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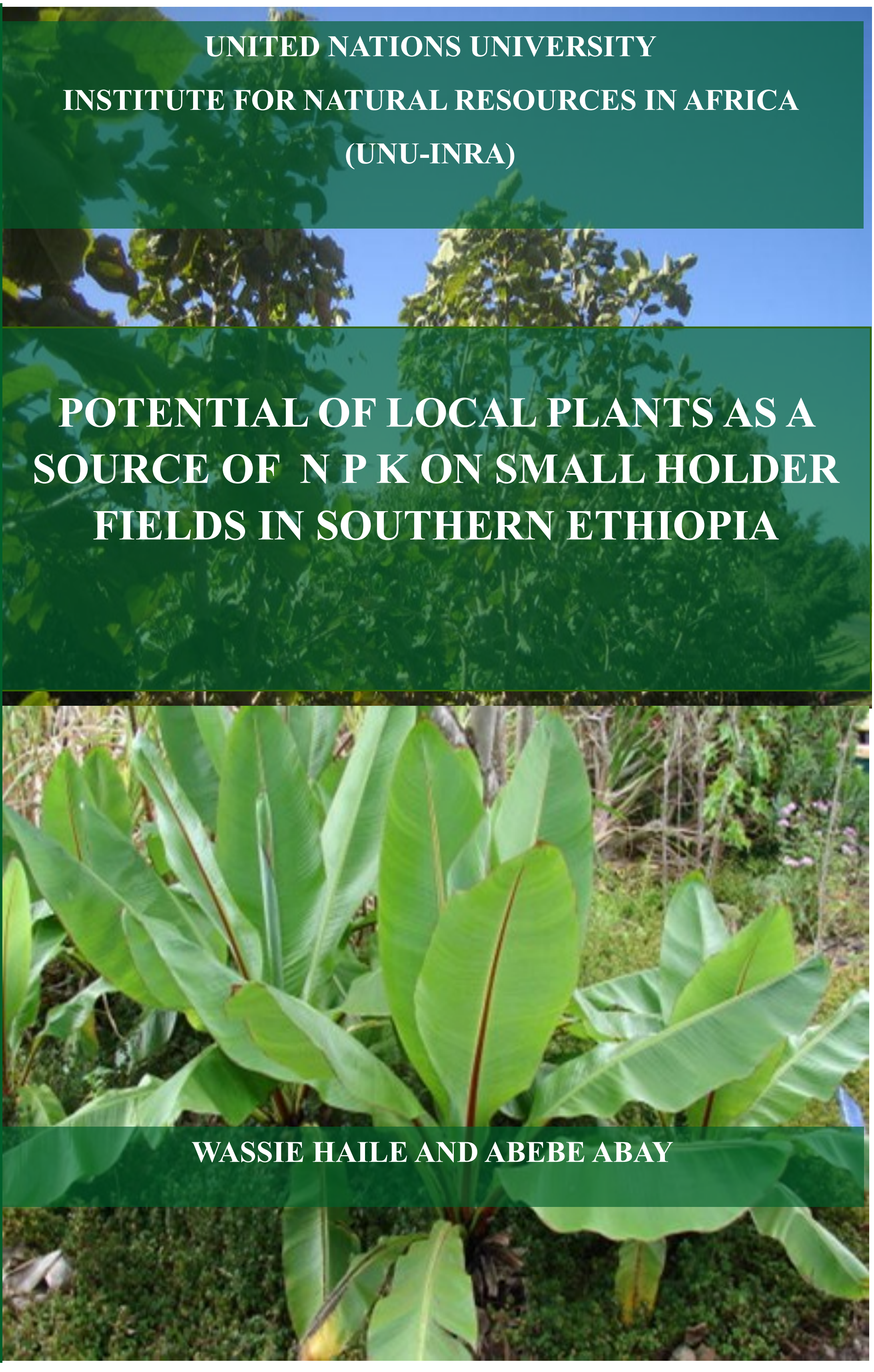
POTENTIAL OF LOCAL PLANTS AS A SOURCE OF N P K ON SMALL HOLDER FIELDS IN SOUTHERN ETHIOPIA



WASSIE HAILE AND ABEBE ABAY

UNITED NATIONS UNIVERSITY
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(UNU-INRA)

POTENTIAL OF *ERYTHRINA BRUCEI*, *ERYTHRINA ABYSSINICA AND ENSETE VENTICOSUM* AS ORGANIC SOURCES OF N P K ON SMALL HOLDER FIELDS IN SOUTHERN ETHIOPIA

BY

WASSIE HAILE AND ABEBE ABAY

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ABSTRACT

Improving food production and security in the face of soil infertility and high cost of inorganic fertilisers is a challenge for smallholder farmers. *Erythrina spp*. and *Ensete ventricosum* are indigenous to Ethiopia and noted as N-fixing agroforestry and high value food producer trees respectively. These trees have been identified with a high potential use as organic fertilisers for increased crop production. The study sought to determine nutrient and chemical compositions of the species, their mineralisation rate and N-equivalence value of *E. brucei*. Composite leaf samples from HagreSelam and Wolaita in southern Ethiopia were analysed for N, P, K, lignin and total polyphenol (TP). The effect of *E. brucei* biomass on wheat grain and straw yields and its N-equivalence value were also observed from 2010-2011. The results revealed that *E. abyssinica* had significantly higher ($p<0.05$) N content (4.2%) than *E. brucei* (3.5%) and *E. ventricosum* (2.4%). All the three plant species had lignin and polyphenol <15 and 5% respectively, implying the likelihood to decompose faster in soil. Based on the N, lignin and polyphenol contents, both *Erythrina* spp. are considered as high quality (Class-1) organic materials. *Enset*, is rated as a Class-3 plant material hence should be composted or mixed with inorganic fertiliser before applying on field. The mean P contents of *E. abyssinica*, *E. brucei* and *E. ventricosum* were found to be 0.39, 0.38 and 0.26 % respectively. In Contrast *E.. Ventricosum* had significantly higher (4.2%) K content than *E. abyssinica*, (2.6%) and *E.brucei* (2.0%).The mineralisation results showed that both Erythrina spp released more than 80% of their N content within two weeks of incubation. E. *ventricosum* achieved maximum N-mineralisation after four weeks of incubation.The experiment on the effect of *E. brucei* biomass on wheat yield and N-equivalence value showed that the application of 2.5 t DM/ha increased wheat grain and straw yields by 127% and 194% respectively. *E. brucei* biomass resulted in N-equivalence value of 43kgha^{-1} of N-fertiliser with relative fertiliser equivalence value of 93%. The study has provided both field and laboratory information on the beneficial effect of *E. bruei* biomass as organic fertiliser for improving crop yield. Thus, dissemination of the technology in areas where the tree is found abundantly in Ethiopia is recommended. Further, real time field experiment on the effect of E. abyssinica and E. *ventricosum* biomass on yields and soil quality should be studied extensively.

