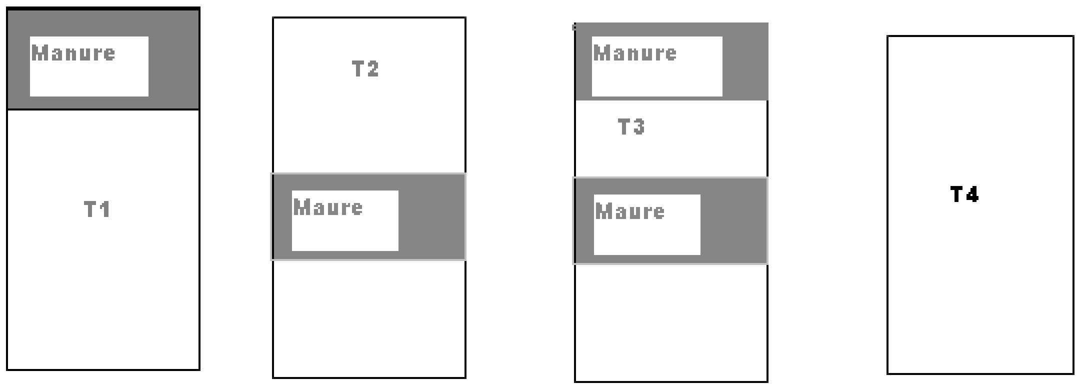


Figure 2. 3: Schematic illustration of manure placement methods

2.3.3.2. Planting material

Treatment effects were assessed on using one clone of enset locally called *Ganticha*. Accordingly, one-year-old equal sized suckers were purchased from farmers and transplanted on pre-prepared polythene bags filled with approximately 80 kg of air dried top soil (0-20 cm depth). To each treatment, 6 kg of manure (estimated to provide 24 g total nitrogen) was applied per pot following the manure placement methods designated above (Fig 2.3). Some of the selected characteristics of soil and manure samples used for the experiment are presented in Appendix 1 and 2. The experimental layout was a completely randomized block design, with eight replications per treatment. Watering was provided twice per week and weeds removed regularly by hand throughout the duration of the experiment. The polythene bags were perforated at the base to allow free drainage of water.

2.3.3.3. Data collection

2.3.3.3.1 Growth parameters

Green leaf number, pseudostem girth, and leaf area development were monitored periodically over a period of 1 year starting from 60 days after transplanting.

Measurement was taken at two-month intervals. Pseudostem girth was measured at the widest point along the lower length of the pseudostem. Total leaf area (in cm^2) was assessed by measuring the leaf length (from the base of the petiole to the tip of the lamina) and the width (the maximum width) of the lamina. Then, the leaf area was estimated for each plant using the empirical relationship developed for banana (Turner, 1972).

LA = (0.83 x l x w)/Pn

Where, l is the length of the lamina, w the maximum lamina width, Pn is the number of leaves per individual plant, and 0.83 is the shape factor.

2.3.3.3.2. Biomass determination

For biomass determination, plants from each treatment were uprooted and sectioned into roots, corm, pseudostem and leaves. Substrate attached to the corm and roots of sampling plants was carefully washed off using tap water. Thereafter, roots were carefully removed from the corm. The total fresh weight and sub sample fresh weight was determined using portable balance in the field. The, sub samples were brought to laboratory (at AAU) and dried at 70^{0} C until constant weight and the total dry weight of each plant part was determined from dry weight of sample plants using the formula described in section 2.3.2.8 above. The total nitrogen content of each plant part was assayed using macro kjeldahl procedure described in section 2.3.2.10.

2.3.3.3.3. Determination of nitrogen uptake efficiency

Whole plant nitrogen uptake for each clone was determined by multiplying dry matter yields by respective tissue nitrogen concentration as described in section 2.3.2.11.

Nitrogen uptake efficiency was determined using the formula described in section 2.3.2.12 above.

2.3.4. Effect of method and duration of storage on manure composition and quality

2.3.4.1. Manure collection

The manure used for the study was obtained from ten households. From each household fresh cattle manure (solid) free of plant material such as feed refusal was collected directly from the barn. Samples were taken in the morning and all the manures collected each day were stored under a shade in covered pile resting on a plastic sheet. At the end of sample collection, the entire manure samples collected were chopped and mixed thoroughly to homogenize differences in quality that could have been caused by different residence times in the collection time.

2.3.4.2. Experimental design and treatment

The experiment consisted of two storage methods with three replications. The storage treatments include i) manure kept in heap in open air (uncovered) and ii) manure kept in heap covered with plastic sheet. Manure kept in heap without cover was a reproduction of traditional practice and manure kept covered with a plastic sheet was introduced to test as alternative storage conditions. Manure sample for the covered storage treatment was both lined and tightly covered with polythene sheet. While that of uncovered treatment was left open following the traditional practices. The experiment was conducted for three months.

2.3.4.3. Sampling and laboratory analysis

2.3.4.3.1 Initial sampling

For determination initial chemical composition of manure, six manure samples of approximately 500 g each were taken from the initial collection pile at the end of collection. Samples were taken, two close to the upper surface of the pile, two from the center, and two from the bottom. These samples were quickly but thoroughly mixed on a plastic sheet and three sub-samples of 300 g were packed in polythene bags and transported to laboratory for analysis. In the laboratory, samples were placed deep frozen until analysis.

2.3.4.3.2. Regular sampling

Samples were taken from the stored manure every month throughout the experiment from different positions of the pile. These samples were mixed to generate a composite sample of each experimental treatment. In the laboratory, the samples were analyzed for % dry matter (% moisture), total nitrogen, carbon, pH and TMN. Total nitrogen, organic carbon, pH and TMN were determined following the procedures described for manure analysis in section 2.3.1.2. Dry matter content was determined using gravimetric methods after drying 20 g manure sample at 70^{0} C for 24 hours.

$$\% \text{ Dry matter} = \frac{(\text{Weight dry sample + container})-(\text{weight empty container})}{(\text{Weight un dried sample + container})-(\text{weight empty container})}$$

% Moisture = 100-% dry matter

2.4. Statistical analysis

Data were subjected to one way or two-way analysis of variance to find out treatment effects and/or interactions between factors. One way and two-way analysis of variance were carried out using MINITAB statistical package version 14. Three-way analysis of variance was carried out using SIGMA version 11. Turkey's Family Error Rate was used to find significant differences among treatments for all data sets. Throughout the text differences between treatment means is considered significant when $P \leq 0.05$.

3. RESULTS

3.1. Mineralization and nitrification of manure nitrogen

3.1.1. Characteristics of soil and manure samples of the study

Laboratory analytical results of selected physicochemical properties of the soil and manure on which this incubation study was conducted are presented in Table 3.1 and 3.2, respectively. The soil used in this study can be characterized as sandy loam, acidic, with medium to high water holding capacity. It had total nitrogen, 0.36 %, organic carbon, 4.6% and C:N ratio of 13:1. On the other hand, the manure used in the study had total nitrogen of 1.89 % (dry weight basis) and a C:N ratio of 18:1. Of the total manure nitrogen, about 82% was found in organic form and the rest was in inorganic form (mainly ammonium).

Table3. 1: Some physical and chemical characteristics of soil used in the incubation study

Texture (%)			pH	Bulk density (g cm^{-3})	Total N (%)	Ava. P (ppm)	Organic carbon (%)	Organic matter (%)	C / N	Water holding capacity (%)
Sand	Clay	Silt								
66	18	16	4.8	1.35	0.36	7	4.6	7.6	13 : 1	45

Table3. 2: Selected chemical properties of manure used in the incubation study

pH (H_2O)	Total N (g kg^{-1} DM)	Inorganic N (g kg^{-1} DM)	Organic N (g kg^{-1} DM)	Organic carbon (%)	Total P (%)	C / N
8.6	18.9	3.4	15.5	34	0.6	18:1

3.1.2. Mineralization of organic nitrogen in manure

The changes in total mineral nitrogen in soil with and without added manures during different incubation periods were used to estimate the mineralization of manure/soil. A change in different fraction of inorganic nitrogen (i.e., total mineral nitrogen, NH_4-N and

NO_3-N) in manure treated and control soil during 150 days of incubation is presented in Table 3.4. During 150 days of incubation, the concentration of inorganic nitrogen in both manure amended and control soil increased to the concentration recorded at the start of the experiment at day 0. In the study, the control soil released a maximum of 70 mg total mineral nitrogen per kg of soil and showed about 54% increase over the concentration recorded at the start of the experiment. On the other hand, manure amended soil released a maximum of 101.5 mg total mineral nitrogen per kg of soil, showing about 81% increase over the concentration recorded at the start of the experiment.

Table 3.3 shows Two-way ANOVA results of the effects of manure treatment, incubation timing, and their interaction on total mineral nitrogen. The statistical analysis showed that there was a significant difference between treatments ($P \leq 0.001$), timings ($P \leq 0.001$), and their interaction ($P \leq 0.001$). The overall changes in total mineral nitrogen, NH_4-N, and NO_3-N (mean of 8 samplings over 150 days) in soil with and without manure is presented in Fig. 3.1. The mean total mineral nitrogen released from soil with manure amendment during 150 days of incubation was 81.6 $\pm$ 4.9 mg kg^{-1} soil, which was significantly ($P \leq 0.001$) higher than that released from control soil (61.2 $\pm$ 2.7 mg kg^{-1} soil). The percentage increase of mineralization of soils with organic manure to the control soil was 33.3 %.

Table3. 3: Two-way ANOVA results of mineralization of organic nitrogen in soil with and without manure amendment

Main effects	df	MS	F	P
Manure (M)	1	4985.76	543.25	0.000
Timing (T)	7	668.84	72.877	0.000
Interaction	7	75.92	8.27	0.000
Error	32	9.18		
Total	47			

Table3. 4: Total mineral nitrogen, NH_4-N, NO_3-N (mg kg^{-1} soil) mineralized in soil with and without manure amendment during 150 days of incubation.

		Days of incubation							
Treatment		0	15	30	45	60	90	120	150
Control	TMN	45.5[a]	58.0[b]	65.0[c]	60.6[b]	66.5[c]	70.0[d]	64.6[c]	59.5[b]
	NH_4-N	36.6[a]	44.0[c]	47.3[d]	46.6[d]	45.5[d]	52.3[c]	45.6[c]	42.0[b]
	NO_3-N	8.8[a]	14.0[b]	17.6[c]	14.0[b]	21.0[c]	17.6[c]	19.0[c]	17.5[c]
Manured	TMN	56.0[a]	73.5[b]	80.5[c]	85.0[d]	93.3[e]	101.5[f]	87.8[d]	75.3[b]
	NH_4-N	44.0[b]	52.5[c]	56.0[d]	42.0[a]	46.3[b]	42.0[a]	44.6[b]	45.8[b]
	NO_3-N	12.0[a]	21.0[b]	24.5[c]	43.0[c]	47.0[c]	59.5[f]	43.1[c]	29.5[d]

Values in rows followed by same letter do not differ significantly

The concentration of NH_4-N was 46.7 $\pm$ 1.8 mg/kg in manure treated soil and 45 $\pm$ 1.6 mg kg^{-1} soil in control soil. The amount of NH_4-N produced was also significantly ($P \leq 0.05$) higher in the soil containing manure compared to that of unamended soil. On the other hand, manure treated soil has accumulated 35 $\pm$ 5.6 mg NO_3-N Kg^{-1} soil, which was also significantly higher ($P \leq 0.001$) than the value obtained in control soil (16.2 ± 1.4 mg/kg soil). Generally, soil amended with manure accumulated significantly ($P \leq 0.001$) more NO_3-N than the soil without manure.

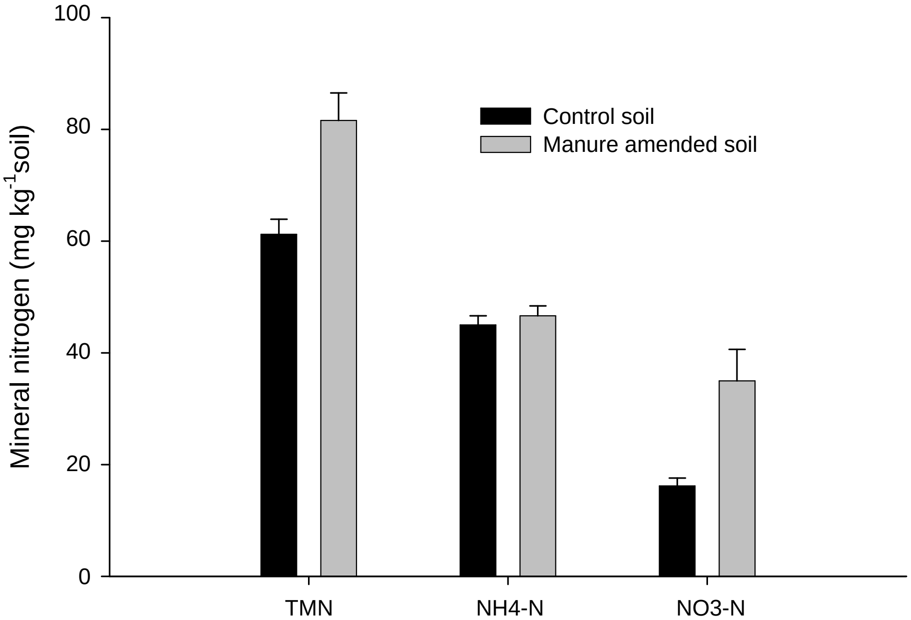


Figure 3.1: Mean total mineral nitrogen (TMN), NH_4-N and NO_3-N mineralized in soil incubated at 25 ^{0}C during 150 days of incubation under controlled condition

The effects of different incubation timing on mineralization was determined by taking average values of total inorganic nitrogen released in soil with and without manure amendment at each incubation time (Fig 3.2). The results revealed that release of mineral nitrogen increased over time. The pattern of mineralization was such that rapid increase in mineral nitrogen was noticed during the initial phase followed by slow linear phase and the maximum mineralization was noticed at day 90 and then declined during the latter periods of incubation.

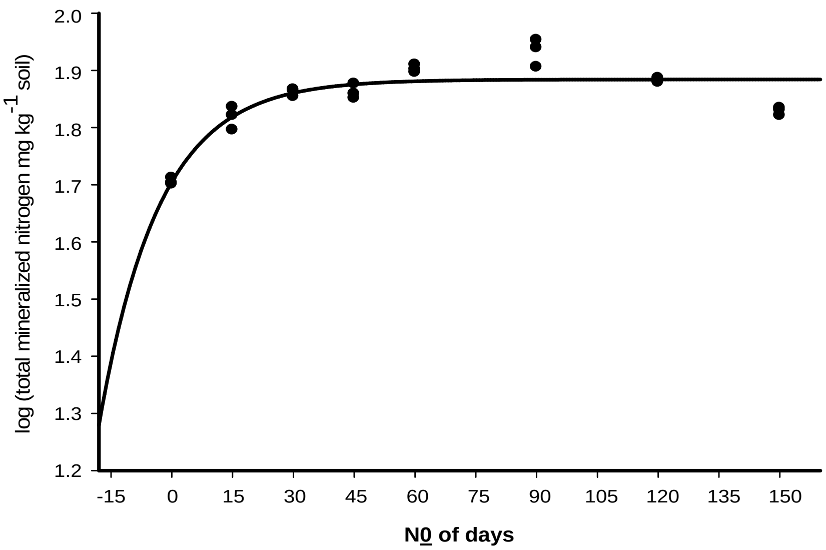


Figure3. 2: Patterns of nitrogen release in soils with and without manure amendment (mean)

3.1.2. Net rates of mineralization of manure organic nitrogen

The net rates of mineralization was calculated according to Griffin *et al.* (2005) by subtracting the initial mineral nitrogen in manure amended and control soil together with mineral nitrogen released from control soil at specific time t. The manure in the present study showed net mineralization of organic nitrogen throughout the incubation period (Fig.3.3). The highest net mineralization value 21 mg N kg^{-1} soil was recorded at day 90. Based on this maximum value, the net nitrogen released as percent of organic nitrogen added found to be 10.5 %. The net rates of mineralization from the mineral nitrogen released from manure ranged from 0.04 to 0.33 mg N/kg soil/day with the mean value of 0.21 mg/kg soil/day. The net rates of mineralization were highest during the initial days of incubation and declines with time.

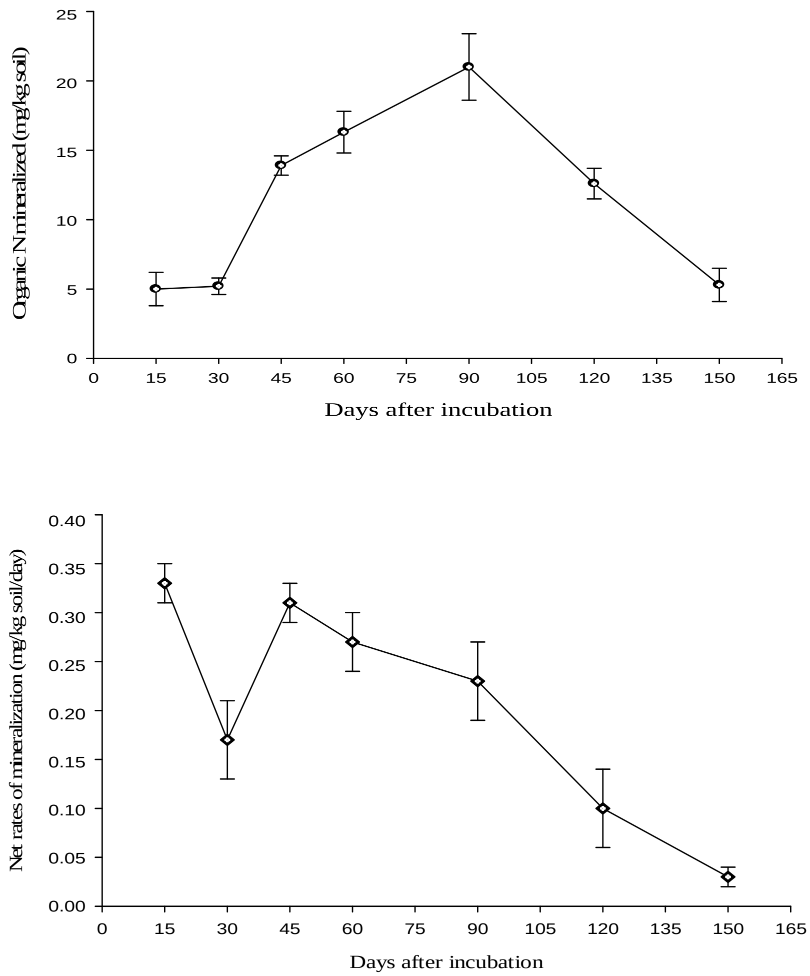


Figure3. 3: Organic N mineralized and net rates of mineralization of manure during 150 days of incubation under controlled laboratory conditions

3.1.3. Nitrification of soil and manure nitrogen

Table 3.5 indicates Two-way ANOVA for nitrification of soils with and without manure amendment at eight incubation timings. The results showed significant difference among treatments ($P \leq 0.001$), timings ($P \leq 0.001$) and their interaction ($P < 0.001$). During 150 days of incubation, soil with manure amendment was able to accumulate total mean NO_3-N, 35 mg N kg^{-1} soil, whereas, soil without manure amendment was able to accumulate an average value of 16.2 mg NO_3-N kg^{-1}soil. Concentration of NO_3-N accumulated in manure-amended soil was more than double to that of control soil. The proportion of NO_3-N to total N indicated that a total of 43% from soil with manure amendment and a total of 26.5% from soil without manure amendment were converted to NO_3-N.