Keywords: *Soil infertility, nutrient sources, N, P, K, lignin, polyphenol*

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LIST OF ACRONYMS

ADF	Acid Detergent Fiber
Av. P	Available Phosphorus
BS	Base Saturation
CEC	Cation Exchange Capacity
FC	Field Capacity
LSD	Least Significant Difference
masl	Meters above sea level
OC	Organic Carbon
ONS	Organic Nutrient Source

1.0 BACKGROUND AND RATIONALE

Ethiopian soils are generally low in native fertility (Okalebo *et al*., 2011) but could sustain adequate crop production in the past. Like other countries of Sub-Saharan Africa (SSA), this could be attributed to the useful traditional soil fertility restoration practices such as bush/land fallowing, shifting cultivation, crop rotation, application of manure and retention of a sufficient amount of crop residue in the soil. However, some of these practices have been completely abandoned due to diminishing farm size (Mugendi *et al*, 2011) This has led to nutrient depletion. The declining soil fertility is further aggravated by severe soil erosion, and organic matter depletion (IFPRI, 2010), nutrient export and deforestation (Pound and Jonfa.2005; Bishaw and Abdulkadir, 1990) and poor soil management practices. According to Stoorvogel and Smaling (1990), on the average 41, 6 and 26 kg /ha/year N, P, and K respectively are removed from Ethiopian soils, showing that nutrient mining rates is alarmingly very high. Currently, declining soil fertility is considered to be one of the major factors that is significantly contributing to decreasing crop production and productivity in Ethiopia. As a result, the country has become one of the worst food insecure countries in SSA. According to IFPRI (2010) more than 5-7 million people in Ethiopia are chronically food insecure, and this is mainly caused by soil degradation. The main contributors to soil fertility decline in Ethiopia and their interrelationships among each others are shown in Figure. 1.

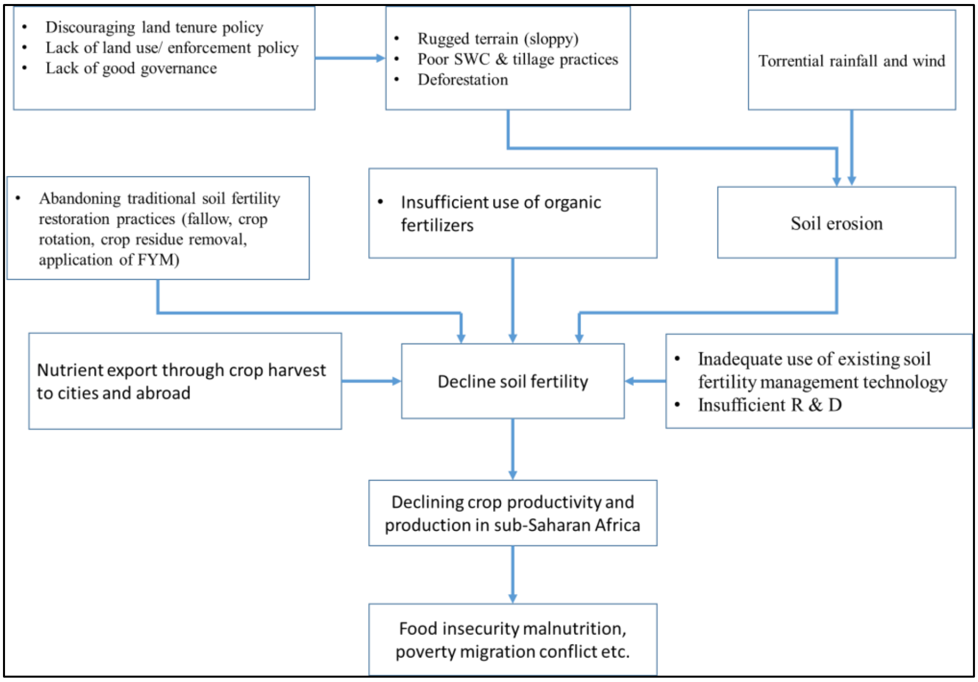


Figure 1: Causes of soil fertility decline and their interrelationship in Sub-Saharan Africa
(Source: Author I, 2012)

To overcome the soil nutrient depletion and increase crop yield, applications of inorganic fertilisers have been adopted more than forty years ago. Dramatic increases in the yield of several crops have been obtained due to this practice, though the yield gains differ from location, crop type and management practices (Wassie and Shiferw, 2009). There were many occasions where the yield of crops was increased by more than 100% (Kena et al., 1992). Thus, fertiliser was the most widely adopted technology by farmers due to the immediate visible effect, ease of handling and application (Parr and Colacicco, 1987). As a result, the fertiliser consumption increased from 3,500 tons from 1967-1972 to over 450,000 tons in 2007/08 cropping season (World Bank, 2008). However, the per capita consumption in 2002 was 2.2 kg ha^{-1} which was far lower compared with world average of 17.7 kg ha^{-1} (http://www.nationmaster.com).

The unprecedented rise in the cost of fertilisers is the major limiting factor for increasing fertiliser consumption. Moreover, application of fertilisers like those being used in Ethiopia acidifies the soil, promotes cation loss and depletes micronutrients. It has also been noted in some parts of Ethiopia that the response of the soil to fertilisers is decreasing or completely stopped (Wassie and Shiferaw, 2009). This could be due to the decline in organic

matter, soil acidity and salinity, depletion of other none amended macro and micronutrients.

Organic inputs such as farm yard manure (FYM) and compost can be used to fertilise the soil for enhanced crop production. The use of FYM and other organic inputs in replenishing the nutrients in the soil for agriculture purposes is an age old practice in Africa. Such materials, in addition to being sources of plant nutrients, increase and stabilise the soil's organic matter content which in turn improves the structure of the soil, thereby enhancing the water holding capacity, infiltration rate, CEC, and microbial activity. They also help to mitigate soil acidity and soil erosion. Soil with high organic matter (OM) requires less inorganic fertiliser and will respond to higher crop yields than soils depleted of OM. But with decreasing land holding in Ethiopia and elsewhere in Africa, animal feed is beco54ming scarce which in turn limits the availability of FYM (Pound and Jonfa 2005). Moveover there is a fierce competition for FYM for use as household fuel source and organic fertiliser. The use of compost is also constrained by several factors. It is labour intensive time consuming and its preparation is skills driven. Moreover, it has an offensive odour and even the volatile acids released during composting could affect human health. Organic fertilisers such as FYM and compost have varying qualities, they are bulky and very low in some essential plant nutrients. Even for the nutrients relatively present in high amount, large amount should be applied per unit of land to meet crop requirement for that particular nutrient.

These problems associated with the use of organic materials make it imperative for the identification of organic inputs which are rich, easily decomposable, high biomass producing, cheap and easy to apply organic nutrient sources that can be used alone or as an integral component of integrated soil fertility management technologies. According to Nair, (1993) and Mugendi *et al*, (2011), there are a number of cover crops and trees that are leguminous that have been identified, characterised and proven to be best for soil fertility improvement in Sub-Saharan Africa (SSA). Such materials include; *Grilicida spp, Mucuna, Callandria calotyrusus* (callandria) *Delicos spp, crotalaria, tithonia ssp* and *luceana* ssp (Mugendi *et al*., 2011), to mention just a few. Cover crops can be used to fertilise soils by growing as green manure crops on cultivated field and plough at its flowering stage; some time before planting the crop of interest. Similarly, leguminous trees can be grown as a farm boundary tree, as a live fence or inside farm lands as alley cropping and the biomass prune periodically and use as mulch and/or incorporated into the soil as organic inputs.