The effect of timing on nitrification was determined by taking an average value of NO_3-N released from control and manure treated soil (Table 3.6). Nitrate accumulation showed significant response to time. The highest NO_3-N concentration 38.58 mg kg^{-1} soil was recorded at day 90. Generally, soil amended with manure accumulated significantly higher NO_3-N than the control soil. The pattern of changes in NO_3-N is such that it increased progressively over time with the highest value attained at day 90 and thereafter decreased towards the latter periods of incubation. Cumulative net nitrification and net nitrification rate of manure is shown in Fig 3.4. The maximum net nitrification was 38.7 mg kg^{-1} of soil recorded at day 90. Net nitrification rate varied between 0.058-0.57 with mean rate value of 0.28 mg kg^{-1} soil day^{-1}.

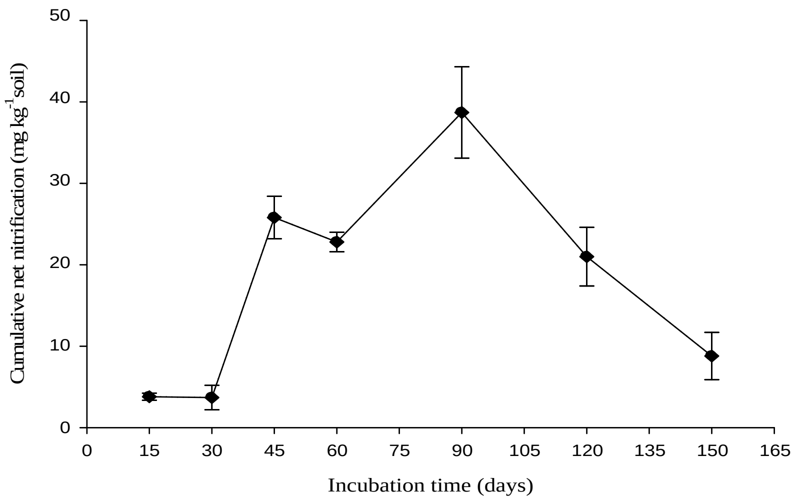
Table3. 5:Two-way ANOVA for nitrification of soils with and without manure treatment, at eight-incubation timings and their interaction.

Source	df	MS	F	P
Manure	1	4213.127	378.79	0.000
Timing	7	513.191	46.14	0.000
Interaction	7	275.975	24.812	0.000
Error	32	11.123		
Total	47			

Table3. 6: Timing effects on NO_3-N release

Parameter	NO_3-N (mg/ kg soil)
0	10.41[a]
15	17.50[b]
30	21.08[b]
45	28.50[c]
60	34.01[d]
90	38.58[e]
120	31.06[cd]
150	23.48[b]
LSD($P \leq 0.05$)	1.88

Means followed by the same letter (s) do not differ significantly ($P \leq 0.05$)



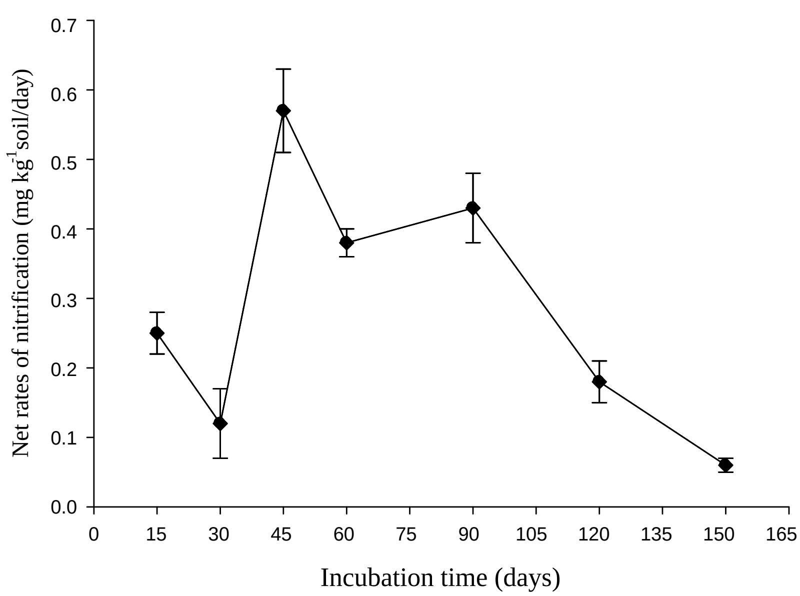


Figure 3. 4: Cumulative net nitrification and net nitrification rates of soil amended with 200 mg N/kg soil during 150 days of aerobic incubation under controlled laboratory conditions.

3.2. Effects of rates of manure nitrogen supply on the growth, biomass production, and nitrogen use efficiency of some selected enset clones

3.2.1. Soil chemical and physical properties

A laboratory analytical result of selected physicochemical properties of the soil in the experimental plot is presented in Table 3.7. The soil had the following physical and chemical properties in the upper 0-30 cm depth. It had sandy loam texture with textural analysis values 600g/kg soil sand, 200g/kg clay and 200g/kg silt. The pH was 4.8 (1:2 soil-water ratios), total nitrogen 0.38 %, organic matter 6.2 % and available phosphorus 7.9 ppm.

3.2.2. Chemical composition of manure

The chemical composition of the manure used in the field experiment is shown in Table 3.8. The manure had the following physical and chemical properties. The pH of the manure extract was alkaline with pH value 8.6. Total nitrogen in the manure was 4.6 g/kg of manure (wet-weight basis) with corresponding C: N ratio of 16:1.

Table3. 7: Some of the physical and chemical characteristics of soils of the experimental site

Depth (cm)	Sand	Clay	Silt	% C	%OM	%N	Avail. P	pH
0-30 cm	60	20	20	3.5	6.02	0.38	7.9	4.8
30-60 cm	56	27	17	3.3	5.7	0.35	6.9	4.5

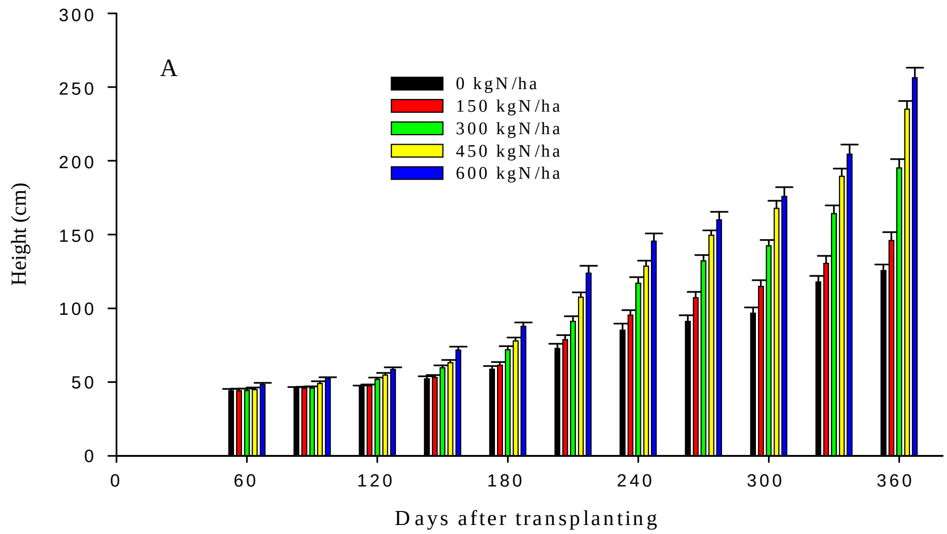
Table3. 8: Some characteristics of manure sample used for the experiment (Total N and P are based on wet-wet bases)

Parameter	Total N %	Org. C %	C : N	Total P %	pH	% solids
Value	0.46	22.8	16	0.2	8.6	33

3.2.3. Growth and physiological parameters

3.2.3.1. Plant height (cm)

The time course of plant height from transplanting until 360 days of the two clones of enset, *Ado* and *Ganticha*, grown under varying levels of nitrogen supply is shown in Fig 3.6 A and B. Two-way ANOVA results showed that plant height was significantly affected by levels of nitrogen supply (Table 3.9). In the study, all levels of nitrogen treatment increased plant height significantly over the control (Table 3.10). However, there was no significant variation between nitrogen supply 450 and 600 kg N ha^{-1}. Averaged across clones, plants treated with 150, 300, 450 and 600 kg N ha^{-1} had mean values of height, which were 12.2, 26.5, 57.5, and 68.9, respectively higher than the control plants. Of the two clones studied, clone *Ado* had mean height 191.6 cm and clone *Ganticha* had 189.5 cm. However, the difference between clones was not statistically significant. There was significant interaction between enset clones and nitrogen supply. The tallest *Ado* and *Ganticha* plants were obtained at nitrogen level (600 kg N ha^{-1}). The shortest plants obtained for both clones in control plots



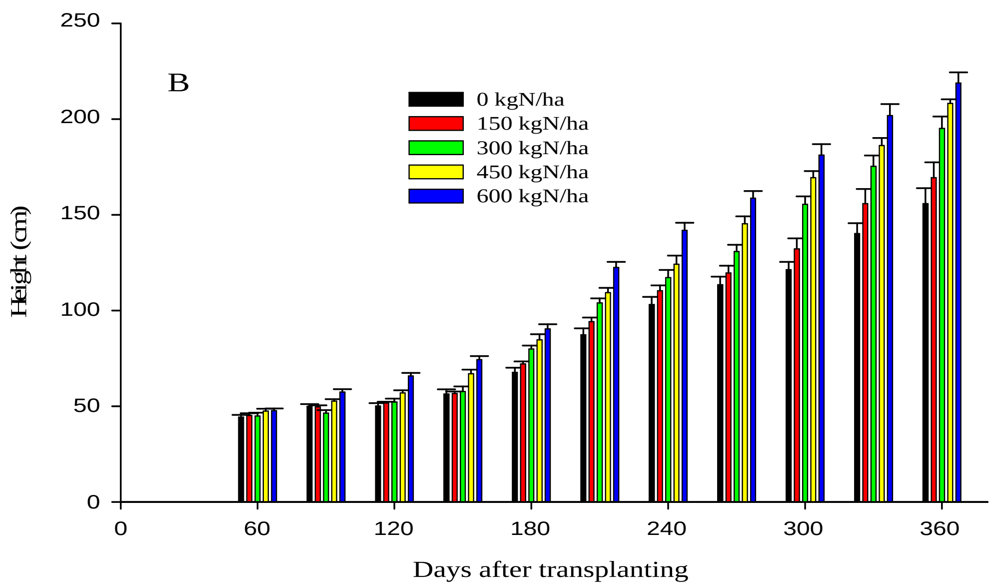


Figure 3.5: Time course of plant height (cm) in two enset clones Ado (A) and Ganticha (B) from 60 days after transplanting until 360 days grown under varying levels of nitrogen supply. Bars are means + SE, n=16

Table3. 9: Two-way ANOVA results of plant height of enset clones as influenced by varying concentration of manure nitrogen supply

Source	df	MS	F	P
Clone	1	180.6	0.31	0.581
Nitrogen supply	4	54096.8	91.63	0.000
Interaction	4	7140.6	12.10	0.000
Error	150	590		
Total	159			

Table3. 10: Plant height (cm) at harvest in two clones of enset grown under varying levels of nitrogen supply

Nitrogen supply (Kg/ha)	Clone *Ado*	Clone *Ganticha*	Mean
0	125.5(4.1)a	155.9(8.1)a	140.7a
150	146.1(5.7)b	169.4(8.0)ab	157.8b
300	195.2(5.9)c	195.1(6.3)b	195.1c
450	235.1(5.6)d	208.2(2.1)c	221.6d
600	256.3(6.8)d	218.8(5.6)c	237.6d

Values sharing the same letter in a column do not differ significantly at $P \leq 0.05$

3.2.1.2. Pseudostem girth (cm)

The Two-way analysis of variance results indicated that the pseudostem girth was significantly ($p \leq 0.05$) influenced by level of nitrogen supply (Table 3.11). The difference between clones and clone by nitrogen rate interaction was also significant ($P \leq 0.05$). Time course in pseudostem girth in two clones of enset, *Ado* and *Ganticha*, starting from 60 days after transplanting until 360 days presented in Fig 3.6 A & B. The pseudostem girth of both clones under all nitrogen levels increased progressively throughout the study period. At the end of the study, the highest pseudostem girth measurement (134.9 cm for *Ado* and 118.5 cm for *Ganticha*) was obtained at 600 kg N ha^{-1} supply, which is 72.1 and 38.3%, respectively higher compared to the control (Table 3.12). There was also statistically significant variation between clones and clone by nitrogen rate interaction on pseudostem girth. Averaged over nitrogen rates, *Ado* had mean pseudostem girth (110.4 cm), which was significantly higher than that of *Ganticha* (104.2 cm). The variation in pseudostem girth at each level of nitrogen supply was also significant up to nitrogen supply 450 kg N ha^{-1} in clone *Ado* and nitrogen supply up to 300 kg N ha^{-1} in clone Gantciha.

Table3. 11:Two-way ANOVA results of pseudostem girth of enset clones as influenced by varying levels of manure nitrogen supply

Source	df	MS	F	P
Clone	1	1581.3	10.49	0.001
Nitrogen rate	4	10955.4	72.65	0.000
Interaction	4	681.3	4.52	0.002
Error	150	150.8		
Total	159			

Table3. 12: Pseudostem girth (cm) at harvest in two clones of enset grown under varying levels of manure nitrogen supply.

Nitrogen supply (Kg/ha)	Clone *Ado*	Clone *Ganticha*	Mean
0	78.4 (3.2)a	85.7 (4.3)a	82.1a
150	97.5 (2.7)b	92.4(2.0)b	94.9b
300	114.1 (4.8)c	110.1(1.6)c	112.1c
450	127.3(2.5)d	114.1(1.2)c	120.7d
600	134.9 (2.1)d	118.5(2.1)c	126.7d

Values with the same letter in a column do not differ significantly at $P \leq 0.05$

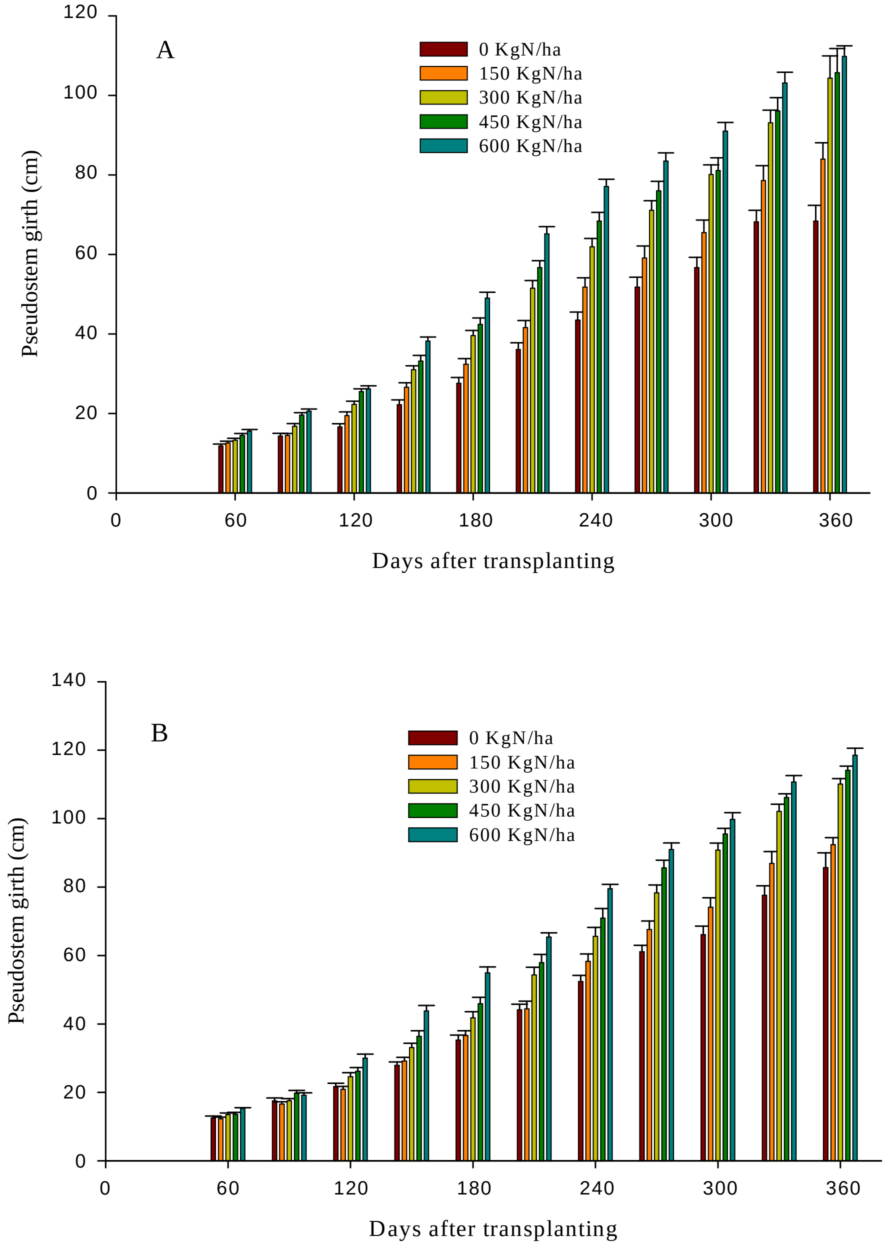


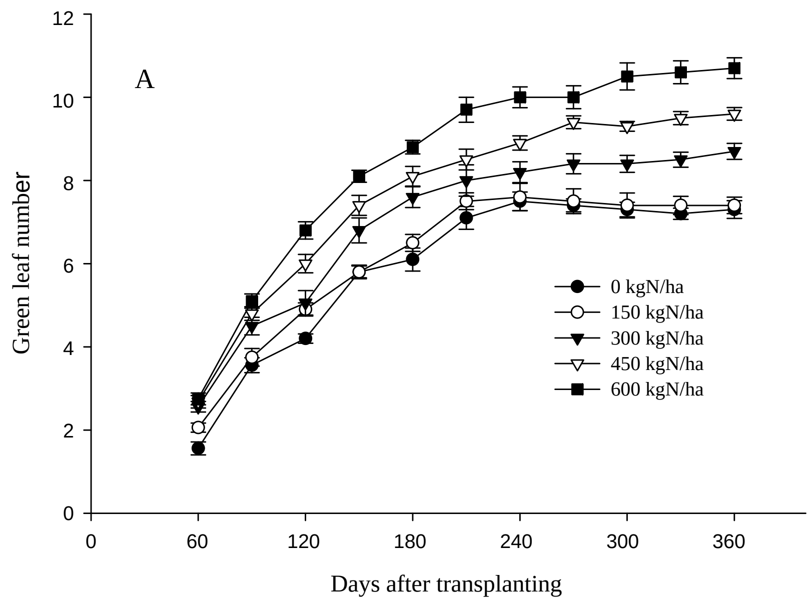
Figure 3.6: Time course of pseudostem girth (cm) in two enset clones Ado (A) and Ganticha (B) from 60 days after transplanting until 360 days as influenced by varying levels of nitrogen supply. Bars are means + SE, n=16

3.2.1.3. Number of green leaves

The number of green leaves maintained at any given time significantly increased with increasing levels of nitrogen supply (Table 3.13). The average number of green leaves that was attained in plants grown under highest nitrogen supply (600 kg ha^{-1}) was higher by about 36.5 % than in control plants. The difference between the clones was also statistically significant. At the end of the experiment, the enset clone *Ado* maintained the highest number of green leaves than *Ganticha*. There was also significant interaction between clones and nitrogen supply. In both clones, the number of green leaves increased with increasing levels of nitrogen supply. The mean green leaf number recorded at the end of the experiment was 7.3 $\pm$ 0.21(0 kg N ha^{-1}) and 10.8 $\pm$ 0.25 (600 kg N ha^{-1}) in clone *Ado* and 7.6 $\pm$ 0.3 (0 kg N ha^{-1}) and 9.5 $\pm$ 0.18 (600 kg N ha^{-1}) in clone *Ganticha* (Fig 3.7 A and B).

Table3. 13:Two-way ANOVA results of green leaf number of enset clones as influenced by varying concentration of manure nitrogen supply

Source	df	MS	F	P
Clone	1	6.806	9.060	0.003
Nitrogen rate	4	36.994	49.243	0.000
Interaction	4	6.556	8.727	0.000
Error	150	0.751		
Total	159			



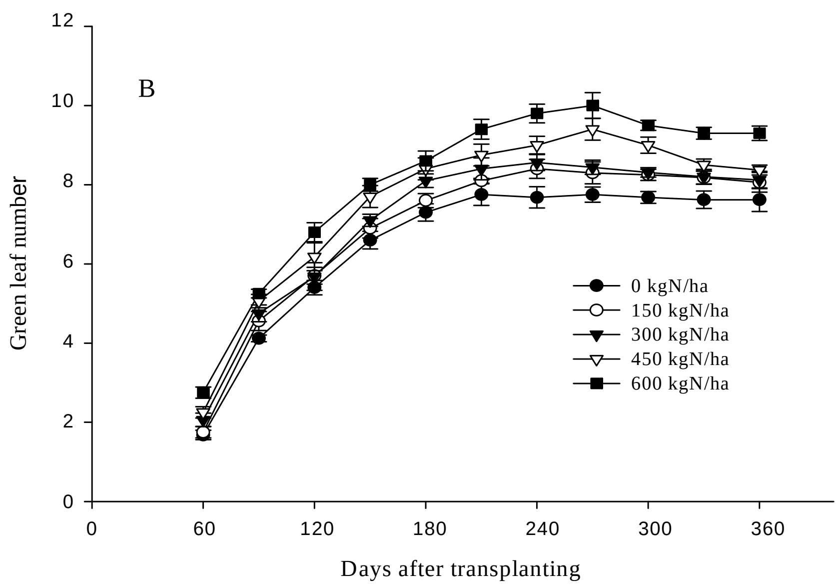


Figure 3.7: The time course of green leaf number in two enset clones, Ado (A) and Ganticha (B) from 60 days after transplanting until 360 days grown under varying levels of manure

3.2.1.4. Total green leaf area

The total leaf area attained by the *enset* clones, *Ado* and *Ganticha*, grown under varying levels of nitrogen supply presented in Fig 3.9. The results showed that nitrogen treatment had significant ($P \leq 0.05$) effect on total leaf area of both clones (Table 3.14). The total leaf area of the plants significantly increased with increasing rates of nitrogen supply. The highest total leaf area (9.2 m^2 for clone *Ado* and 7.11 m^2 for clone *Ganticha*) was recorded at rate of 600 kg ha^{-1} nitrogen supply, while the lowest total leaf area was recorded in control plants (Fig 3.8). The total leaf area showed significant increment at each level of nitrogen supply for both clones. Of the two clones, *Ado* showed the highest total leaf area growth response compared to the enset clone *Ganticha*.

Table3. 14:Two-way ANOVA results of total leaf area of enset clones as influenced by varying concentration of manure nitrogen supply

Source	df	MS	F	P
Clone	1	8.837	4.188	0.042
Nitrogen rate	4	110.498	52.372	0.000
Interaction	4	9.936	4.709	0.000
Error	150	2.110		
Total	159			

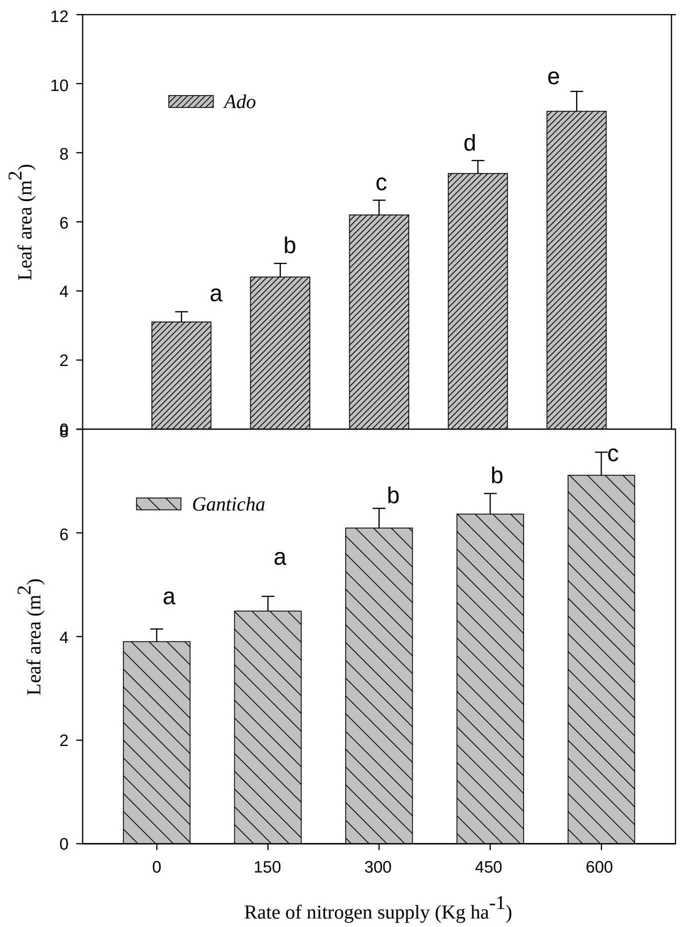


Figure 3. 8: Total leaf area (m^2) of enset clones as influenced by varying levels of nitrogen supply

3.2.1.5. Leaf Area Index

Fig 3.9 shows the influence of rates of nitrogen supply on leaf area index of the two-enset clones. Results indicated that the leaf area index was significantly ($P \leq 0.05$) influenced by rates of nitrogen supply. The leaf area index significantly ($P<0.05$) increased with increasing levels of nitrogen supply. The highest leaf area index (3.05 for clone *Ado* and 2.37 for clone Gantciha) was obtained with the highest nitrogen rates, while the lowest leaf area index (1.03 for clone *Ado* and 1.31 for clone *Ganticha*) was recorded in control plants. The enset clone *Ado* showed the highest increase in leaf area index compared to that of *Ganticha*.

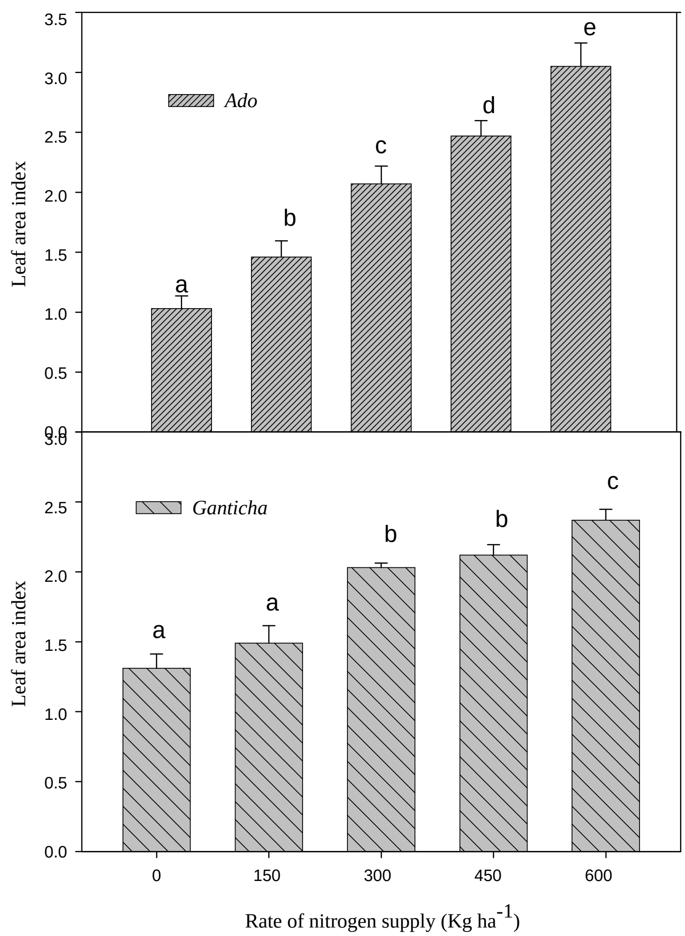


Figure 3. 9: Effect of rate of nitrogen supply on leaf area index of two enset clones

3.2.1.6. Chlorophyll Content

Data on leaf chlorophyll measurement using chlorophyll meter (SPAD) is presented in Table 3.15**.** The results showed that leaf chlorophyll content of enset plants was significantly ($P \leq 0.001$) influenced by rates of nitrogen supply but not by type of enset clones and their interaction effects. The SPAD value generally increased with increasing rates of nitrogen application. The highest SPAD value was recorded in plants treated with highest level of nitrogen supply and the lowest SPAD value was recorded in control plants.

The variations in SPAD at each level of nitrogen supply were also significant except nitrogen supply at a rate of 450 and 600 kg N ha^{-1} (Table 3.15).

Table3. 15: SPAD values measured on the third leaves of enset clones at 240 days after transplanting

Nitrogen supply (Kg/ha)	Clone *Ado*	Clone *Ganticha*	Mean
0	40.6 (0.38)a	41.1 (0.44)a	40.8a
150	43.1 (0.41)b	43.4(0.43)b	43.2b
300	45.2(0.40)c	46.0(0.51)c	45.6c
450	47.0(0.49)d	46.5(0.97)c	46.7d
600	47.8 (0.26)d	46.0(0.48)c	46.9d

Figures sharing the same letter in a column do not differ significantly at $P \leq 0.05$

3.2.1.7. Photosynthetic rate

Varying nitrogen levels showed significant ($P \leq 0.05$) differences on photosynthetic rate. The photosynthetic rate ranged from 8.5 to 10.4 $\mu molm^{-2}s^{-1}$, irrespective of enset clones. In plants supplied with highest nitrogen level (600 kg ha^{-1}) significantly ($P<0.05$) higher photosynthetic rate was recorded relative to control plants. Averaged across nitrogen treatments, the photosynthetic rate in clone *Ado* was about 9.9 $\mu molm^{-2}s^{-1}$, while that of *Ganticha* was 9.5 $\mu molm^{-2}s^{-1}$, although the variation was not significant (Fig 3.10).

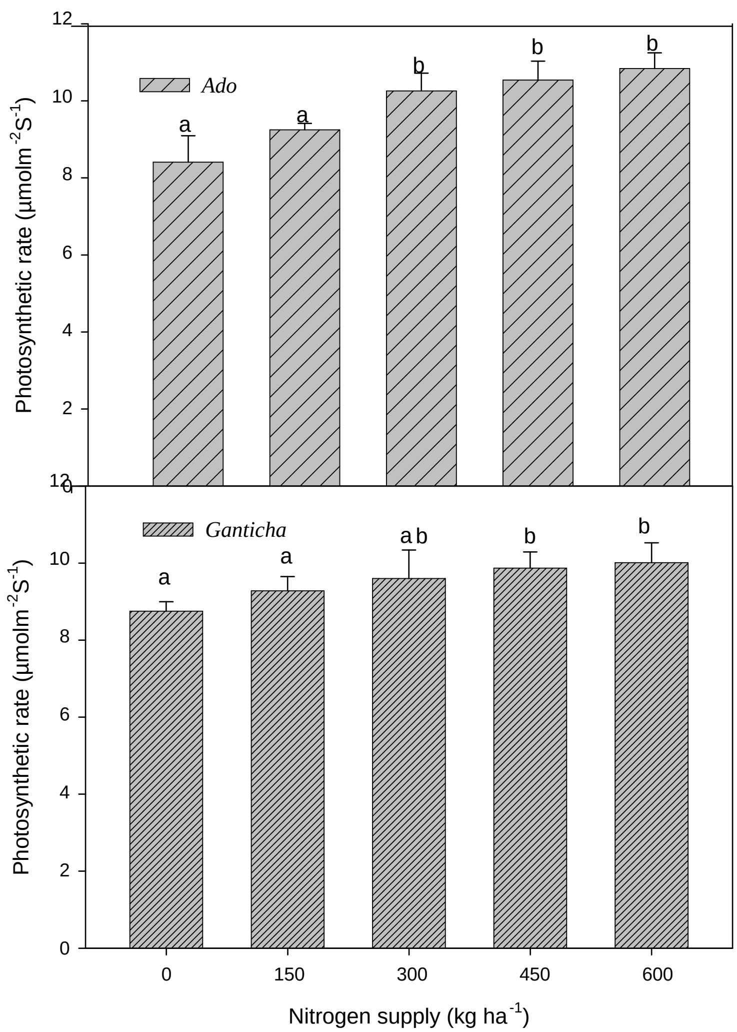


Figure 3.10: Net photosynthesis rate in two enset clones as influenced by levels of nitrogen supply

3.2.4. Biomass accumulation

Table 3.16 depicts Two-way ANOVA results of total biomass yield and the results showed significant effect of nitrogen rate, clone and nitrogen rate by clone interaction on biomass yield. Total biomass yield in both clones increased with increasing nitrogen rate.

Biomass yield of enset clones at control treatment ranged from 6376 kg ha^{-1} in clone *Ado* and 6747.5 kg ha^{-1} for clone *Ganticha*, resulting in an average yield of 6561.5 kg ha^{-1}. With highest nitrogen application (600 kg ha^{-1}), the range for biomass yield was 10022 kg ha^{-1} for clone *Ganticha* to 11475 kg ha^{-1} for clone *Ado* with an average yield of 10748.5 kg ha^{-1} (Fig.3.11 and Fig. 3.12). Increase in biomass yield over the control ranged from 48.5 % for clone *Ganticha* to 79.9 % for clone *Ado*. The rate of increase in biomass yield was found to be large at lowest level of nitrogen supply and incremental yield gains obtained became smaller as the nitrogen supply increased. Accordingly, no significant differences in biomass yield were observed beyond nitrogen application rate 300 kg ha^{-1} in case of the enset clone *Ganticha* and beyond nitrogen application rate 450 kg ha^{-1} in case of clone *Ado*. The difference in biomass yield between the two clones was also apparent in that clone *Ado* produced significantly ($P<0.001$) higher biomass yield compared to that of *Ganticha.*

Table3. 16: Two ways ANOVA for biomass of two enset clones grown under varying levels of nitrogen supply

Source	df	M	F	P
Clone	1	4563678	20.04	0.000
Nitrogen supply	4	25223833	110.76	0.000
Interaction	4	1932038	8.48	0.000
Error	30	227735		
Total	39			

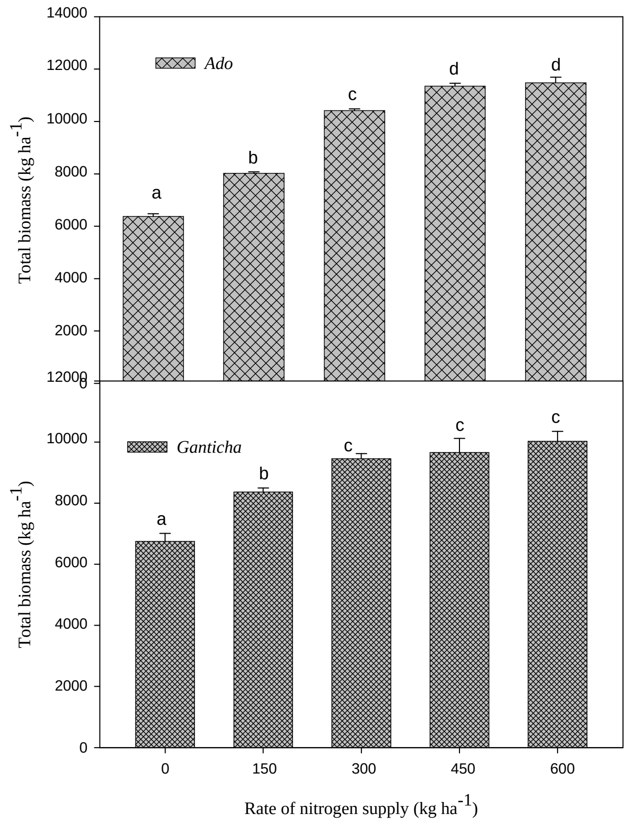


Figure3. 11:Total biomass accumulated in two clones of enset, Ado and Ganticha as influenced by varying levels of N supply (Bars Mean +SE, n=4)

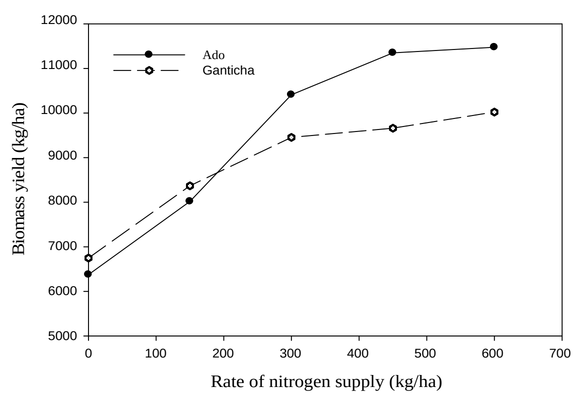


Figure3. 12: Biomass yield response of the two enset clones plotted against rate of nitrogen supply

3.2.5. Biomass allocation

Biomass allocation patterns for each clone as influenced by nitrogen application rate are shown in Table 3.17. In both clones, the highest dry matter was allocated to belowground parts in plants grown under lowest nitrogen supply. In the study the enset clone *Ado* allocated the greatest proportion of dry matter (30.3 %) to belowground parts compared to that of *Ganticha* (23.8%).