There is innumerable evidence indicating that if these organic resources are used properly, they can produce the same yield of crops as the one produced with recommended dose of inorganic fertilisers. For instance, Young (1989) reported that pruned biomass of *Leucaena leucocephala* incorporated at 10 tha^{-1} produced the same grain yield of maize as that produced by 100 kg Nha^{-1}. In a similar study, Makumba and Phiri (2003) found that *Tephrosia candida* applied at 6 t ha^{-1} dry matter (DM) doubled the yield of cabbage and increased the yield of tomato by 150%. Green manures are especially important source of N. In some instance it has been shown that the entire N demand of crops can be met with GM (Rao *et al*., 1991). Mureithi et al., (2004) reported that incorporating *Mucuna pruriens* biomass at 4-11 t $DMha^{-1}$ into the soil for maize increased the grain yield by 120% over those in the control group. Some of the green manure crops such as *Delicos labalab*, *Tithonia diversifolia*, *Tephrosia vogeli*, *Crotolaria juncea* were tested for their adaptability and role as organic fertilisers and encouraging results were obtained (ARC, 2011). For instance, Wassie and Shiferaw (2009) reported that the yield of wheat grown increased by 63% and 97% over the control group when Delios lablab was ploughed into the soil as green manure at Kokate and Hossana, in southern Ethiopia respectively.

Despite, these encouraging results with green manure (GM), the use of crops and trees as sources of organic fertilisers for soil fertility improvement are not widely adopted by farmers in Ethiopia (Wassie and Shiferaw 2009) and other Sub-Saharan Africa countries (Bationo *et al*., 2011). One of the reasons is that researchers and extension workers do not work with sufficient collaboration effectively to advance such technologies to smallholder farmers who could then adopt them.

The other reason is that some of the GM crops and trees that were tested and proven to be used as organic fertiliser are exotic in origin. As such, local farmers will not accept them easily because of their unfamiliarity with those crops and trees. (Wassie and Shiferaw, 2009). Limited adoption of leguminous cover crops and trees are not only problematic in Ethiopia but also in other SSA countries due to socio-economic and biophysical constraints e.g. sacrifice of time and space that are normally used for food crop production (Nandwa *et al*., 2011). Thus, while making continued efforts to get the exotic green manure crops and trees adopted for soil fertility and other related purposes, it is important to identify organic sources which are nutrient rich, easy to use, available, easy to propagate and that are fast decomposing plant materials from local sources. If such materials are identified in a particular locality for soil fertility improvement, it will be easy to be adopted by farmers for the reason that farmers know these plants and

have lived with them from generation to generation and know how to manage and grow them.

In this regard, Ethiopia can be seen as having a rich plant biodiversity. This indicates that there is a possibility to obtain locally available high quality organic nutrient source to be used as organic fertilisers. Plant materials of such type include *Erytrina brucei*, *Erythrina abyssinica* and *Ensete ventricosum* which are widely and abundantly available in southern Ethiopia and could have a high plant nutrient potential as organic fertiliser. This is due to the fact that farmers in some places of southern Ethiopia reported that the falling leaves of Erythrina and other species like *Corida Africana*, Ficus and Hagenenia species enrich the soil (Pound and Jonfa.2005; Elias, 2002). For this reason, they deliberately leave the trees to grow on farmlands. Also, the *Erythrina spp*. are N-fixing (Fassil, 1993; Legesse, 2002) and this property is an important indication that they can be used as organic sources of nitrogen. In the case of *Ensete ventricosum*, it is not N-fixing plant but in Ethiopia where it is grown as food crop particularly in the south and south west, it is considered to be a high value crop and thus receives the highest amount of organic fertilisers like manure, household refuse compost etc. (Elias, 2003). This implies that its biomass might contain a large amount of essential plant nutrients and its none edible part could be a potential source of organic nutrients for soil fertility improvement.

However, there is the need to study the NPK lignin, polyphenol composition and C/N ratio, and mineralisation rate of these materials to aid in decision making on how to use them as organic fertilisers with respect to amount, time and methods of applications. More information on nitrogen (N), lignin and polyphenols contents, especially, are important in predicting N- release rate of organic materials by comparing them with critical values and indices established in the literature (Palm *et al*., 2001). Organic plant materials with high N, low lignin and polyphenol contents release N faster than those organic materials with higher lignin and polyphenol contents (Palm, 1995). Such information ultimately devise optimum management practices (Franzluebbers, *et al*., 1994), that helps to synchronise the nutrient released from organic materials mentioned above and the likes with crop demand resulting in increased nutrient uptake and yield of crops for enhanced crop production and sustained land productivity.

1.1 Objectives

The study sought to determine the potential of *Erythrina brucei*, *Erythrina abyssinica* and *Ensete ventricosum* (indigenous plants of Ethiopia) as N P and K sources for crop production.

1.1.1 Specific objectives

- To investigate the N, P, K content of *Erythrina brucei*, *Erythrina abyssinica* and *Ensete ventricosum*
- To study the lignin and polyphenol content of the selected plants to aid in decision making on how to use them as organic fertiliser.
- To investigate the nutrient release pattern (mineralisation rates) of these plant species.
- To determine the N-equivalence value of *E. brucei*
- To get these organic nutrient sources included in the data base (D-base) of Tropical Soil Biology and Fertility Program (TSBF)

1.2 Overview of Important Organic Nutrient Sources

Materials of biological origin containing carbon element as its integral component is called organic nutrient sources/input/fertilissers. There are various types and they include manure of different types, compost, household refuse, crop residues, sewage slugs, cover crop and green manures, and trees. From the perspectives of smallholder farmers in SSA, it is becoming increasingly difficult to get sufficient manures, crop residues and composting materials to be used as organic fertilisers. This is due to the increasing land shortage resulting from high population pressure especially in the highlands of Africa. Thus, the focus should be on the use of cover crops and trees that are available, renewable, nutrient-rich, widely adaptable and farmer friendly for soil fertility enhancement. Furthermore, exploration and identification of nutrient-rich, easy to propagate, high biomass accumulation potentials for plant nutrient released from local sources should be encouraged.

Green manures and cover crops are those plants that rapidly grow and are used to protect the soil and can be left as mulch or ploughed for soil fertility improvement. They can be N-fixers or non-fixers but emphasis is given to the fixing ones due to their N-input to the soil.

Green manures can be divided into two types; legumes and non-legumes (usually grains). Leguminous green manures include clover, vetch, peas, fava

beans, and alfalfa. Legumes have the advantage of adding to the nitrogen reserves of the soil. Non-leguminous cover crop includes oats, wheat, canola (rapeseed), buckwheat and *Tithonia* spp. These plants do not add nitrogen to the soil, but they do keep it "in the system". They tend to grow faster in fall than in spring, which results in better weed suppression. Also, since they break down more slowly than legumes, they add more organic matter to the soil and imposes more favourable structural properties on the soil. Some of the common cover crops and green manure crops are presented in Table 1.

Table 1: Chemical properties of selected legumes used for soil fertility improvement in East Africa

Genus	Nitrogen (%)	Phosphorus mg kg^{-1}	Lignin (%)	Total soluble polyphenol (%)
Canavalia esiformis	3.5	0.16	5.5.	2.4
Crotalaria juncea	3.9	0.16	6.8	1.3
Crotalaria ochroleuca	4.5	0.16	4.9	2.0
Desmodium intortum	3.4	0.15	8.8	5.5
Desmodium unicinatum	3.3	0.16	11.0	5.0
Mucuna pruriens	4.0	0.18	5.6	2.5
Lablab purpureus	3.6	0.17	7.5	3.3
Vicia benghalensis	3.7	0.16	5.0	1.1
Crotalaria grahamiana	3.2	0.13	6.8	2.0
Tephrosia vogelii	2.9	0.18	8.0	5.2
Delicos lablab	1.2	0.18	17.6	0
Calliandra calothyrsus	3.4	0.15	17.6	9.9
Archis hypgaea	2.2	-	6.3	1.3
Leuceana diversifolia	3.9	0.25	10.4	5.4
Cajanus cajan	3.1	0.13	14.7	4.9
Phaseolus sp.	0.8	0.06	11.3	0.3

Adapted from Mugendi et al., (2011)

1.3 The Role of Organic Nutrient Sources in Improving Soil Fertility for Enhanced Crop Production

Literature is available on the beneficial effects of green manures and tree legumes in increasing soil fertility and increasing crop yields (Mugendi, *et al*., 2011, Wassie, 2012, Wassie and Shiferaw, 2009).

For instance, Mureithi *et al*., (2004) reported that incorporating Mucuna biomass at 4-11 t DM ha^{-1} in the soil for maize increased the grain yield by 120%. Similarly, the performance of green manure legumes under different combinations with crops was studied at Kururina and Gachoka locations of the Mount Kenya region. The results showed that in the long rainy season, maize grain yield of 6.48 and 3.14 t ha^{-1} were obtained in the two sites

respectively against 3.49 and 2.71 t ha^{-1} of grain yield in the control group respectively (Gitari *et al*, 2000).

Mombeyarara *et al*., (2011) studied the effect of *Ipomoea stenosiphon* locally available plant material with N content of 2.3% and applied at 75 kg/ha N equivalence on maize and it was found that, the grain yield was increased by 111 and 161 % over two soils. Fracis *et al*., (2011) reported that the yield of maize grown on Mucuna and Archis biomass incorporated into the soil in Kenya was increased by 0.5-2 Mg ha^{-1} and 0.5–3 Mg ha^{-1} over the control respectively.

However, the extent of benefits or response obtained from organic residues depend on the quality of the organic input in question and also, the extent of soil nutrient depletion to which the organic residues are added, management of organics, test crop and climatic condition.

1.4 Important Quality Indicator Characteristics for Selection of Plant Material as Organic Nutrient Fertiliser for Local Source

Organic nutrient sources are diverse in their types and nutrient composition. Even the organic source of the same type, for example cereal residue, green manure leguminous crops and tree legumes, could vary in their nutrient composition to a great extent depending on climate, soil type (Mombeyarara et al., 2011) and age of the materials. This makes it difficult to give a general recommendation of plant material for their fertiliser value.

Thus, knowledge of the quality characteristic of different organic nutrient sources is crucial for its proper management so that it will be possible to make best decision out of the use of such materials in the crop production. Important characteristics in deciding on organic materials to adopt include C/N ratio, N, P, K, polyphenol and lignin contents and mineralisation rates. Plant materials high in lignin and polyphenol contents are supposed to be resistant to microbial decomposition.

C/N ratio is one of the most important quality indicators of organic crop residues for soil fertility improvement. The higher the C/N ratio of the organic material, the more difficult it is to decompose rapidly. When materials with high C/N ratio such as maize straw are incorporated, it takes a long time to decompose and microbial immobilisation of soil available N occurs. In the short term, crops grown in soil incorporated high materials having wide C/N ratio will face deficiency of nutrients like nitrogen.

The other important quality parameter of organic nutrient source is the nitrogen content. Organic nutrient sources vary widely in their nitrogen content and generally those plant materials having N content greater that 2.5% N will likely mineralise faster. Usually, leguminous crops and trees have high nitrogen content due to their nitrogen fixing ability in symbiotic association with some micro-organism like Rhizobia. In addition to the nitrogen content, lignin and polyphenol content of the plant material, composition and type of micro-organisms, the soil and environmental factors also affect the rate of minerialisation. Organic materials having lignin values greater than 15% and polyphenol content greater than 5% will decompose slowly even if they have high N content and suitable soil and environmental conditions (Sanginga and Woomer, 2009).

The selection of a particular organic input such as cover crops and trees for soil fertility management depends not only on chemical characteristics but also on the availability, adaptability, biomass production potential, growth rate, ease to propagate and tolerance to stress (drought, acidity, diseases and pests. etc.).

1.5 Management of Organic Nutrient Sources for Efficient Nutrient Availability to and Uptake by Crops

The management of organic nutrient sources refers to the synchronisation of nutrient released from decomposing plant material with the crop demand. Time, method, quantity and quality of material to be incorporated are the key factors to consider in organic nutrient sources for effective soil fertility management (Anderson and Ingram, 1993). It is also affected by soil physico-chemical properties and climate.

Time of incorporation is a basic factor affecting synchrony of nutrients with plant demand which in turn depends on the quality of material to be added. High quality materials such as legumes can be incorporated into the soil in one, two or four weeks before the seedlings of the crops are nursed for planting. However, low quality plant material (<2.5% N) should be incorporated beyond a month or more to give sufficient time for the material to decompose. Even for very low plant materials such as cereal residues, there is a need to apply them with starter inorganic fertiliser to harness mineralisation. This is to prevent immobilisation and the crop starved of nutrients. Decision guide on how to use organic nutrients for an effective synchronisation of nutrient released with crop demand is based on quality parameters of organic nutrient sources and is presented in Figure 2.

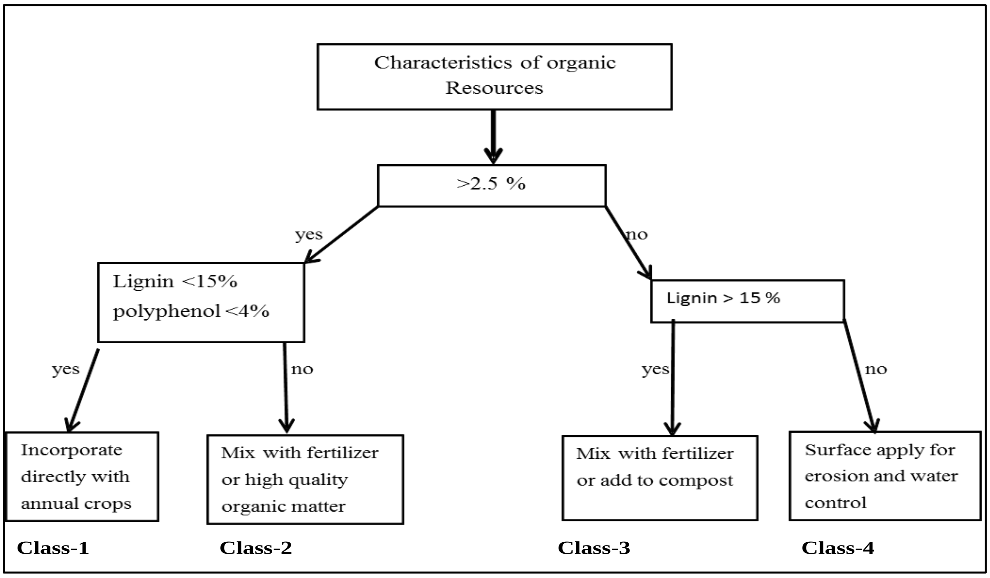


Figure 2: Decision tree to assist management of organic resources in Agriculture based on Palm, *et al*., (2001).
(Adapted from Sangiga and Woomer (2009))