Table3. 17:Dry matter partitioned to above and belowground plant parts (% of total) in two enset clones grown at varying rates of nitrogen supply (Mean + SE, n=4)

		Rate of nitrogen supply (Kg/ha)				
Clone	Plant part	0	150	300	450	600
Ado	Belowground	30.3 (0.21)[a]	29.6 (0.67)[a]	27.0(0.37)[ab]	24.9(0.19)[b]	23.4 (0.21)[b]
	Aboveground	69.7 (0.21)[a]	70.4(0.67)[a]	73.0(0.37)[ab]	75.1 (0.19)[b]	76.6 (0.21)[b]
Ganticha	Belowground	23.8(0.5)[a]	21.5 (0.6)[a]	20.9 (0.2)[a]	18.9 (1.0)[b]	17.0(0.6)[b]
	Aboveground	76.2(0.5)[a]	78.5(0.6)[a]	79.1(0.2)[a]	81.1(1.0)[b]	83(0.6)[a]

Rows followed by the same letters are not significant at $P \leq 0.05$

3.2.6. Harvest Index

The harvest index value was significantly ($P \leq 0.001$) affected by nitrogen supply (Table 3.18). The mean harvest index showed an increase initially with increasing rates of nitrogen up to 300 kg ha^{-1} and then decreased with further increase in application rate. There was no significant difference between the two clones with respect to harvest index.

Table3. 18: Harvest index of the two enset clones as influenced by varying levels of nitrogen supply

	Rate of manure application (kg total N/ha)				
Clone Type	0	150	300	450	600
Ado	0.56	0.58	0.59	0.61	0.60
Ganticha	0.60	0.62	0.62	0.55	0.51
Mean	0.58	0.60	0.61	0.58	0.56

3.2.7. Nitrogen concentration in different plant parts

Total nitrogen concentration (%) in different parts of the two enset clones as influenced by rates of nitrogen supply is shown in Table 3.19 A and B. The results revealed that rate of nitrogen supply significantly ($P \leq 0.05$) influenced the nitrogen concentration in different parts of the plant except the root. The mean nitrogen concentration (mean of the two clones) in leaf ranged from 3.06% to (control) to 3.48 (600 kg N ha^{-1}) and that of the pseudostem ranged from 1.7 % (control) to 1.95% (600 kg N ha^{-1}). There was also significant nitrogen level by clone interaction with respect to both pseudostem and leaf nitrogen content. In both clones, the nitrogen concentration increased with increasing rates of nitrogen supply. The highest tissue nitrogen concentration obtained in plants receiving the highest level of nitrogen supply (600 kg N ha^{-1}) and the lowest nitrogen concentration was obtained in treatment with lowest level of nitrogen supply. On the other hand, the mean nitrogen concentration in a corm ranged from 1.70% (control) and 1.88% (600 kg N ha^{-1}) supply and that of the root ranged from 1.47 % (control) and 1.52% (600 kg N ha^{-1}). The mean differences between clones with respect to corm nitrogen concentration was also significant (P≤0.001). Of the two clones, *Ado* had significantly higher mean nitrogen concentration (1.78%) compared to that of *Ganticha* (1.68%). Nitrogen rate by clone interaction was also significant. The highest corm nitrogen concentrations, 1.91 % for clone *Ado* and 1.85% for clone *Ganticha*, were obtained in plants receiving the highest nitrogen supply and the lowest corm nitrogen concentrations 1.64% for clone *Ado* and 1.77% for *Ganticha* were obtained in control plants. In the present investigation, the effect of nitrogen rate on root nitrogen concentration was not significant. However, the mean root nitrogen concentration of clone *Ado* (1.63%) was significantly higher than that of *Ganticha* (1.45%). Interactions between nitrogen supply and clones were also significant with respect to root nitrogen concentration.

Table 3.19: Total nitrogen concentration (%) in aboveground plant parts (A) and belowground plant parts (B) in two clones of enset as influenced by different levels of nitrogen supply. Mean + SE, n=4

A			**Aboveground plant parts**			
N-level		Leaf			Pseudostem	
(kg/ha)	*Ado*	*Ganticha*	Mean	*Ado*	*Ganticha*	Mean
0	3.02a	3.10a	3.06a	1.67a	1.72a	1.70a
150	3.14b	3.27b	3.20b	1.79b	1.65a	1.72b
300	3.21b	3.30b	3.26b	1.79b	1.87b	1.84b
450	3.33c	3.31b	3.37c	1.88c	1.91b	1.89b
600	3.41c	3.34b	3.48d	1.90c	2.0b	1.95b

Means within a column followed by the same letter (s) are not significantly different at 5 %

B	*Belowground plant parts*					
N-level	Corm			Root		
(kg/ha)	*Ado*	*Ganticha*	Mean	*Ado*	*Ganticha*	Mean
0	1.64a	1.77a	1.70a	1.45a	1.49a	1.47a
150	1.73a	1.58b	1.66b	1.49a	1.47a	1.48a
300	1.77b	1.58b	1.68c	1.64b	1.55a	1.59a
450	1.83b	1.62b	1.72c	1.79b	1.49a	1.64a
600	1.91b	1.85a	1.88c	1.77b	1.26b	1.52a

Means within a column followed by the same letter (s) are not significantly different at 5 %

3.2.8. Nitrogen uptake

Results for nitrogen uptake by aboveground biomass (i.e., pseudostem and leaf) and belowground plant parts (i.e, corm and root) in two clones of enset, *Ado* and *Ganticha*, as influenced by rate of nitrogen supply is presented in Table 3.21. The nitrogen uptake in both aboveground and belowground biomass of plants was increased significantly ($P \leq 0.05$) with increasing rates of nitrogen supply (Table 3.20). The mean nitrogen uptake by aboveground biomass ranged from 107.8 kg ha^{-1} (control) to 221.4 kg ha^{-1} (600 kg/ha) and that of belowground biomass ranged from 29.4 kg ha^{-1} (control) to 40.4 kg ha^{-1} (600 kg ha^{-1}). Clonal differences in nitrogen uptake by both aboveground and belowground plant parts were also highly significant ($P \leq 0.05$). Of the two clones, *Ado* had the highest mean nitrogen uptake value (176.4 kg ha^{-1} for aboveground and 44.5 kg ha^{-1} for belowground), which was significantly ($P \leq 0.05$) higher than that of *Ganticha* (165.3 kg ha^{-1} for aboveground and 29.4 kg ha^{-1} for belowground). The interaction between clones and nitrogen supply was also highly significant ($P \leq 0.05$).

Table3. 20:Two-way ANOVA results of nitrogen uptake by aboveground (A) and belowground (B) biomass in two enset clones supplied with different rates of manure nitrogen

A

Source	Df	MS	F	P
Clone	1	1229.258	14.482	0.000
Nitrogen supply	4	17322.687	204.083	0.000
Interaction	4	347.029	4.088	0.009
Error	30	84.880		
Total	39			

B

Source	Df	MS	F	P
Clone	1	2278.435	127.914	0.000
Nitrogen supply	4	201.578	11.317	0.000
Interaction	4	122.670	6.887	0.000
Error	30	17.812		
Total	39			

Table3. 21: Nitrogen uptake (kg/ha) by plant parts in two enset clones as influenced by rates of nitrogen supply (n=4)

Enset Clone	N-rate (kg/ha)	Aboveground			Belowground		
		Pseudostem	Leaf	Total	Corm	Root	Total
Ado	0	34.5a	71.9a	106.4a	25.6a	5.3a	30.9a
	150	49.2b	91.1b	140.2b	33.4b	6.5b	39.9b
	300	70.1c	118.1c	188.1c	41.0c	8.1c	49.1c
	450	84.8d	133.5d	218.3d	45.3c	6.3b	51.6c
	600	88.8d	140.2d	229d	44.2c	6.6b	50.8c
Ganticha	0	62.4a	46.9a	109.3a	25.3a	2.6a	27.9a
	150	76.7b	62.6b	139.3b	25.6a	2.7a	28.3a
	300	91.7c	84.6c	176.4c	28.0a	3.2b	31.3a
	450	96.6c	91.2c	187.8c	26.0a	3.5b	29.5a
	600	94.9c	118.8d	213.8d	26.4a	3.6b	30.0a

Means in the same column followed by the same letter are not significantly different at $P \leq 0.05$.

3.2.9. Nitrogen use efficiency

3.2.9.1. Agronomic efficiency of nitrogen

Two-way analysis of variance for agronomic efficiency of nitrogen (AE_N) of the two enset is shown in Table 3.22. The results showed that AE_N was significantly ($P \leq 0.05$) influenced by nitrogen rate, clone as well as nitrogen rate by clone interaction. The AE_N decreased with increasing nitrogen rates. Averaged over clones, the AE_N ranged from 10.8 kg kg $^{-1}$ at 150 kg N ha^{-1} supply to 6.97 kg/kg at 600 kg N ha^{-1} supply (Table 3.23). The highest nitrogen agronomic efficiency value was observed at 300 kg/ha. There was also significant difference between the two-enset clones. Averaged across the different nitrogen rates, clone *Ado* had significantly higher (10.95 kg kg^{-1}) AE_N compared to that of *Ganticha* (7.93 kg kg $^{-1}$). Nitrogen supply by clone interaction was also significant. At all nitrogen rates AE_N value of clone *Ado* was higher than that of *Ganticha* (Table 3.23)

Table3. 22:Two-way analysis of variance results of agronomic efficiency of nitrogen (AEN) (kg/kg) in two enset clones, Ado and Ganticha, grown under varying levels of nitrogen supply

Source	*df*	MS	F	P
Clone	1	74.2	33.107	0.000
Nitrogen level	3	31.4	19.4	0.000
Interaction	3	8.48	4.96	0.008
Error	24	1.71		
Total	31			

Table3. 23: Agronomic efficiency of nitrogen (kg/kg) of the two enset clones at varying levels of nitrogen supply

	Rate of nitrogen supply (Kg/ha)				
Clone	0	150	300	450	600
Ado	-	10.9 (0.35)[a]	13.4(0.24)[b]	11.0(0.24)[a]	8.5(0.08)[c]
Ganticha	-	10.8(0.4)[a]	9.0(0.27)[a]	6.5(0.5)[b]	5.4(0.27)[b]
Mean	-	10.8	11.2	8.76	6.97

Means within a row for each clone followed by the same letter(s) are not significantly different at 5% probability level

3.2.9.2. Nitrogen recovery efficiency (REN)

The REN also varied significantly according to nitrogen rate and clones though the interaction was not significant (Table 3.24). The REN value with both aboveground and belowground plant parts decreases with increasing nitrogen rates. Averaged across the clones, the highest mean nitrogen recovery value 24% and 3.56% by aboveground and belowground plant parts, respectively was obtained at nitrogen rate 300 kg N ha^{-1} and the lowest nitrogen recovery value 18% and 1.8% by aboveground and belowground plant parts, respectively was obtained at a rate of 600 Kg N ha^{-1} (Table 3.25 and 3.26). Of the two clones, clone *Ado* had the highest overall mean nitrogen recovery value 23.2% and 4.96 for aboveground and belowground plant parts, respectively compared to that of *Ganticha* (19% and 0.51 for aboveground and belowground parts, respectively)

Table3. 24:Two-way analysis of variance results of nitrogen recovery efficiency (%) in two enset clones, Ado and Ganticha, grown under varying levels of nitrogen supply

Source	*df*	MS	F	P
Clone	1	161.223	21.20	0.000
Nitrogen level	3	47.343	6.23	0.003
Interaction	3	9.709	1.28	0.305
Error	24	7.605		
Total	31			

Table3. 25: Nitrogen recovery efficiency (%) of the two enset clones by above ground biomass as influenced by nitrogen supply

	Rate of nitrogen supply (Kg/ha)				
Clone	0	150	300	450	600
Ado	-	22	27	24	20
Ganticha	-	20	22	17	17
Mean	-	21	24	21	18

Table3. 26: Nitrogen recovery (%) by below ground biomass in two clones of enset as influenced by varying levels of nitrogen supply. Values, Means +SE, n=4

	Rate of nitrogen supply (Kg/ha)				
Clone	0	150	300	450	600
Ado	-	6	6.03	4.52	3.31
Ganticha	-	0.26	1.1	0.35	0.34
Mean	-	3.13	3.56	2.4	1.8

3.2.9.3. Physiological nitrogen use efficiency

Nitrogen rates and interaction between clones and nitrogen rates significantly influenced nitrogen physiological efficiency (Table 3.27). However, the physiological use efficiency did not differ between clones. The mean nitrogen physiological efficiency value of the two clones showed that NPE value decline with increasing rates of nitrogen supply. The mean physiological nitrogen use efficiency ranged from 35.9 kg/kg (at 150 kgN/ha) to 33.1 kg/kg (at 600 kgN/ha) (Table 3.28). The highest mean nitrogen physiological efficiency value was observed at 300 kg/ha. Averaged across nitrogen rates, the enset clone *Ado* had nitrogen physiological efficiency value 37.9 kg/kg, while that of the enset clone *Ganticha* was 34.7 kg/kg.

Table3. 27:Two-way analysis of variance results of physiological nitrogen efficiency (kg/kg) in two enset clones, Ado and Ganticha, grown under varying levels of nitrogen supply

Source	*df*	MS	F	P
Clone	1	23.766	3.092	0.09
Nitrogen level	3	232.759	30.279	0.000
Interaction	3	169.409	22.038	0.000
Error	24	7.687		
Total	31			

Table3.28: Nitrogen physiological efficiency (kg/kg) of the two-enset clones as influenced by varying levels of nitrogen supply. Values, Means ±SE, n=4

	Rate of nitrogen supply (kg/ha)				
Clone	0	150	300	450	600
Ado	-	38.3 (0.24)a	40.2(0.35)a	37.4 (0.24)ab	35.7 (0.29)b
Ganticha	-	33.6 (2.4)a	38.3 (1.2)b	36.2(2.5)b	30.6 (0.45)c
Mean	-	35.9	39.3	36.8	33.1

3.2.10. Soil analysis at harvest

ANOVA results of soil residual total mineral nitrogen as influenced by nitrogen supply, enset clones and sampling depth is shown in Table 3.29. Table 3.30 shows the mean values of total mineral nitrogen, ammonium nitrogen and nitrate nitrogen as influenced by clone, nitrogen rate and soil depth. The result showed that total mineral nitrogen at harvest was significantly ($P<0.001$) affected by interaction of clone, nitrogen rate and depth of soil sampling. The highest mean total mineral nitrogen (51.9 kg ha^{-1}) was obtained under plot of *Ganticha* and the lowest total mineral nitrogen (46.7 kg ha^{-1}) was obtained from plots of clone *Ado* (3.30A). Averaged across clones and sampling depth, total mineral nitrogen also significantly increased with increasing rate of nitrogen supply. The highest mean total mineral nitrogen (74.5 kg ha^{-1}) was obtained from plots treated with 600 kg N ha^{-1} and the lowest was obtained from that of control plots (29.5 kg ha^{-1}). (Table3.30B). On the other hand, the mean total mineral nitrogen computed across nitrogen rates and clones significantly influenced by depth of sampling (Table 3.30C). Total mineral nitrogen decreased with increasing depth of sampling. The highest total mineral nitrogen was obtained in the upper 0-30 cm soil depth and the lowest total mineral nitrogen obtained from 60-90 cm depth (Table3.30C). The Two-way analysis of variance also showed significant ($P\leq0.001$) interaction between clone and nitrogen rate. In both clones, total mineral nitrogen increased with increasing rate of nitrogen supply. The highest total mineral nitrogen, 68.8 kg ha^{-1} and 80.2 kg ha^{-1}, in clone *Ado* and *Ganticha*, respectively were recorded at nitrogen rate 600 kg ha^{-1} and the lowest total mineral nitrogen content i.e, 28.7 kg N ha^{-1} and 30.4 kg N ha^{-1} in clone *Ado* and *Ganticha*, respectively, were obtained from control plots (Table 3.31). Total mineral nitrogen also showed significant interaction with clone and sampling depth (Table 3.32), and between nitrogen rate and sampling depth (Table 3.33). In both clones, total mineral nitrogen significantly reduced with depth. In clone *Ado*, the highest total mineral nitrogen 54.1 kg ha^{-1} was obtained at soil depth 0-30 cm followed by 48.7 kg/ha at 30-60 cm depth and followed by 37.4 kg/ha at 60-90 cm depth. Similarly, in clone *Ganticha* the highest total mineral nitrogen obtained at depth 0-30 cm was 65 kg ha^{-1} followed by 48 kg ha^{-1} at depth of 30-60 cm and 42.9 kg ha^{-1} at depth 60-90 cm depth (Table 3.32). Nitrogen supply and sampling depth also showed significant (P<0.000) interaction in that for each nitrogen treatment level, total mineral nitrogen decreased significantly with increased depth of sampling. Soil nitrate nitrogen at harvest ranged from 11.2 to 9.1 kg ha^{-1} while that of ammonium nitrogen ranged from 47.8 to 31.1 kg ha^{-1}. Higher levels of soil NH_4-N were observed for all depths and nitrogen treatments (Table 3.30).