The quality of a particular organic input such as NPK content and lignin and polyphenol compositions are key factors to consider for their management. In this regard, decision guideline on how to use organic inputs is based on nutrient compositions (Sanginga and Woomer, 2009). These authors suggest that organic input should be directly incorporated into the soil if it has N content >2.5% and lignin and polyphenol content < 15 and 5 % respectively. Similarly if a particular input has > 2.5% N and > 15 and 5 % lignin and poly phenol content respectively it is wise to apply it along with inorganic fertilisers. Based on the N, lignin and polyphenol contents, decision guide is developed as to how to use a particular organic input for soil fertility improvement (Figure. 2).

The quantity of organic input to be applied as a nutrient source depends on the nutrient content mainly on N content and sometimes based on P. It also depends on the availability of crop nutrient requirement and soil nutrient content. There is no higher limit for organic nutrient input because there is no harm from applying high dose of such material except in some cases where very high doses of manure and sewage slugs could create pollution. Thus, the concern is to get the minimal dose of organic input to obtain the optimum yield.

Method of application is also an important factor to consider in managing organic residue. Incorporation of organic residues into the soil generally

accelerates the decomposition rate of the material than surface application. This is because the decomposing agents, mainly micro organisms, are more abundant in the few CM depth of the soil than at the surface.

1.6 Methods of Integration of Herbaceous Legumes into the Traditional Cropping System for Soil Fertility Enhancement

Even if there are better legume technologies, fitting these technologies into the traditional cropping systems is the most challenging task (Mugendi et al., 2011). There are a number of strategies that enable legume based technologies to be incorporated into the traditional cropping system. Thus, the first is to identify appropriate niches in a particular cropping system where the legume based technologies could be best fitted. According to Mugendi *et al*., (2011), potential niches for integration of legumes into smallholder farming systems form temporal niches that could be rotated. The intercropping of food crops and legume species and the spatial niches created has been defined as the best place in the farming system to plant legume species (Gachene *et al*., 2000). It is based on these demarcations that the legume technologies could be integrated into the farming system.

The system falls into two broad categories: the simultaneous system in which components are grown in mixtures and the sequential or rotational system. The simultaneous system includes intercropping, alley cropping and relay cropping systems. On the other hand, sequential/rotation system includes biomass transfer and improved fallow systems.

1.7 Description of *E. brucei, E. abyssinica and Ensete ventricosum* and their Potential Organic Nutrient Sources for Soil Fertility improvement in Ethiopia

1.7.1 *Erythrina brucei*

Erythrina brucei is a leguminous tree endemic to Ethiopia. It belongs to the family fabaceae (Thulin, 1989; Gillett, 1961) with leaf symbiotic N-fixing characteristics (Negash, 2002). *E. brucei* is adapted to grow in areas with an altitude ranging from 1400–2600 m asl. It fixes atmospheric nitrogen through its leaves in contrast to angiosperms of Rubiaceae and Primulaceae (Legesse, 2002; Miller, 1990). It is a fast growing tree that reaches up to 3m in height within 6 months of planting (Demil, 1994). *E. brucei* has important agro-forestry attributes such as spreading leaves, source of large quantities of swiftly decomposable litters, vigorous re-growth, high coppicing ability as well as rapid recovery after a spell of prolonged drought (Demil, 1994;

Negash, 2002). The young *Erythrina brucei* trees grown as live fences are shown in Plate 1. Farmers of Gedio area observed that its falling leaves are excellent organic manure (SLU, 2006). It is propagated both by seed and cuttings. The pruned branches and leaves are used by farmers as animal feed in times of animal feed shortage. In the Wolaita, Kembata, Hadya, Gedio, Sidama and Guragie zones in southern Ethiopia, *E. brucei* is grown abundantly as live fences, along farm boundary and inside farmlands in alleys as Agro-forestry tree (Haile and Boke, 2009; SLU, 2006; Elias, 2002). Production of up to 50kg of fodder biomass (Leave + twigs) per tree per year is potential of *Erythrina* relatives (Na-songkhla, 1997). Optimal doses of 10 tons of biomass per hectare of *E. brucei* can easily be obtained from only 200 trees.

Plate 1: Erythrina brucei found in Southern Ethiopia
(Photo credit: Wassie (2010))

1.7.2 *Erythrina abyssinica*

*Erythrina ab*yssinica is a tree species of the genus *Erythrina* belonging to the family Fabaceae (or Leguminosae) family. It is leguminous tree species native to East Africa and Eastern Democratic Republic of Congo, and especially to northern and western Ethiopia. It is found mostly in areas with altitude ranging between 1250 and 2400 m.a.s.l, with mean annual temperature of 10-26 oC, mean annual rainfall of 800 to 2000 mm, and grows best in well-drained soils of pH ranging from 3.5 to 5.0. (*http:///Database.Prota.Org/Protahtml/ Erythrina%20abyssinicaEn.Htm*, accessed on Sept. 2011).

In Ethiopia, it occurs in areas with altitude above 2500 m asl. *E. abyssinica* is a N-fixing tree and moderate fast growing (Plate 2). It can be propagated

by both seed and vegetative means. It is a multipurpose tree also used as an ornamental and shade tree, for soil conservation and live fence. The wood is used in making bee hives and household utensils. The leaves of *E. abyssinica* is used as animal feed. It is also used as a medicinal plant for treating several diseases by traditional people.

Erythrina spp. grows in a range of natural habitats including open forest, savannah dry brush and scrub, river banks, swamps and coastal regions (*http://www.fao.org/docrep/X5327e/x5327e11.htm*). In Ethiopia, it is grown as live fence, in graveyards, as farm boundary and on farmlands.

Plate 2: *Erythrina brucei* used as live fence in Southern Ethiopia
Photo Credit: Wassie (2009)

1.7.3 *Ensete ventricosum*

Enset (*Enste ventricosum*) is commonly called Abyssinia banana or Ethiopian banana (Plate 3). It belongs to the Musaceae and genus Ensete family (Plate 3). The plant is a monocarpic, an herbaceous perennial with huge leaves shaped like giant boat paddles. It grows to a height of 4m – 8m and sometimes it can reach up to 11m (Tsegaye, 2007). Its leaves can be up to 6m long and 1m – 1.5 m wide. They are bright olive-green and the midribs on the undersides are maroon. The Ensete is native_to the eastern edge of the Great African Plateau, extending northwards from the Transvaal through Mozambique, Zimbabwe, Malawi, Kenya, Uganda and Tanzania to Ethiopia, and west to the Congo, being found in high rainfall forests on mountains, and along forested ravines and streams (*http://en.wikipedia.org/wiki/Ensete _ventricosum*). It is only in Ethiopia that it is grown as a food crop. And even that is limited to southern Ethiopia. It is the main staple food crop for 11-15 million people in that region (http://www.kew.org/plants-fungi/ Ensete*ventricosum*.htm).

Plate 3: Young Enset plants
(Photo Credit: Abebe (2012))

It grows in areas with altitude ranging from 1,400 to 3,100 m above sea level. In Ethiopia, Enset is primarily grown as a food crop. It has other multiple uses.It is used as industrial starch, its leaves are used locally as wrapping material, as animal feed and in compost making. Because of its perennial nature, it provides food to households all year round And also because of its multi purpose uses and perennial nature, it has been named a ‘food security crop’.

In those parts of Ethiopia, particularly in the south and southwest, where Enset is grown as staple food crop, it receives a significant amount of organic fertiliser from many sources including; animal manure, organic feed residues, plant residues, household refuse, and traditional forms of compost. Enset is non N-fixing plant but because of a wide range of organic input it receives from the above mentioned sources, the soil productivity and fertility is maintained for the sustained production of the crop (Elias, 2003)

2.0 MATERIALS AND METHODS

2.1 Nutrient and Chemical Analyses of Organic Resources

2.1.1 Description of plant sampling sites

The plant samples were collected from two zones, namely; Hagereselam and Wolaita zones (Figure 3) in Southern Ethiopia in March 2012. Wolayta zone is situated 385 km south west of Addis Ababa, the capital of Ethiopia (6°54'N to 07 ^{o} 09' 34.3''and 37 ^{o} 35' 33'' to 37°45'E), with elevation ranging between 1600 and 2100 m asl. On the other hand, Hagreselam is situated at 400 km South East of Addis Ababa, (6 ^{o} 29' 26.1 and 06^{o}35'48.2'' N and 038 ^{o} 23' 53.7 '' and 38 ^{o} 31' 28.5 '' E) with elevation ranging between 1941 and 2767 m asl. The specific locations within which samples of *E. brucei* and *Ensete ventricosum* were collected in Hagreselam and Wolaita zones (districts) are presented in Table 2 and 3 respectively. The two zones have *Enste ventricosum* in common and *E. brucei* is unique to wolaita and *E. abbysinica* is unique to HagreSelam zone.

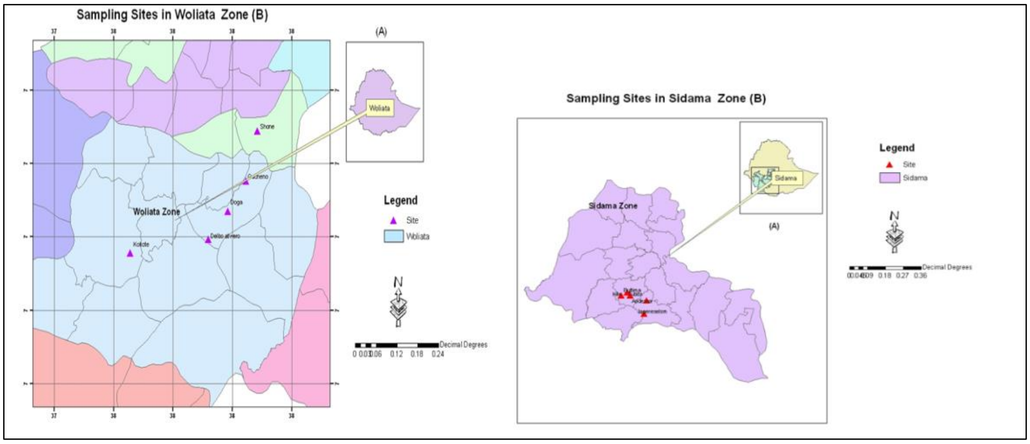


Figure 3: Map of Southern Ethiopia showing locations where leave samples from *E. brucei* (left) and *E. abyssinica* (right) and from *Ensete ventricosum* (both locations) were collected.

Adapted from Abebe (2012)

Table 2: Locations within Hagreselam zone, where the plants samples were collected.

SN	District	Site	Northerns	Easterns	Plant type
1	Aletawondo	Bultima	6°35'48.2''	38°25'36.6''	*E .abysinica* and *E.ventricosum*
2	Aletawondo	Tubito	6°34'53.2''	38°26'39.3''	*E .abysinica* and *E.ventricosum*
3	Aletawondo	Kila	6°34'56.7''	38°23'53.7''	*E .abysinica* and *E. ventricosum*
4	Titecha	Aridessa	6°33'28.2''	38°31'28.5''	*E .abysinica* and *E .ventricosum*
5	Hula	Hagereselam	6°29'26.1''	38°30'45.3''	*E .abysinica* and *E. ventricosum*

**= meters above sea level (Source: Abebe (2012)*

Table 3: Specific sampling sites in Wolaita Zone, geographic location and species type sampled.

SN	Districts	Site	Northerns	Easterns	Plant type
1	Soddo zuria	Delbo atwero	6°54'34.2''	37°49'4.0''	*E.brucei and E.ventricosum*
2	Damot Gale	Doga	6° 58'26''	37°52'25.7''	*E.brucei and E.ventricosum*
3	Gacheno	Gacheno	7°02'37.7''	37°55'33''	*E.brucei and E.ventricosum*
4	Soddo Zuria	Kokote	6°52'37.7''	37°35'33''	*E.brucei and E.ventricosum*
5	Soddo Zuria	Shone	7°09'34.3''	37°57'25.5''	*E.brucei and E. ventricosum,*

* = meters above sea level Source:Abebe (2012)

2.1.2 Plant sampling methods and sample preparation

Three replicate leaf samples from each location and each species were collected according to the procedure indicated in Mutuo and Palm (1999) in which from each tree branch, one in the top, middle and lower canopy were randomly selected. And from each, branch, leaf and twig samples were taken and composed. The composed samples were kept in paper bags and samples labelled with codes, date of sampling and other relevant information. Then the samples were taken to Hawassa Soil Laboratory where they were air dried and milled and passed through a 2mm sieve.

2.1.3 Chemical analyses of organic resources

The processed samples were analysed for the N, P, K, OC, lignin and polyphenol contents following standard procedures. The total nitrogen content of the plant material was analysed by wet oxidation of the modified Kjeldahl procedure (AOAC, 1990). Phosphorus (P) and potassium (K) content was determined by dry ashing method. The ground plant sample was re-dried for 2 hours at 60-70 °C before analysis. One gram plant material was then weighed in to a crucible and precalcinated in hot plate then it was transferred into Muffle Furnas and calcianted at 450 ^{o}C for 6 hours followed by cooling and dissolving in 20ml, 20% nitric acid while it was in the crucible. Then, it was heated to boil, stirred carefully, and then filtered into 100ml volumetric flask making up to the mark with distilled water (Sertsu and Bekele, 2000). The P in the extract was determined calorimetrically and K was determined by flame photometre.

Organic carbon was determined by calcination method in which ash free dry weight of the littr was obtained by combustion in a furnace at 550^{0}C for 3 hrs. Fifty percent of the ash free material was considered to be total organic carbon (TSBF 1993).