Table3. 29:ANOVA results of soil analysis (residual inorganic nitrogen) at harvest in two clones of enset supplied with varying levels of nitrogen supply

Source	df	MS	F	P
Clone	1	616.4	17.078	0.000
N-level	4	4979.610	137.966	0.000
Depth	2	2849.682	78.954	0.000
Clone x N-level	4	206.304	5.716	0.000
Clone x depth	2	250.504	6.941	0.002
N-level x depth	8	207.002	5.735	0.000
Clone x N-level x depth	8	114.347	3.168	0.005
Residual	60	36.093		
Total	89			

Table3.30: Showing the mean total mineral nitrogen, ammonium nitrogen and nitrate nitrogen as influenced by clone, nitrogen rate and depth of sampling

	Total mineral N	NH_4-N	NO_3-N
Clone (A)			
Ado	46.7a	35.9a	8.8a
Ganticha	51.9b	39.1b	12.86b
$P\leq0.05$	0.89	0.91	1.3
N rate (B)			
0	29.5a	20.3a	8.4a
150	43.8b	27.1b	11.7b
300	44.4b	33.3c	11.1b
450	54.4d	41.7d	12.7b
600	74.5e	64.3e	10.1b
$P\leq0.05$	1.4	1.4	2.0
Soil depth (C)			
0-30	59.1a	47.8	11.2
30-60	48.4b	36.1	12.2
60-90	40.1c	31.1	9.1
$P\leq0.05$	1.1	1.1	1.5

Table3. 31: Showing nitrogen rate by clone interaction effects on soil residual total mineral nitrogen (kg ha-1)

Nitrogen rate	*Ado*	*Ganticha*
0	28.7a	30.4a
150	45.4b	42.2b
300	38c	50.9c
450	52.7d	56.2c
600	68.8e	80.2d

Figures in column followed by the same letter did not differ significantly

Table3. 32: Showing clone by sampling depth interaction effects on soil residual mineral nitrogen

Clone	Soil depth(cm)	TMN (kg/ha)
Ado	0-30 30-60 60-90	54.1 48.7 37.4
Ganticha	0-30 30-60 60-90	65.0 48.0 42.9
	LSD ($P \leq 0.05$)	1.5

Table3. 33: Showing nitrogen rate by depth interaction effects on soil residual nitrogen

Nitrogen level (kg ha^{-1})	Depth	TMN (kg ha^{-1})
0	0-30 30-60 60-90	38.6 30.6 19.3
150	0-30 30-60 60-90	45.5 44.0 42.0
300	0-30 30-60 60-90	52.3 46.5 34.4
450	0-30 30-60 60-90	70.5 48.2 44.6
600	0-30 30-60 60-90	90.8 72.3 60.4
	LSD($P \leq 0.05$)	2.43

Manure nitrogen recovered by the soil

Mineral nitrogen available from manure and recovered by the soil was calculated as total mineral nitrogen in soil of treatment plot minus total mineral nitrogen in soil of control plot divided by total amount of manure nitrogen applied. The results revealed that the amount total mineral nitrogen available from manure and recovered by the soil was significantly influenced by rate of nitrogen supply. In the present investigation, the lowest soil recovery value (4.9 %) was obtained at plot treated with 300 kg N/ha and the highest soil recovery value (9.45 %) was observed in the soil in plot treated with 150 kg N/ha (Table 3.34). There were also differences with respect to the two clones in that the lowest mean total mineral nitrogen recovery was obtained in plots of *Ado* (6.5%) compared to that of *Ganticha* (7.1%) (Table 3.34).

Table3. 34: Total mineral nitrogen recovered (%) by the soil as influenced by enset clones and rates of nitrogen supply

	Recovery of manure N by soil (%)				
	0	150	300	450	600
Ado	-	11.1	3.1	5.3	6.7
Ganticha	-	7.8	6.8	5.7	8.3
Mean		9.45	4.9	5.5	7.5

Table 3.35 shows the amount of manure total nitrogen that had been recovered by the plant and soil. The results revealed that clone *Ado* had the highest plant recovery value and the lowest soil recovery value. On the other hand, *Ganticha* had the lowest total mineral nitrogen recovered by the plant and the highest mineral nitrogen recovered by the soil. The overall mean total mineral nitrogen recovered by the soil and plant indicated

that of the total manure nitrogen applied above 30% of nitrogen became plant available during the growth period of one year.

Table3.35: Showing mineral nitrogen available from manure during the growing period and recovered by plant and soil

	Manure N recovery (%)		
Clone	Plant	Soil	Total
Ado	28.2	6.5	34.7
Ganticha	19.51	7.15	27.01
Mean	23.85	6.82	**30.67**

3.3. Manure placement effects on growth, biomass production and recovery efficiency of manure nitrogen in enset clone *Ganticha*

In the study three manure placement methods, whereby the full dose of manure was applied as top dressing (T_1), bottom dressing (T_2) or a split combination thereof (T_3), were assessed together with a no manure control (T_4). The results showed significant ($P \leq 0.05$) treatment effects in all of the parameters studied.

Pseudostem girth

The time course of pseudostem girth growth in enset plant grown under different manure placement is shown in Fig 3.13. The results indicated that the pseudostem growth of plants was significantly influenced by methods of manure placement**.** At the end of the experiment, the highest increase in pseudostem girth (80.1 cm) was associated with bottom dressing (T_2) followed by (T_3) (77.2 cm) and the lowest pseudostem girth measurement was obtained in control plants (T_4) (48.3 cm).

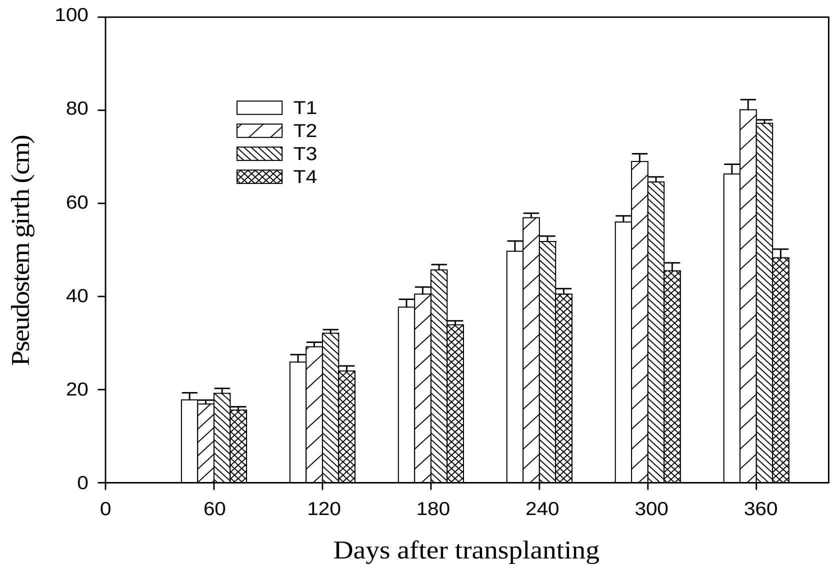


Figure 3. 13: Showing the effect of manure placement on pseudostem girth

Green leaf number

The influence of methods of manure placement on number of green leaves is shown in Fig 3.14. The results showed significant ($P \leq 0.05$) treatment effects on green leaf number. By the end of the experiment, those plants with subsurface manure application retained greater amount of green leaves, (T_2= 9.75 and T_3=9.6) and those without manure amendment retained the least number of green leaves (6.2). The differences between T_2 (bottom dressing) and T_3 (split application) plants with respect to green leaves was not statistically significant.

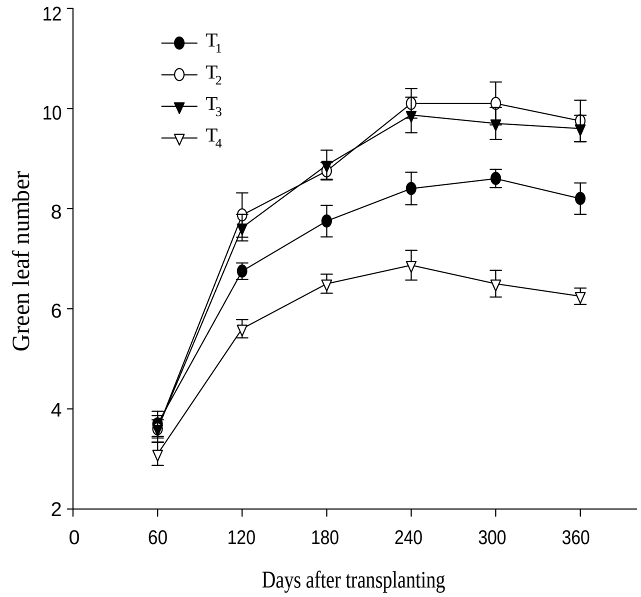


Figure3. 14: Effect of manure placement on green leaf number.

Leaf area

The development of plant leaf area was also significantly influenced by the method of manure application. T_2 and T_3 treatments produced the highest leaf area while that of control plants produced the lowest (Fig 3.15).

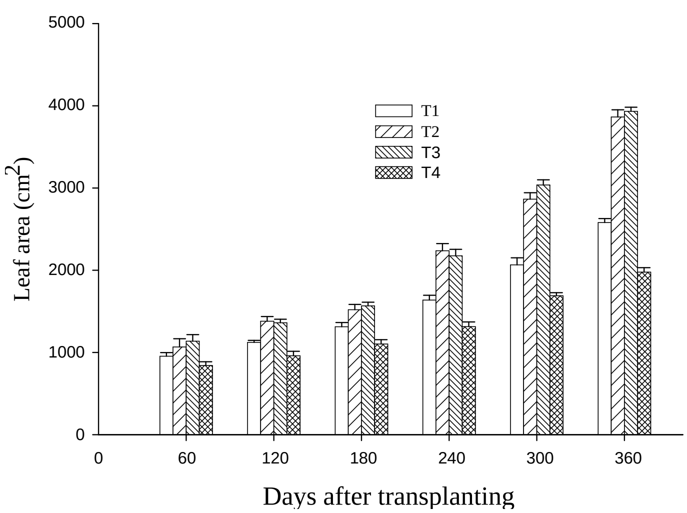


Figure3. 15: Manure placement effect on leaf area

Biomass production and partitioning

Biomass yield and distribution were significantly ($P<0.05$) influenced by manure placement (Fig 3.16). By the end of the experiment, the highest dry matter production was achieved by T_3 plants (514.3 g) followed by T_2 (though no significant variation between the two treatments) and control (T_4=155.6) plants produced the lowest biomass yield. The biomass distribution (% of total) is shown in Table 3.36. The control plants partitioned more than 50% of their total biomass to underground parts (i.e., roots and corm), compared to the other treatments.

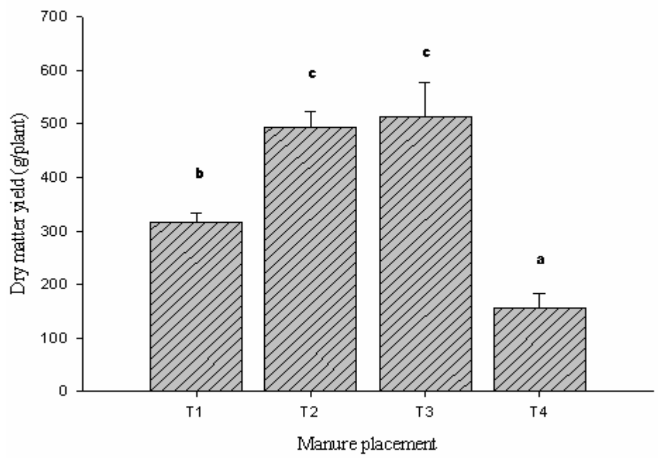


Figure3. 16: Effect of manure placement on dry matter yield

Table3. 36: Biomass distribution pattern of enset in response to manure placement

Manure placement	Biomass distribution (% of total)			
	Root	Corm	Pseudostem	Leaves
T_1	13.5	25.6	39.8	21.1
T_2	15.4	20.8	40.7	23.0
T_3	14.5	18.5	40.0	26.9
T_4	16.4	33.6	32.1	17.9
LSD (0.05)	Ns	4.7	6.8	Ns

Tissue nitrogen concentration

Nitrogen content in different plant parts as influenced by manure placement is shown in Table 3.37. There were significant differences in tissue nitrogen content between manure placement treatments. T_2 plants showed the highest nitrogen content in all parts followed by T_3 plants. While the control plants showed the lowest.

Table3. 37: Concentration of nitrogen in different parts of enset as influenced by manure placement

Manure placement	Nitrogen (%)			
	Root	Corm	Pseudostem	Leaves
T_1	1.31	1.56	1.69	2.86
T_2	1.30	1.64	1.88	3.1
T_3	1.28	1.59	1.81	3.02
T_4	1.17	1.48	1.8	2.78
LSD (0.05)	Ns	3.8	5.9	6.9

Nitrogen uptake

Nitrogen uptake by plant parts under different manure placement treatment is shown in Table 3.38. The results showed that nitrogen uptake by plant parts significantly influenced by manure placement. Bottom dressing and split top and bottom application resulted in highest uptake value and the lowest value was obtained in control plants.

Nitrogen recovery

The influence of manure placement on nitrogen recovery is presented in Table 3.40. T_3 plants showed the highest recovery efficiency (32%) followed by T_2 plants (30.4%) and T_1 (13%). The differences between T_2 and T_3 treatments were not statistically significant (Table 3.39).

Table3.38: Nitrogen uptake (g/plant part) as influenced by manure placement

	Manure placement				
Plant part	T_1	T_2	T_3	T_4	LSD($P\leq0.05$)
Root	0.55	0.97	0.89	0.29	0.10
Corm	1.25	1.62	1.51	0.78	0.32
Pseudostem	2.14	3.82	3.76	0.91	1.05
Leaf	1.92	3.64	4.26	0.76	1.54
Total	5.86	10.05	10.42	2.74	3.01

Table3. 39: Manure placement effect on manure N recovery efficiency (%) by different plant parts

	Manure placement			
Plant part	T_4	T_1	T_2	T_3
Root	-	1.0	2.83	2.5
Corm	-	1.95	3.50	3.04
Pseudostem	-	5.12	12.12	11.8
Leaf	-	4.83	12.00	14.6
Total	-	13	30.45	32

3.4. Effect of method and duration of manure storage on manure chemical composition and quality

3.4.1. Moisture content

Two-way ANOVA results of the effect of method and duration of manure storage on moisture content (%) is shown in Table 3.40. The results showed that the moisture content of the manure was significantly ($P<0.001$) influenced by methods and duration of storage and their interaction. At the end of the experiment, manure stored in uncovered heap lost about 63.1% of its initial moisture compared to that of covered one (Fig 3.17).

The effect of duration of storage on moisture content was also significant (P<0.001). The mean percentage moisture decreases with increasing duration of storage.

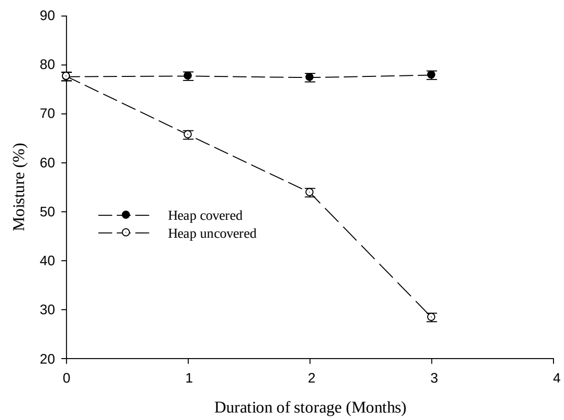


Figure 3. 17: Effect of method and duration of manure storage on moisture content

Table 3. 40: Two-way ANOVA results of the effects of methods and duration of manure storage on (A) moisture content (B) Organic carbon (C) Total nitrogen (D) Total mineral nitrogen (E) pH (F) C/N ratio

A

Source of variation	df	MS	F	P
Method of storage	1	681.6	1201.058	0.000
Duration of storage	3	147.78	2604.377	0.000
Interaction	3	152.872	269.377	0.000
Error	16	0.568		
Total	23	69.245		

B

Source of variation	df	MS	F	P
Method of storage	1	98.4	107.9	0.000
Duration of storage	3	12.3	13.4	0.000
Interaction	3	15.1	16.6	0.000
Error	16	0.911		
Total	23	8.488		

C

Source of variation	df	MS	F	P
Method of storage	1	0.56	140.5	0.000
Duration of storage	3	0.21	54.25	0.000
Interaction	3	0.06	15.8	0.000
Error	16	0.0039		
Total	23	0.0367		

D

Source of variation	df	MS	F	P
Method of storage	1	248483.67	3220.826	0.000
Duration of storage	3	1668.258	21.624	0.000
Interaction	3	27692.456	358.947	0.000
Error	16	77.149		
Total	23	14686.965		

E

Source of variation	df	MS	F	P
Method of storage	1	2.714	256.903	0.000
Duration of storage	3	1.467	138.853	0.000
Interaction	3	0.442	41.821	0.000
Error	16	0.0106		
Total	23	0.374		

F

Source of variation	df	MS	F	P
Method of storage	1	31.49	12.69	0.003
Duration of storage	3	44.86	18.08	0.001
Interaction	3	4.74	1.91	0.168
Error	16	2.48		
Total	23	9.56		

3.4.2. Organic carbon

The organic carbon content of manure was significantly influenced by methods ($P<0.001$), duration of storage ($P<0.001$) and their interaction ($P\leq 0.001$). (Table 3.40B). At the end of the experiment, approximately 21 % of the initial organic carbon from manure stored without cover was lost (Table3.41). On the other hand, no significant reduction in organic carbon was observed in manure stored under polythene cover. The effect of duration of storage on organic carbon content was also significant. The carbon content showed significant reduction with increasing duration of storage particularly in manure stored without cover (Fig 3.18).