Lignin and polyphenol contents of organic nutrient sources were determined via acid detergent (ADF) method and the revised Folin-Denis method, respectively (Anderson and Ingram, 1993). The P and K contents were determined by colorimetric method and flame photometre respectively Serstu and Bekele (2000).

2.2 Laboratory Incubation Studies (Mineralisation Rates)

The mineralisation rates of *E brucei*, *E. abyssinica* and *E ventricosum* was studied at Hawassa University, College of Agriculture, Soil Laboratory in 2012. Soil samples for laboratory incubation studies were brought from Hagreselam and Wolaita zones where the plants (organic nutrient sources) were sourced. Composite samples were collected from a depth of 0-15 cm using augur and brought to the laboratory. Then the samples were air dried and crushed and sieved to pass a 2mm mesh thick sieve. One kilogram of a portion of the processed soil from each zone was taken and analysed for its physico-chemical properties according to methods and procedures described in Sestu and Bekele (2000). The remaining soil from each location was used in incubation experiment.

2.2.1 Physicochemical analyses of the soil samples

Soil particle size was analysed by the hydrometre method (Bouyoucos, 1951). The moisture content was determined gravimetrically. The soil moisture contents at field capacity (FC, - 0.3 bars) and at the permanent wilting point (PWP, -15 bars) were measured using the pressure plate apparatus. Finally, the plant available water content of the soil was determined from the difference between water content at FC and PWP (Hillel, 1980).

2.2.2 Soil chemical properties

Soil pH and electrical conductivity were determined by pH metre and Electrical Conductivity metre, respectively. Organic carbon content was determined using wet digestion (Walkley and Black, 1934) method. The OM content was worked out by multiplying the OC content using the conventional 'Van Bemmelem factor' of 1.724.

The total N content in soils was determined using the Kjeldahl procedure. Available P was determined by the Olsen's method using sodium bicarbonate (0.5M $NaHCO_3$) as an extraction solution (Olsen and Sommers, 1982). Exchangeable bases (Ca, Mg, K and Na) and CEC were determined by the ammonium acetate (1M NH_4OAc at pH 7) extraction method. The percentage base saturation (PBS) was determined following the equation 1.

$$\text{PBS (\%)} = \frac{\text{Sum of exchangeable bases (Ca, Mg, K and Na)}}{\textit{CEC of soil}} \times 100 \quad \ldots\ldots\ldots \quad \mathbf{(1)}$$

2.2.3 Incubation experiment

The mineralisation rate of *E. brucei, E abyssinica* and *E. ventricosum* were studied through laboratory incubation experiment at Hawassa University soil laboratory college of Agriculture from February 02, 2012 to March 08, 2012. The plant samples from each species were cleaned with distilled water and oven dried at 70^{o}C for 24 hours. The plant materials were cut to 1 cm size. The soil samples, in which incubation study was made were collected from HagreSelam and Wolaita areas of southern Ethiopia where these organic resources are found in abundance. The physical and chemical properties of soils used in the incubation experiments are shown in Tables 5, 6, and 7. The soil samples were processed in the laboratory and 200g of it was transferred into 300 ml capacity plastic cups. Then processed plant material *E. brucei, E abyssinica* and *E. ventricosum* were added to the soil filled cups at a rate of

2.7, 2.2 and 3.7 t DM/ha. These rates were calculated to correspond to 92kg/ha of N which is the recommendation for wheat in some soils of Ethiopia. The soil and organic nutrient resource mixtures were thoroughly mixed, watered and incubated for 5 weeks. Initial weight of each cup was weighed and periodically re-weighed and the lost moisture was adjusted. The incubation studies experiment was laid out in Complete Randomised Design (CRD) replicated three times with three plant species as treatments.

The samples from each cup were taken weekly and analysed for NH_4-N, NO_3-N, and total nitrogen. Mineral N was extracted at a ratio of 1:4 (soil: 2*M* KCl) after shaking for 1hour followed by filtration through Whatman No. 42 filter paper.

The mineral N content of the extract was determined using steam distillation and titration method described in Keeney and Nelson (1982). Aliquot (40 ml) of the extracts was added into a distillation flask, and steam distillation was carried out after adding magnesium oxide (for NH_4^+ -N). After cooling the distillation flask, Devarda's alloy was added (for NO_3^--N) and again distilled. The distillate was collected in separate 25 ml of boric acid containing bromocresol green-methyl red mixed indicator and titrated against 0.05 M Hydrochloric acid (HCl) for the determination of mineral N and expressed as mg kg^{-1}.

2.3 Effect of *E. bruce*i Biomass on Yield of Wheat and its N-equivalence Value of *E. brucei*

A two year field experiment was conducted in southern Ethiopia during 2010 and 2011 cropping seasons at Kokate (Latitude: 6° 52'N and Longitude: 37° 48'E) at an altitude of 2156 m asl with average annual rainfall of 1325 mm and mean maximum temperature of 22.5 ° C.

The soil is characterised as Dystric Nitisol having clay loam texture and pH of 5.8, total N of 0.215%, available P of 3. mg kg^{-1}, OC of 2.15% and available K of 45.5 mg kg^{-1} (ARC Progress Report, 2005**).**

The N rate of 46 kg ha^{-1} was taken as a recommended N fertiliser benchmark for wheat production and based on this rate treatment, combinations were set using protocol by Mutto and Palm (1999) as shown in Table 4.

Table 4:Treatment combinations of inorganic and organic N sourced from (Erythrina brucei biomass).

Treatment No (T#)	**Combinations of Nitrogen sources applied**	
	Inorganic N (kg/ha)	**Organic N (t DM*/ha)**
1	0 (0%)	0 (0 %)
2	46 (100 %)	0 (0%)
3	34.5 (75 %)	0.63 (25 %)
4	23 (50 %)	2.5 (50 %)
5	11.5 (25 %)	1.9 (75 %)
6	0 (0 %)	2.5 (100 %)
7	30	0
8	60	0
9	90	0

** DM = Dry Matter (Source: Author I)*

The *E. brucei* had 4.8% of N on dry matter basis at time of incorporation and it was assumed that 40% of N would have been mineralised in one season. Based on these assumptions 2.5 t DM ha^{-1} of *E. brucei* would have provided N equivalent to 48 kg ha^{-1}. The *E. brucei* leave and twig biomass were collected from around homestead areas at Kokate and were chopped into pieces of size < 10 cm and incorporated into the soil to a depth of 0 – 20 cm 2 weeks before planting of the wheat as shown in (Plate 4.).

Plate 4: Field assistant chopping *E.brucei* biomass before incorporated into the soil

The experiment was laid out in Randomised Complete Block Design (RCBD) with three blocks. The plot size was 4 x 4 m. Wheat variety used as test crop was Simaba planted at 20 cm apart rows and there were 20 rows per plot. The planted seed rate used was 150 kg ha-1.

Nitrogen was applied in the form of urea as per the treatment (Table 4). The urea was split applied; half at planting and the remaining half after one and half month of planting of wheat. Triple super phosphate was applied at a rate of 40 kg P_2O_5/ ha uniformly to all plots at the time of planting. Field data were collected on plant height, days to flowering, spike length, number of spikelets per spike, grain and straw yield.