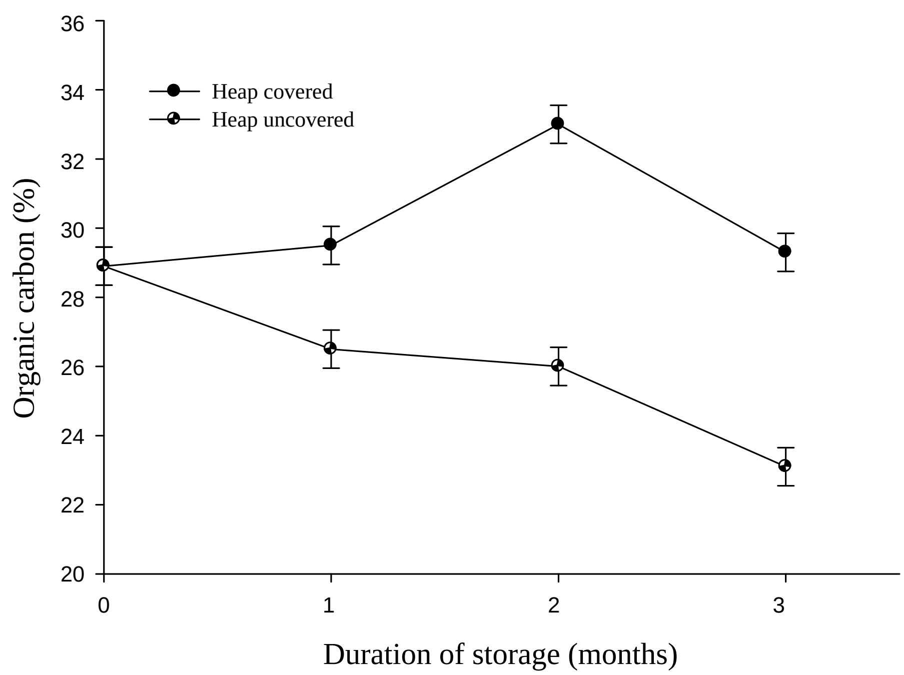


Figure 3.18: Effect of method and duration of manure storage on manure organic carbon

Table3. 41: Chemical composition of manure (initially and at the end) stored under different storage practices

		Moisture (%)	Carbon (%)	Total N (%)	NH4-N (mg/kg)	pH	C/N
Cover	Start of storage	77.6	29.0	1.49	177.6	8.6	19:1
	End of storage	77.4	29.3	1.31	302.6	6.8	22:1
Uncover	Start of storage	77.6	29.0	1.49	177.6	8.6	19:1
	End of storage	28.6	23.1	0.87	29.1	8.1	27:1

3.4.3. Total nitrogen and mineral nitrogen

There were significant ($P<0.001$) differences in total nitrogen and mineral nitrogen concentration between manure stored in heaps with and without coverage (Table 3.40C and D). At the end of the experiment, manure stored in uncovered heap has lost the highest total nitrogen compared to that of manure stored with cover. The percent nitrogen loss over the initial concentration in manure with and without coverage was found to be 12.08 and 41.6%, respectively. Similarly, at the end of storage, the concentration of ammonium in uncovered manure showed about 83.6% reduction over the initial concentration. In contrast, the concentration of ammonium in the manure with polythene sheet showed about 70.4% increase over the initial concentration. In the present study, NO_3-N was not detected in manure samples from both treatments and thus, the total mineral nitrogen is represented by ammonium. Fig 3.19 depicts changes in total nitrogen and ammonium nitrogen over time in manure samples with and without cover storage treatments.

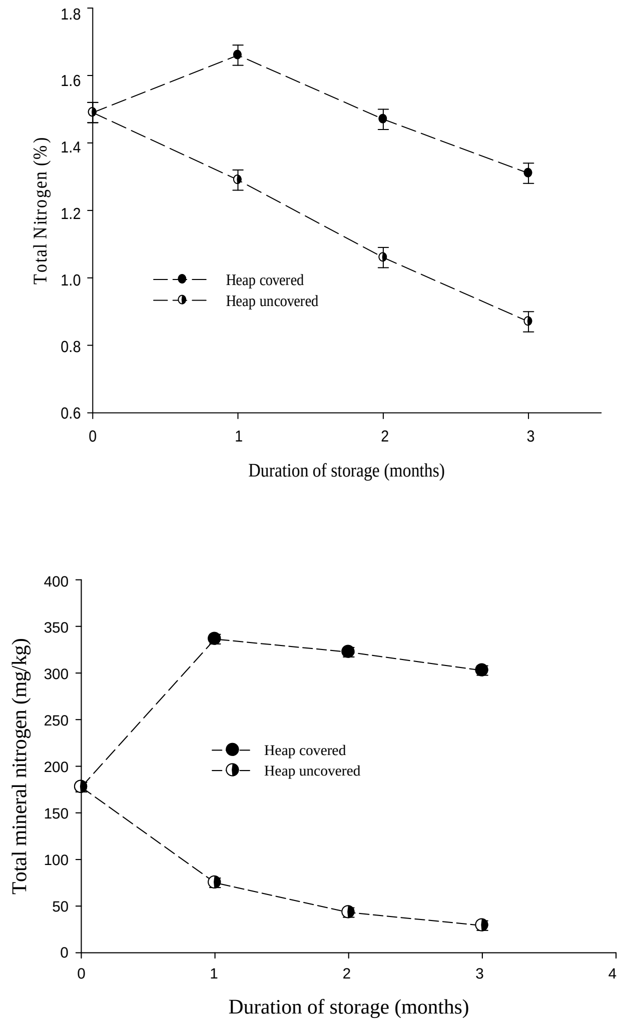


Figure 3. 19: Effect of method and duration of manure storage on total and mineral nitrogen

3.4.4. pH

The method and duration of storage and their interaction significantly (P<0.001) influenced the pH of the manure (Table 3.40E). The pH was reduced during storage in both manure with and without cover. Nevertheless, the pH decline in manure covered with polythene sheet was significantly higher than that of uncovered heap. The pH of manure covered with polythene sheet declined from initial 8.6 to 6.8 while that of uncovered heap was declined from initial 8.6 to 8.1 during three months of storage (Fig 3.20).

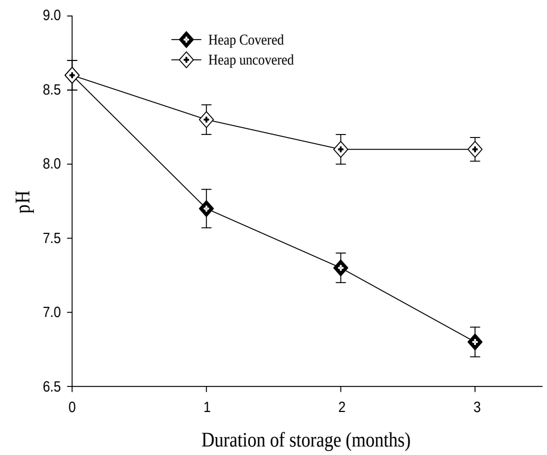


Figure 3. 20: Effect of method and duration of manure storage on manure pH

3.4.5. C/N ratio

The method and duration of storage significantly influenced the C/N ratio of manure. In both storage methods tested, the C/N ratio tends to increase with increasing duration of storage. However, at the end of the experiment the manure without coverage had C/N ratio significantly higher than that with coverage (Fig 3.21).

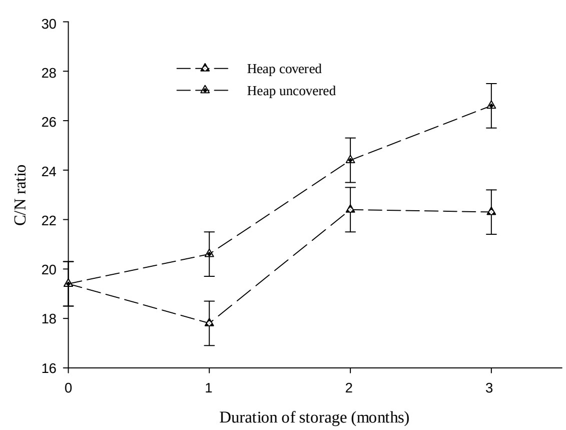


Figure3. 21: Effect of method and duration of storage on C/N ratio

4. DISCUSSION

4.1 Mineralization of manure nitrogen

The mineralization potential of manure is usually determined by measuring the amount of inorganic nitrogen (NH_4^+ and NO_3^-) released during specified period under uniform conditions (Abbasi *et al.*, 2007). The rate of release of inorganic nitrogen (mineralization) during incubation reflects the potential availability of NH_4^+ and NO_3- to plants and microorganisms. The NH_4^+ released also converted to NO_3^-. In the present study, a substantial increase in total mineral nitrogen concentration in both soils with and without manure amendment was observed during 150 days of incubation. The mineral nitrogen released from the soil with manure amendment was substantially higher than in soil without manure amendment. Control soil without manure amendment released a maximum of 70 mg mineral Nkg^{-1} soil, whereas soil with manure amendment released a maximum of 101 mg Nkg^{-1} soil at day 90. The increase in total mineral nitrogen in soil without added manure was due to mineralization of organic matter present in the soil.

Cattle manure applications represent an important source of nitrogen (N) to the soil. However, manure nitrogen consists of inorganic and organic forms of nitrogen. The inorganic nitrogen in manure is readily available but the organic nitrogen must be mineralized before it becomes available to plants. The proportion of organic nitrogen in cattle manure typically ranges from 80 to 100% (Paul and Beauchamp, 1993; Opala, 2011). Mineralization is a conversion of organic forms of nitrogen to inorganic form. Since the bulk of manure nitrogen is found in organic form, an understanding of manure nitrogen mineralization is required to predict short and long-term release of plant available nitrogen.

The present study showed the higher potential for mineralization of the soil investigated. The mineral nitrogen released from manure treated soil was significantly higher than that of the control soil. The higher mineral nitrogen value in soil with manure amendment is obviously due to higher concentration of total nitrogen in manured soil over that of the control; and consequently higher levels of microbial biomass and activity in this soil. It has been shown in a number of studies that the activities of microorganisms depend on the availability of nitrogen. Because nitrogen controls the growth and rate of turnover of soil microorganisms, it plays a key role in the net decomposition of organic matter (Van Kessel *et al*., 2002).

In the study, net mineralization of manure was observed and the net rates varied ranging from 0.04 to 0.33 mg Nkg^{-1} /day with the mean value 0.21 mg N kg^{-1} soil day^{-1}. The net rate of mineralization was highest during the initial periods of incubation and then slowed down during the latter periods. The observed high rates of mineralization during the initial phase might be attributed to decomposition of “fast” organic nitrogen pool. Studies indicate that manure contains fast and slow organic nitrogen pools with different mineralization rates (Lerch *et al*., 1992). The fast or rapid organic nitrogen pool is made up of amino acids and proteins ((Lerch *et al*., 1992). These organic compounds degrade rapidly (with in 2 to 4 weeks in laboratory incubation). The slow organic nitrogen pool is made up of more resistant nitrogen compounds that take months or years to complete decomposition. The highest net rates of mineralization during the initial phase observed in the present study indicates that application of manure 3-4 months before transplanting of suckers, as generally practiced by traditional farmers, may cause a substantial loss of nitrogen mineralized. Therefore, application of manure close to transplanting is recommended so that the establishing suckers may utilize the initial mineralized nitrogen. In the present study, the mean net mineralization rate was found to be 0.21 mg N kg^{-1} soil per day therefore; 31.5 mg organic nitrogen kg^{-1} soil would be mineralized during 150 days of incubation. Because the manure in this incubation was applied at a rate of 200 mg organic Nkg^{-1} soil, this is equivalent to mineralization rate of 16%. This mineralization coefficient is close to those reported by various researchers. Griffin, He and Honeycutt (2005) estimated mineralization rates of different manures and reported an average of 10% per growing season. Abbasi *et al.* (2007) reported mean mineralization coefficient value of 11 % for three manures (Cattle, sheep and poultry) over 120 days of incubation. Eghball *et al*. (1997) estimated organic nitrogen mineralization of 11% for composted manure and 21% for non-composted manure during the corn-growing season. Wen *et al*. (1995) reported apparent N mineralization of approximately 10% from a manure compost over a field-growing season, as measured by crop N recovery. It is normally considered that organic amendments added to the soil that have a C/N ratio of less than 20:1 are likely to result in net mineralization of N (Alexander, 1977; Abbasi *et al*., 2007). The observed net nitrogen mineralization throughout the incubation period in this study, thus, may be attributed to favorable C/N ratio (18:1) of the manure use in the incubation study. Moreover, the observed 16% mineralization rate in the present study suggests that the manure used was slow release nitrogen source. This slow release manure is highly valued for perennial crops like enset because of its value in long-term soil building.

Nevertheless, it has limitations in enhancing short-term nitrogen availability. Thus, higher rates of application may be required to increase its short-term soil nitrogen supply. Nitrification is the conversion of NH_4-N^+ into NO_3-N through microbial oxidation (Gasser, 1970). Nitrification is a two-step process in which NH_4 is converted to nitrite (NO_2^-) and then further to NO_3^-, by *nitrosomonas* and then *nitrobactor* bacteria, respectively. Nitrification is a microbial process and therefore highly dependent on the soil environment conditions. Several factors that influence the rate of nitrification include supply of NH_4^+, population of nitrifying organisms, soil pH, moisture and temperature (Havilin *et al*., 2005). The amount and supply of available NH_4^+ with respect to the population of nitrifying organisms will play an important role on the nitrification process. In the present study, NO_3-N accumulated in soil with manure amendment was significantly higher than that of the control soil. Accumulation of NO_3-N in manure-amended soil was 35 mg kg^{-1} soil relative to 16.6 mg kg^{-1} in control soil. Soil with manure amendment had accumulated about 2.1 times more NO_3-N than the control. This is probably due to the presence of higher concentration of ammonium in manure treated soil than in control soil. Nitrification of added manure (mean net nitrification over 150 days of incubation) was found to be 17.78 mg kg^{-1} of soil. The proportion of total inorganic N to NO_3-N indicates that a total of 43 % of mineral nitrogen from manure added soil and 26.5 % of mineral nitrogen from control soil, were converted to NO_3-N during 150 days of incubation. The result indicates that the soil had low potential for nitrification. The low nitrification potential of the nitrifying organisms in the soil of the present study might be due to acidic nature of the soil (4.8), which may have decreased the growth and activity of the nitrifier microorganisms in the soil. Nitrification is reported to be most rapid around neutral pH and decreases in substrates with high and low pH (Sahrawat, 2008). In support of this Havilin *et al.* (2005) also indicated that soil pH of 8.5 is optimum for nitrification, although the process can occur between the pH ranges of 4.5 to 10. In the study, NH_4-N was the dominant form of inorganic nitrogen, which agrees with that reported by Maithani *et al*. (1998) and Abbasi *et al*. (2007). In contrast, Yousif and Mubarak (2000), who worked on alkaline soil (pH >7) obtained NO_3-N as the dominant form of inorganic nitrogen. Retention of a large proportion of ammonium in mineral pool of the soil has important significance particularly in high land areas like Hagereselam where leaching and denitrification are important pathways of nitrogen losses.

4.2. Effect of rates of manure nitrogen supply on growth, biomass production and nitrogen use efficiency of some selected enset clones

In the present study, height (Table 3.10) and pseudostem girth (Table 3.12) of enset clones were significantly influenced by nitrogen treatments when compared to the controls. Both parameters increased with increase in nitrogen levels. The difference between the two clones was also significant with respect to girth. In both the clones studied, the highest height and girth increase was obtained in plants that received the highest rates of manure nitrogen supply and the lowest recorded from control plants. The observed positive effect of nitrogen supply on growth of height and pseudostem girth of enset signifies the well-known role of nitrogen in plant growth and development. Growth is determined by the available incident radiation, by the proportion of radiation absorbed by the canopy and the efficiency by which absorbed radiation is converted into biomass (Barneix, 1990). Effects of nitrogen on growth might result from the effects on photosynthetic rate and/or leaf area development (Novoa and Loomis, 1981), and hence, on light interception. Nitrogen is also an integral component of many compounds that are essential for growth including chlorophyll and many enzymes (Mkhabela *et al*., 2001). Our findings are in general agreement with previous reports (Yohannis Uloro and Mengel; 1994; Kelsa Kena, 1996; and Abay Ayalew and Mikias Yeshitila, 2011), who reported increase in height and girth of enset plants in response to inorganic nitrogen fertilization. Positive increase of plant parameters of growth in response to nitrogen application has also been reported for a number of other crops other than enset such as banana (Srnivas, 1997), rice (Hiluf G/kidan and Mulugeta Seyoum, 2006), wheat (Maqsood *et al*., 2001; Kenbaev and Sade, 2002; Salwa *et al.*, 2005; Arif *et al.*, 2006), maize (Akbar *et al.,* 1999; Onasanya *et al*., 2009, Amanullah *et al*., 2009).

Nitrogen supply significantly influenced number of green leaves of both clones in this study. The study also showed the existence of significant differences between clones for number of green leaves. Increasing the nitrogen rates resulted in more green leaves per plant with the highest mean values at 600 kg N ha^{-1}. The significant differences observed in number of green leaves among nitrogen rates is indications that the number of leaves produced by enset plants was affected by levels of nitrogen supply. The high sensitivity of leaf growth to nitrogen availability has also been demonstrated in many studies such as wheat (Jacob and Lowlor, 1991; Rodriguez *et al*., 1998), on sunflower (Radin and Boyer, 1982), on banana (Srinivas, 1997), maize (Gungula *et al*., 2005; Onasanya *et al.*, 2009) and rice (Aluko and Fischer, 1989). The number of green leaves maintained by the enset clone *Ado* was significantly higher than that of *Ganticha*, which may imply the existence of clonal differences in performance despite exposure to similar rate of nitrogen supply.

Results showed that total leaf area of enset clones was significantly affected by rates of nitrogen supply. The difference between clones and clone by nitrogen rate interaction was also significant with respect to total leaf area. The total leaf area increased with increasing rate of nitrogen application. The leaf area been largely a result of cell division and cell expansion and it is well established that nitrogen affects both of these processes in the leaf and hence, the leaf area development. The limitation of cell division and expansion under condition of nitrogen deficiency are the results of decreased protein and RNA synthesis. Thus, the reduction in total leaf area of enset plants grown under low nitrogen supply compared to higher nitrogen supply signifies the crucial role of nitrogen in leaf area development. Our results are in general agreement with previous observations in different plant species such as rice (Hassan *et al*., 2005), lettuce (Boroujerdinia and Ansari, 2002), and maize (Gungula *et al*., 2005).

The data on the effect of nitrogen supply on the development of leaf area index showed that it increased with increasing levels of nitrogen supply (Fig 3.9). The difference between the two-enset clones was also significant. The increased leaf area index with increasing nitrogen supply may be due to the effect of nitrogen on the rate of growth of meristem and the appearance and development of leaves. The observed differences between the clones may be related to the difference in the number of green leaves maintained and the higher leaf area growth. The enset clone *Ado* that maintained the highest number of green leaves and having the highest area showed the highest leaf area index value. Biomass production of a crop is dependent on the amount of radiation intercepted and efficiency of use in dry matter production. The amount of incident radiation intercepted in turn depends on the rate of leaf area development. In this study, the enset clone *Ado*, which achieved the highest leaf area index had also produced a significantly higher dry matter yield compared to the enset clone *Ganticha*.

Results of chlorophyll contents showed the presence of significant differences under variable nitrogen levels (Table 3.15). The chlorophyll content values increased with increasing levels of nitrogen application. Across nitrogen rates, the mean chlorophyll contents of the enset clone *Ado* was higher than the enset clone *Ganticha* though the difference was not statistically significant. The increase in chlorophyll content with increasing levels of nitrogen supply might be attributed to increased nitrogen availability that eventually resulted in higher leaf nitrogen and hence, higher leaf chlorophyll content. Since most nitrogen in the plant system is contained in the rubisco enzyme found in chloroplasts and chlorophyll proteins, there is a close relationship between leaf nitrogen and leaf chlorophyll content (Blackman and Schepers, 1995; Chapman and Barreto, 1995). The existence of positive linear relationship between chlorophyll content and nitrogen supply (Maurmicile *et al*., 2006; Boonlertninum *et al*., 2010) and between SPAD values and leaf nitrogen and total chlorophyll content is well documented (Pang *et al*., 1996; Bojovic and Stojanovic, 2005; Sabo *et al*., 2002; Fritschi and Ray, 2007; Houles *et al*., 2007; Hokmalipour and Darbandi, 2011). Early symptoms of nitrogen deficiency are a general yellowing of leaves, or chlorosis, due to an inhibition of chlorophyll synthesis (Marschner, 1995).

Varying levels of nitrogen supply showed significant influence on photosynthetic rate of the two-enset clones (Fig 3.10). The photosynthetic rate in plants under high nitrogen supply was significantly higher than in control plants. Physiological response of plants to nitrogen availability has been well documented (Egli and Schmid, 1999; Shangguan *et al.*, 2000; Chen *et al*., 2005). Sugiharto *et al.* (1990) found a significant and positive correlation between photosynthetic capacity and nitrogen concentration of plant leaves suggesting the most of the nitrogen is used for synthesis of components of the photosynthetic apparatus. It is generally established that increase in nitrogen supply increases the rate of leaf production as well as the development of individual and total leaf area, resulting in an increased area for light interception. In addition, increase in nitrogen availability results in increase in carboxylases and chlorophyll content, all of which determine the photosynthetic activity of the leaf and ultimately dry matter production and allocation to the various organs (Brown *et al*., 1996; Aluko *et al*., 1987; Sinclair and Horie, 1989). Marked differences in photosynthetic rates under varying levels of nitrogen supply were reported by various researchers (Sharma and Singh, 1994; Momin, 2003; Hamid *et al*., 2004; Hassen *et al*., 2007). The photosynthetic rate of the enset clone *Ado* was higher than *Ganticha*, although the difference was not statistically significant.

Application of different nitrogen rates had an effect on dry matter yield of both clones (Fig.3.11). The biomass yield of both clones increased significantly with increasing nitrogen application. However, the biomass yield increase obtained beyond nitrogen application rate 300 kg ha^{-1} for clone *Ganticha* and 450 kg ha^{-1} for clone *Ado* did not differ significantly. Lack of significant difference at the nitrogen rates 300, 450 and 600 kg N ha^{-1}, in case of the enset clone *Ganticha* and between nitrogen rates 450 and 600 kg ha^{-1} in case of the enset clone *Ado*, suggests that the rate of nitrogen fertilizer may be adjusted according to the clones to improve nitrogen use efficiency; while maintaining potential yield. The yield response of the two-enset clones under varying levels of nitrogen supply also differed significantly. The enset clone *Ado* produced significantly higher total plant dry matter than *Ganticha*. The maximum dry matter yield accumulated by clone *Ado* was 14.5 % higher than the maximum yield achieved by clone *Ganticha*. Nitrogen provides needed matter for growth of vegetative organs (Hamidi and Dabagh and Mohamadinasab, 1996). High nitrogen rates can promote leaf area development during vegetative development and it can help maintain functional leaf area during the growth period (Cox and Cherry, 1997). Biomass production of a crop is dependent on the amount of radiation intercepted and its efficiency of use in dry matter production. The development and maintenance of green leaf area, thus, are important determinants of the proportion of incident radiation intercepted. In the present investigation, increase in number of leaves, leaf area and chlorophyll content and hence, photosynthetic capacity with increase in nitrogen levels might attribute to observed higher biomass production of plants in response to increasing nitrogen supply. In addition, the significant differences in number of green leaves, leaf area and leaf area index might be the reasons for the variation in total plant dry matter production between the two enset clones. Increase in vegetative growth, photosynthetic capacity and dry matter accumulation with increasing levels of nitrogen supply have also been reported for various crops such as corn varieties (Allen and Morgan, 1972; Gluser, 2005; Sadeghi and Bahrani, 1998; Gungula *et al.*, 2005; Cox *et al*., 1999; Davani *et al*., 2010), wheat (Balasubramanian and Singh, 1982), barley (Ryen et al., 2009), perennial grasses such as bluegrass, smooth bromagrass, and orhcardgrass (Zemenchik and Albrecht, 2002) .

Rates of nitrogen supply also influenced the proportion of dry matter allocated to belowground and aboveground parts (Table 3.17). Enset clones grown under low nitrogen supply allocated relatively higher percentage of their biomass to belowground parts than plants under higher nitrogen supply. Altered biomass partitioning under low nitrogen supply have been considered as strategy in coping up with the stress condition. An increase in dry matter allocation to the root under nitrogen deficiency is well-established (Brouwer, 1962; Ingestand and Lund, 1979; Van der Warf *et al*., 1993; Paponov *et al*., 2000).

Harvest index (the ratio of economic yield to biological yield) and it was significantly affected by various nitrogen levels (Table 3.18). Maximum harvest index (0.61) was obtained at nitrogen rate 300 kg/ha and the lowest harvest index was observed from treatment receiving 600 kg/ha. The harvest index is used to asses' crop efficiency and forecast potential crop yield. The observation indicates that enset harvest index varies with level of nitrogen that is applied in cultivation of the crop. It decreases with increasing rates of nitrogen fertilizer. This explains that vigorous vegetative growth of the plants promoted by higher rates of nitrogen application results in lower harvest index by favoring higher dry matter accumulation in the leaves than pseudostem and corm. This suggests that an optimum supply of nitrogen is essential for favorable partitioning of dry matter between (e.g., corm and pseudostem) and other parts of the plant. A number of similar studies reported decreasing trends of harvest index with increasing rates of applied fertilizer for maize (Maobe *et al*., 2010), rice (Kumar and Rao, 1992; Patra *et al*., 1992; Hari *et al.*, 1997; Heluf Gebrekidan and Mulugeta Seyoum, 2006).

Nitrogen uptake in the aboveground and belowground biomass was significantly influenced by rate of nitrogen supply, by the type of enset clone and their interaction (Table 3.20 and 3.21). Nitrogen uptake by both aboveground and belowground parts significantly ($P \leq 0.001$) increased with increasing levels of nitrogen supply. Of the two clones, the clone *Ado* absorbed the largest mean amount of nitrogen, which was significantly higher than that absorbed by enset clone *Ganticha*. This corresponded with this clone (*Ado*) producing the highest biomass yield. The enset clone *Ganticha* absorbed comparatively less nitrogen and ended up with the lowest biomass yield averaged over all nitrogen levels. A very close relationship between nitrogen uptake and dry matter production has been reported for various crop species such as maize (Bundy and Carter, 1988; Farooq *et al.*, 1994; Mkhabela *et al*., 2001), Cabbage (Baitilwake *et al*., 2011), wheat (Yasin *et al.*, 1991), rice (Zia *et al*., 1994; Aluko and Fischer, 1989).

Nitrogen agronomic efficiency or amount of biomass yield produced per unit of nitrogen applied is one of the most important indices of nitrogen use efficiency. The nitrogen agronomic efficiency data presented in Table 3.23 suggest that the highest return from manure nitrogen fertilizer 11.2 kg biomass yield per kg of nitrogen fertilizer rate was obtained with the lowest nitrogen fertilizer rate (300 kg N ha^{-1}). Each succeeding nitrogen fertilizer rate resulted in gradual decline in nitrogen use efficiency reaching 61% between the lowest and the highest agronomic efficiency. The results indicated that the capability of yield increase per kilogram of nitrogen applied declined remarkably with increasing nitrogen application. Similar results have been reported by various researchers in different crop species (Tyefe *et al*., 2011; Mooleki *et al*., 2002; Wen *et al*., 2003a; Quanbao *et al*., 2007), who reported that increase in nitrogen fertilizer rate results in decrease of its nitrogen use efficiency. The highest reduction in yield was obtained at nitrogen rate 600 kg N ha^{-1}. The observed decline in agronomic nitrogen use efficiency with increasing nitrogen supply might be associated with diminishing returns with increasing inputs. The incremental yield gain obtained per unit of applied nitrogen becomes smaller and smaller as the rate of nitrogen supply increased. Of the two clones studied, the enset clone *Ado* performed better than the enset clone *Ganticha* through the entire nitrogen level ranges. These results indicated that potential of selecting nitrogen use efficient enset clones.

The apparent recovery of fertilizer nitrogen reflects the efficiency of the crop in obtaining fertilizer nitrogen applied to the soil. It is one component of nutrient use efficiency (Moll et al., 1982). Results of the present study showed that enset clones and nitrogen rates affected nitrogen recovery. Moreover, there was a significant interaction between enset clones and nitrogen rates for recovery efficiency (Table 3.24). In this study, the highest nitrogen recovery by aboveground and belowground biomass was obtained at lowest nitrogen rate (300 kg N ha^{-1}) and the lowest nitrogen recovery efficiency was obtained at higher rate (600 kg N ha^{-1}) indicating that fertilizer nitrogen applied more efficiently utilized at lower application rate (Table 3.25 and Table3.26). Many other researchers found a similar trend on various crop species (Farooq *et al.*, 1994; Limon-Ortiga *et al*., 2000; Jarwar *et al*., 2005; Zhas *et al*., 2006; Quanbao *et al*., 2007; Tayfe *et al*., 2011). At the higher manure application rates, crop nitrogen uptake (kg N ha^{-1}) of manure generally reaches a plateau as the crop can only take and accumulate finite amount of nitrogen. Therefore, manure nitrogen recovery as a proportion of the applied decreased with increasing application rate (Mooleki *et al*., 2002; Wen *et al*., 2003a).

The nitrogen recovery of manure nitrogen in this study (aboveground plus belowground parts) ranged from 20 to 28% at higher and lower nitrogen rates, respectively and it is in broad agreement with that of Kirchman (1985) who reported 15-35% recovery by the first crop after manure application. Paul *et al*. (1990) also reported a range of apparent recoveries in silage corn of 5-28% for cattle manure and 14-95% for inorganic fertilizer. In fact, direct comparisons of results of nitrogen efficiency could be difficult because of several reasons. Reported estimates of fertilizer nitrogen use efficiencies vary widely, as do reporting methods themselves. Foremost, large range of values mainly attributable to variations among the climatic, edaphic, crop and soil management factors. Moreover, estimates of fertilizer nitrogen recovery can be based on either the amount of nitrogen in the grain, aboveground biomass, or whole plant biomass. In our present investigation the calculations of nitrogen recovery was based on the whole plant biomass including those recovered by the roots.

The enset clones also showed variations in that the enset clone *Ado* showed the highest nitrogen recovery efficiency compared to *Ganticha*. The interactions between nitrogen supply and clone were also highly significant. The enset clone *Ado* showed better performance at both low and high nitrogen supply compared to *Ganticha*. Genotypic differences in the efficiency of nitrogen acquisition may arise from differences in the efficiency of absorption and assimilation of nitrogen (Kundu *et al.,* 1996) and/or differences in the extent and distribution of roots (Kundu and Ladha, 1997). Significant genetic variation in nitrogen uptake efficiency has been demonstrated among genotypes of oilseed rape (Kessel and Becker, 1999), wheat (Alizadeh and Ghaderi, 2006), maize (Pollmer *et al*., 1979; Moll *et al*., 1982; Muruli and Paulsen, 1981).

The physiological nitrogen use efficiency decreased significantly with increasing levels of nitrogen supply (Table 3.28). Maximum physiological nitrogen use efficiency (39.3 kg kg^{-1}) was found under nitrogen supply 300 kg N ha^{-1} supply followed by 150 kg N ha^{-1} supply and 450 kg N ha^{-1} supply. The lowest physiological nitrogen use efficiency (33.1 kg kg^{-1}) was observed at 600 kg N ha^{-1} supply. Decrease in physiological nitrogen use efficiency with increasing levels of nitrogen might have been due to association with diminishing returns with increasing inputs. Every additional increase in the dose of nitrogen brings about less than proportionate increase in yield as compared to preceding dose. This is due to the fact that fraction of nitrogen recovered through plant decreases progressively as the amount of nitrogen application increases. Decrease in physiological nitrogen use efficiency with increasing rates of nitrogen supply also reported by different researchers (Kanwar *et al*., 1984; Somani *et al.,* 1989).

The enset clone *Ado*, which achieved the highest level of agronomic and nitrogen recovery efficiency had also produced significantly higher physiological nitrogen efficiency than the clone *Ganticha*. Nitrogen supply by clone interactions was also significant with respect of physiological nitrogen use efficiency. The enset clone *Ado* showed the highest physiological efficiency value (kg of yield per kg of taken up) at both low and high nitrogen supply regimes compared to that of *Ganticha*.

In the present investigation, clones, levels of nitrogen and sampling depth caused significant difference in the available nutrient status of soil at harvest stage (Table 3.30). Residual nitrogen of soil immediately after harvest of enset was low in plots of enset clone *Ado* compared to that of *Ganticha*. The relatively lower residual nitrogen in plots of enset clone *Ado* might be related to higher uptake efficiency by this clone. In plots where nitrogen was applied at higher dose, residual nitrogen status was higher, where as in plots where nitrogen was applied at lower levels, the crop would have drawn the requirements from the soil and hence it had lower residual nitrogen after harvest. The residual inorganic nitrogen also showed significant decline with depth of sampling. This probably attributed to higher mineralization rate of manure organic nitrogen in the upper soil layer and the less movement of inorganic nitrogen to lower soil layers.

The overall average nitrogen recovery (30%) of manure nitrogen both in the crop plus in the soil observed in the present investigation suggests that more than one-third of manure nitrogen became plant available during the first year of application. In this study, ammonium was found to be the predominant form of inorganic nitrogen, which is less mobile in soil.

4.3. Effects of manure placement on growth, biomass production and nitrogen recovery

In the present investigation, a significant difference in crop growth, biomass production, and nitrogen recovery in response to fertilizer placement was observed. The manure placement method, whereby the full dose of manure applied as top dressing supported less growth and biomass production of enset plant compared to bottom dressing or a split combination application. The significant difference recorded in plant growth and biomass yield, thus, suggest that placement of manure probably affected nutrient release pattern and the eventual quantity of nutrients available to plant roots for absorption and utilization by the crop. Bottom dressing and split application might have increased crop uptake of manure nitrogen not only by reducing NH_3 volatilization, but also by bringing manure deeper into the soil, thus making it more available to plant roots. When applied to the surface, solid manure remains on the surface and movement of manure nitrogen down to the soil profile is minor especially when NH_4^+ is the major form of inorganic nitrogen (Sommer *et al.,* 2004). In addition, lack of intimate contact between the soil and manure, in case of surface applied manure, would reduce mineralization and nitrification of manure nitrogen. For mineralization and nitrification, the manure must be in a location where conditions permit microbial activity (Mattila, 2006). Our observation is also in line with the reports of similar studies conducted elsewhere. Carter *et al*. (2010) reported that surface broadcast application of manure resulted in significant nitrogen loss as ammonia, reducing manure nitrogen available to crop and potentially lowering yields. Manure application to the soil surface may not be as effective as incorporated manure for crop production because of potential nitrogen loss (Eghball and Power, 1999). Baiyari and

Tenkouano (2007) studied manure placement effects on root, shoot growth of plantain, and reported that split dressing at the top and the bottom gave the best growth followed by bottom dressing. Application methods that immediately incorporate manure into the soil can reduce volatilization losses of NH_3 by 80>90% (Thompson *et al.*, 1987; Lockeyer *et al*., 1989; Thompson and Meisinger, 2002; Schoenau, 2005). Furthermore, they suggested that to minimize volatile ammonia loss during application, it is essential that anhydrous ammonia be placed at a depth sufficient to give the ammonia gas opportunity to react with water and convert to the ammonium form, which is retained in the soil and therefore for plant uptake. Other researchers (Hoff *et al.,* 1981; Dendooven *et al.*, 1998; Chantingny *et al.*, 2001) also noted lower volatilization rates of manure with incorporation.

Fertilizer best management practices are based on the concept of applying the right fertilizer at the right rate, right time, and right place (Fixen and Reetz, 2006). The results of the present study showed that bottom dressing or split application support better biomass growth and better nitrogen recovery efficiency than placing manure on the surface of the soil.

4.4. Effect of traditional method and duration of storage on manure chemical composition and quality

The study showed that both the method and duration of storage have significant effects on carbon and nitrogen contents of cattle manure. After storage, manure stored uncovered has lost about 21% of its initial carbon compared to that of covered manure (Table 3.41) This could be attributed to greater decomposition of carbon from manure stored in open air, which increases oxygen access to manure. Conversely, low carbon losses from covered manure could be attributed to reduced aeration, which restricts microbial activity and thus decomposition of organic matter (Hanssen *et al*., 2006). Nitrogen losses were also significantly ($P \leq 0.001$) affected by the storage condition and were lowest from covered heap (about 12%). On the other hand, 41% of the total nitrogen was lost from manure stored in uncovered heaps (Table 3.41). At the end of storage period, NH_4-N concentration was lower in uncovered manure heap, probably due to by loss of NH_3 volatilization. In this study, no NO_3-N was detected in samples from covered and uncovered storage treatments. In addition, the quantity of rainfall recorded during the study periods was quite low. Consequently, less loss of nitrogen through leaching. Covering the manure heaps blocks air circulation, slows organic matter degradation, and lowers internal heat production as well as the pH, which reduce the NH_3 emission. Furthermore, the formation of nitrate is prevented through anaerobic conditions and thus also the possibility of denitrification losses (Kirchmann, 1985). The losses of nitrogen from manure stored under different condition have also been indicated in studies carried out elsewhere. Harris (2002) found nitrogen losses of up to 59% from manure stored under open air in Ghana. Murwira (2004) reported less loss of ammonical nitrogen from manure composed anaerobically in pit than composted aerobically in an open air.

In addition, the method and duration of manure storage have significant influence on C/N ratio of manure. Irrespective of the methods, the C/N ratio of the manure increased with increasing duration of storage. However, the manure stored in heaps in open air had significantly higher C/N (27:1) ratio compared to covered one (22:1). Obviously, such changes in C/N ratio have significant influence in the mineralization of manure organic nitrogen and the availability to plants. Al-Kanani *et al*. (1992) reported that the C/N ratio between 15 and 25:1 as an ideal ratio for net mineralization. When the C/N ratio is greater than 25:1 a deficiency of nitrogen likely to occur, thereby restricting the growth of microbial population responsible for decomposition of manure nitrogen. Therefore, the high C/N ratio that resulted from uncovered manure storage in the present study would likely to result in immobilization of nitrogen and hence, reduced availability to the crop.

Overall the results of this study indicated that the traditional manure management practices commonly used by farmers in enset system is likely to result in significant nitrogen and carbon losses and hence in poor manure quality with very low contents of plant available nutrients. The present study also revealed significant effect of duration of storage on the nutrient content of manure. Irrespective of the storage methods, the nutrient content such as nitrogen decreased significantly with increasing duration of storage. The result suggest that reducing the period of storage or more frequent application followed by immediate incorporation into the soil could have larger impact on retaining of nitrogen within the farm.

5. SUMMARY AND RECOMMENDATIONS

The present study provides information on mineralization and nitrification potential of cattle manure. It also provides information on the effect of varying levels of manure nitrogen supply on growth, biomass production, and nitrogen use efficiency of enset; including information on the influence of methods of manure placement on growth performance and nitrogen recovery of enset. In relation to manure handing management, the study also highlights the effect of traditional methods and duration of manure storage on manure chemical composition and quality. The major findings of the study are summarized as follows.

Mineralization and nitrification of manure organic nitrogen

In the present study, a laboratory incubation study was undertaken to determine the rate of manure organic nitrogen mineralization and nitrification. Nitrogen release potential of organic manure was determined by measuring changes in total mineral nitrogen periodically over 150 days of incubation. The results revealed that addition of manure significantly increased the amount of inorganic nitrogen released compared to that of the control soil (soil without amendment). Moreover, net mineralization of organic nitrogen of manure was observed throughout the incubation period as measured by an increase in total inorganic nitrogen after taking into account the initial mineral nitrogen present in manure and control soil. The net rates varied between 0.04 to 0.33 mg N kg^{-1} of soil/day with mean value of 0.21 mg N kg^{-1} soil/day. The net rates of mineralization were highest during the initial periods of incubation and slow during the latter periods. This indicates that that application of manure 3-4 months before transplanting suckers as generally practiced by farmers may cause substantial loss of nitrogen mineralized. Therefore, application of manure close to transplanting and immediate incorporation into the soil is recommended so that the initial mineralized nitrogen may be well utilized by establishing enset suckers.

In the present investigation, the maximum net nitrogen released from manure was 21 mg/kg soil by day 90. Based on this value, the net nitrogen released as percent of added nitrogen from manure was 10.5%. This demonstrates that the manure was slow release nitrogen source. This result in turn indicates the value of this amendment in long-term soil building and its limitations in enhancing short-term nitrogen availability. Thus, very large amendment application rates may be required to increase short-term soil nitrogen supply.

In the present study, the proportion of total inorganic N to NO_3-N indicates that a total of 43 % of mineral nitrogen from manure added soil and 26.5 % of mineral nitrogen from control soil, were converted to NO_3-N during 150 days of incubation. The result indicates that the soil had low potential for nitrification and a substantial amount of ammonium remained in the mineral pool after 150 days of incubation. The potential of a soil to retain the applied NH_4^+ in the mineral pool is desirable characteristic particularly for highland areas where leaching and denitrification are important pathways of nitrogen losses.

Rate of manure nitrogen supply and nitrogen use efficiency

The results showed that nitrogen supply significantly affected all the growth parameters studied, biomass yield and nitrogen use efficiency of the two enset clones. The observed increase in growth of enset with nitrogen supply has affirmed the widely known effects of nitrogen on crop growth and biomass production. The observed growth response of fertilized plants over the unfertilized (control) plants showed the beneficial effect of fertilizer application to increase the productivity of enset crop within the environment of this study. However, application of nitrogen beyond 300 kg N ha^{-1} and 450 kg N ha^{-1}, in clone *Ganticha* and *Ado*, respectively, did not result in any significant increase in most of the parameters studied, indicating the need for optimizing the rate of nitrogen application to most economical level. The higher soil residual inorganic nitrogen at higher levels of nitrogen supply observed in the present study also suggest the need to reduce the rate of fertilizer application to the level of crop demand.

The nitrogen efficiency (agronomic, recovery and physiological efficiency) also decreased with increasing levels of nitrogen supply. In the present study, the highest nitrogen efficiency values were observed at 300 kg N ha^{-1} than 600 kg N $ha^{-1.}$ The higher nitrogen efficiency at lower fertilization levels indicate the possibility for reducing manure inputs to most economical level without having significant reduction in yield (The yield variation between these two levels small and even non significant in case of the enset clone *Ganticha*). Application of nitrogen fertilizer to the level of highest efficiency not only makes nitrogen fertilization more profitable, but also reduces the potential negative impacts to the environment (Fixen, 2004). The study also showed the existence of significant variation between the two-enset clones in nitrogen use efficiency. Of the two clones studied, clone *Ado* showed superiority in over the enset clone *Ganticha* in both biomass yield and nitrogen use efficiency. This indicates the existence of genetic potential for improvement of the productivity of resource poor farmers through selection and breeding of enset clones for higher nutrient use efficiency.

Manure placement effect

The present study revealed that methods of manure placement significantly affected growth, biomass yield, and apparent nitrogen recovery of enset. In the study, incorporation of manure into the soil or split application above and below the soil surface induced better growth, biomass yield and nitrogen recovery efficiency compared to surface application. Therefore, incorporation of manure into the soil is recommended to increase its efficiency of utilization by the enset crop.

Method and duration of manure storage

The results of this study showed that the current practice of handling and storage of manure by traditional farmers is inefficient due to considerable losses during manure storage. Storage of manure in heap in open air not only reduces the carbon and the nitrogen content of manure but also increase the C/N ratio. The high C/N ratio coupled with low ammonium content could result in immobilization of nitrogen and may result in delay of availability to the crop. The carbon and nitrogen losses during manure storage can be reduced remarkably by covering the heaps with impermeable plastic sheet. In addition, covering of the manure increased ammonical content that may subsequently improve manure nitrogen utilization after field application.

The study also showed significant effect of duration of manure storage on manure quality. Irrespective of the storage method used, increasing the duration of storage decreases the quality of manure. Therefore, immediate application and incorporation into the soil is recommended to obtain greater value from manure and increasing its efficiency of utilization by the crop.

Based on the results of this study it can be concluded that enset growth and yield in smallholder farms can substantially be increased with planting nitrogen efficient clones along with improved crop management practices.

Aspects that need future investigation:-

1. Further study on manure nitrogen efficiency under variable environment: Under field conditions, the uptake, recovery, and utilization of manure nitrogen can vary widely depending on its interaction with environmental conditions such as climate, soil, and crop. Our present investigation was carried out at one site, the recommendations of which may not be applicable to the whole region. Therefore, similar researches need to be conducted with some more clones under variable agro ecological conditions to come up with recommendations that would apply to the whole regions.

2. On relationship between cattle feed and manure quality. Livestock production is an important component of enset-based farming system. Thus, future research and development studies on enset need to include a research component that alleviates constraints to livestock productivity. In addition, optimization of the utilization of nutrients in cattle manure requires a whole chain of approach from cattle feed via the cattle manure to the soil and crop. There are also reports indicating that the nutrient content of manure is closely related to the chemical content of the feeds consumed. Studies conducted elsewhere also showed the existence of strong relationship between cattle feed and manure quality. Thus, we feel that there is a possibility of improving manure quality through better management of animal feed coupled with improved collection and storage methods. However, the quantitative understanding of the relationship between cattle feed and manure quality is lacking in Ethiopia in general and enset system in particular. Future research should focus on assessing the effects of feed on the manure composition and its value as fertilizer. Moreover, nitrogen loss (directly) after excretion, before manure is collected and stored requires further attention

3. On nitrogen supply and water stress interaction: Nowadays owing to increasing population pressure and land shortage, enset farming is expanding to moisture stressed low lands with marginal soils. Consequently, enset plants in the middle and low altitudes are experiencing differing degrees and length of drought and low nitrogen supply. Limited researches works available, so far, have focused on the effects of either drought or nitrogen supply but have ignored the complex interaction between these two factors, which are of importance for selecting nitrogen efficient and drought tolerant clones. Thus, future work in this area should target on the effects of water and nitrogen interaction on the productivity and nitrogen efficiency of enset clones.

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7. APPENDICES

Appendix 1:Characteristics of soil (0 to 20 cm depth) used for placement experiment

Texture			PH	Organic	Total	Phosphorus (%)
Sand	Clay	Silt	H_2O	Carbon (%)	Nitrogen (%)	
58	25	17	4.8	3.3	0.3	7.9

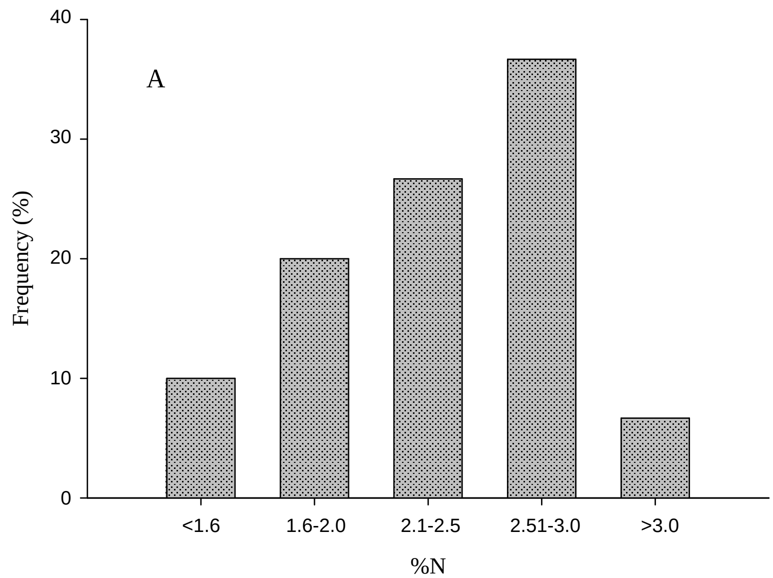
Appendix 2: Characteristics of manure sample used for placement experiment

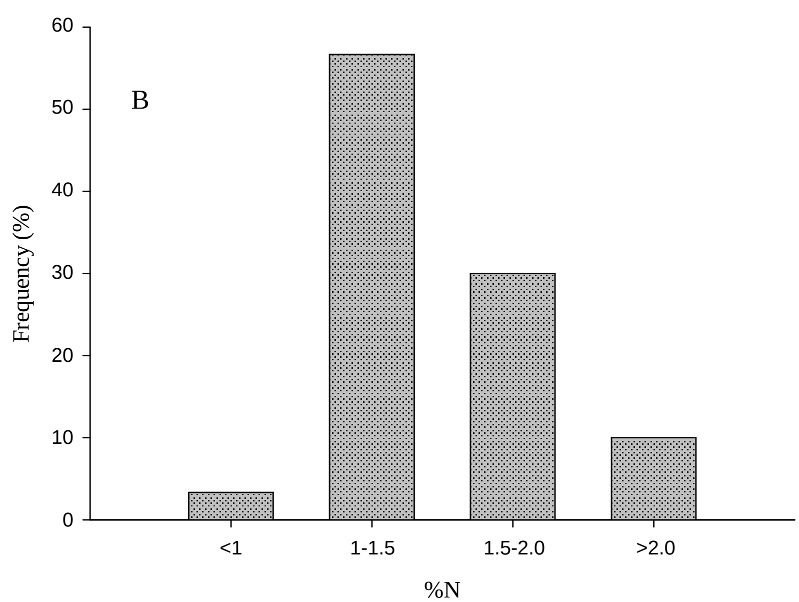
Total nitrogen (wet-weight basis)	PH H_2O	Organic Carbon (%)	Organic matter	Phosphorus (%) Wet-weight basis
0.4	8.2	34	58	0.22

Appendix 3: Mean characteristics of manure samples collected from 30 households in Hagereselam during wet and dry seasons, 2009-2010.

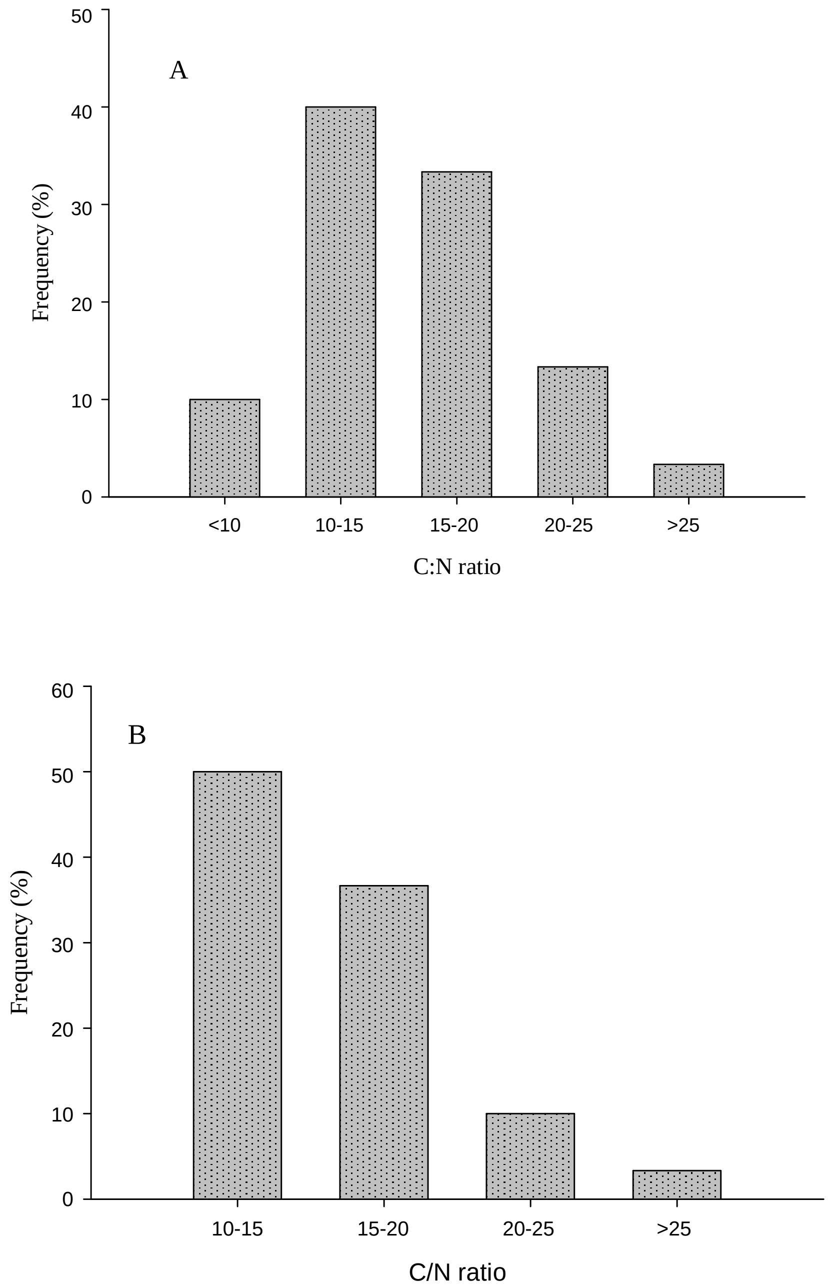
Season	Variable	Mean	SD	Minimum	Maximum
Wet	%N	2.27	0.47	1.43	3.12
	%C	34.2	4.26	25.9	38.6
	C:N	15.9	4.33	9.7	26.8
Dry	%N	1.53	0.33	0.94	2.26
	%C	23.9	3.8	15.4	28.9
	C:N	16.3	4.4	10.4	29.1

Appendix 4: Frequency distribution of the nitrogen content (%) of wet (A) and dry (B) season manure samples from Hagereselam, Sidama





Appendix 5: Frequency distribution of C/N ratio of wet (A) and dry (B) season manure samples from Hagereselam, Sidama



Appendix 6: Showing total mineral nitrogen (TMN), ammonium nitrogen and nitrate nitrogen analysis result from two enset plots, *Ado* and *Ganticha*

A. Soil from *Ado* plots

N-level	Depth	TMN(kg/ha)	NH4-N(kg/ha)	NO3-N(kg/ha)
0	0-30	38.6	31.8	6.8
	30-60	34.3	22.1	12.2
	60-90	13.1	13.1	-
150	0-30	45.5	38.6	6.9
	30-60	48.9	35.7	13.2
	60-90	42.0	28.8	13.2
300	0-30	45.5	43.2	2.3
	30-60	41.6	29.4	12.2
	60-90	26.9	19.7	9.9
450	0-30	65.9	56.8	9.1
	30-60	47.6	36.7	10.9
	60-90	44.6	33.5	11.1
600	0-30	75	65.9	9.1
	30-60	71	61.2	9.8
	60-90	60.4	52.5	7.9
	P(≤0.05)	2.9	3.4	4.4

B. Soil from *Ganticha* plots

N-level	Depth	TMN(kg/ha)	NH4-N(kg/ha)	NO3-N(kg/ha)
0	0-30	38.6	29.6	9.0
	30-60	29.9	18.2	11.7
	60-90	22.8	11.6	11.2
150	0-30	45.5	26.9	18.6
	30-60	39.2	23.6	15.6
	60-90	42.0	38.6	3.4
300	0-30	59.1	44.5	14.6
	30-60	51.4	34.3	17.1
	60-90	42.0	28.8	13.2
450	0-30	75	52.3	22.7
	30-60	48.9	36.7	12.2
	60-90	44.6	34.1	10.5
600	0-30	106.6	93.2	13.4
	30-60	73.6	63.5	10.1
	60-90	60.3	49.7	10.6
	P(≤0.05)	3.94	3.57	5.2

Declaration

I, the undersigned, declare that this Thesis is based on my original work and that it has not been presented for a degree in any other university. All sources of materials have been duly acknowledged.

Firew Kebede Signature……………………………………

This Thesis has been submitted for examination with my approval as supervisor of the Thesis

Prof. Masresha Fetene Signature…………………………………….