To determine the nitrogen fertiliser equivalence value of *E. brucei*, first the inorganic N response curve based on treatments of T#1, T#2, T#7, T#8 and T# 9 (Table 4) were developed (Figure. 4). After developing the response curve and best fitting regression equation generated, the corresponding N-equivalence value of the Erythrina biomass was calculated from equation 3.

$Y = ax^2 + bx + c$……………………………………………………………**(2)**

The fertiliser equivalence (FE) value was therefore calculated as:

$x = \frac{-b\pm\sqrt{b^2-4ac}}{2a}$ ……………………………………………………………**(3)**

Where Y = grain yield (dependent variable), X= Nitrogen (independent variable); a, b, and c are contestants with value -0.0039, 0.5826 and 11.797 respectively.

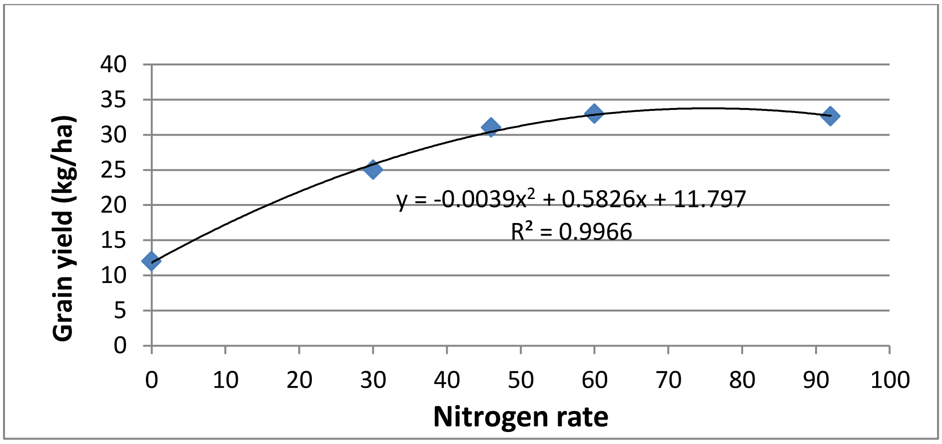


Figure 4: The effects of different rates of N fertiliser on the grain yield of wheat at Kokate, Southern Ethiopia. (Source: Author I's Field work, 2012)

The percentage fertiliser equivalence value (FE) was calculated as in equation 4

$$\% FE = \frac{FE \times 100}{N\ applied}$$ ……………………………………………………………...**(4)**

2.4 Statistical Analyses

The NPK, OC lignin and polyphenol contents of organic nutrient sources were subjected to analysis of variance (ANOVA) using GLM of SAS software. The plant species were taken as the treatments and sampling locations as blocks. The ANOVA of the mineralisation rates of organic sources was also performed using the same software.

The grain and straw yield data from N-equivalence value of *E. brucei* biomass trials were subjected to ANOVA using GLM of SAS software. The parameters that were significantly different were further compared using the Least Significant Difference (LSD) method.

3.0 RESULTS

3.1 Physicochemical Properties of Soils Used in the Mineralisation Study

Some of the physical properties of soil samples from HageresSelam and Wolaita location in which the mineralisation rate of the three organic nutrient souces studied in the laboratory used in the mineralisation study are shown in Table 5. The textural class of the soils from both sites are clayey. The two soils were also found to be similar in their FC and BD but differ in PWP.

Table 5: Some of the physical properties of soils used in the study of mineralisation

Site	Depth (cm)	Particles size			Textural Class	FC (%)	PWP (%)	BD Cmkg-1
		Sand	Silt	Clay				
HagreSelam	0-20	14	32	54	Clay	46.2	31.55	1.23
Kokate	0-20	16	36	48	Clay	42.74	27.57	1.23

Source: Abebe (2012)

The soil pH was more acidic in HagreSelam (4.8) soil than Wolaita soils (5.7). Ec was higher in Wolaita soil than HagreSelam soil. OC and TN was higher in HagreSelam soil than Wolaita soil. C/N ratio was higher in Wolaita soil than HagereSelam soil. Available P was slightly higher in Wolaita soil than HagreSelam soil (Table 6).

Table 6: Electrical Conductivity, OC, T.N and Av.P. of soil used in the mineralisation study (Abebe, 2012).

Soil sampling site (Zone)	pH	EC (dS/m)	OC (%)	TN (%)	C/N	AvP mg kg^{-1}
HagreSelam	4.8	0.014	1.76	0.16	11	3.2
Kokate	5.7	0.064	1.52	0.13	12	3.92

Source: Abebe (2012)

The exchangeable cations, CEC, BS and micronutrient contents of soils used in the mineralisations study are shown in Table 7. Exchangerble bases, CEC and % BS were higher in the Wolaita soil than HagreSelam soils. Fe, MN and Cu were higher in the Wolaita soil than HagereSelam soil, whereas Zn was higher in the HagereSelam soil than Wolaita soil.

Table 7: Exchangeable Cations and CEC, BS, and micronutrient contents of the Soils of used in the Mineralisation study.

Soil sampling site (Zone)		Na	Ca	Mg	CEC	BS (%)	Fe	Zn	Mn	Cu	Mn
		Cmol (+)/kg					Cmol (+)/kg				
HagreSelam	0.2	0.2	6.7	3.8	21.7	50	6.3	4.8	3.5	1.2	4.5
Kokate	0.2	0.8	10.2	4.1	23.3	66	11.6	2.4	5.0	1.5	5.0

Source: Abebe (2012)

3.2 Nutrient and Chemical Composition of *E. brucei*, *E. abyssinica* and *Ensete ventricosum*

The nitrogen (N), Phosphorus (N) and potassium (K) contents *of Erythrina brucei*, *Erythrina abyssinica* and *Ensete ventricosum* are presented in Table 8. There was a significant difference among these tree species (organic nutrient sources) in their NPK contents. The highest N content was found in *E abyssinica* followed by *E. brucei* and the least content of N was in *E. ventricosum*. The N content of *E. abyssinica* was 68% significantly higher ($p < 0.05$) than the N contents of *E.ventrocosom* and 20% higher than *E. brucei.* However there was no ficantly difference between the two Erythrina spp. in their N contents.

With respect to phosphorus content, *E. abyssinica and E. brucei contain* significantly higher amount of P than that of *E. ventricosum*. But there was no significant difference between *E. brucei* and *E. abyssinica* in their P contents.

Table 8: Nitrogen (N), Phosphorus (P) and Potassium (K) content of the Ethiopian indigenous tree species.

NO.	Tree species	N	TN (%)	P (%)	K (cmol kg^{-1})
1.	*Erythrina brucei*	15	3.5a (2.77-3.93)*	0.38b (0.36-0.43)	2.0c (1.94-2.08)
2.	*Erythrina abyssinica*	15	4.2a (3.26-5.16)	0.39a (0.3-0.42)	2.6b (2.54-2.68)
3.	*Enste ventricosum*	30	2.4b (2.45-3.0)	0.26b (0.23-.28)	4.2a (4.04-4.56)
	LSD(0.05)		0.76	0.054	0.36
	CV(%)		13.0	8.0	6.3

**Figures in the parentheses are data ranges. Source: Abebe (2012)*

In the case of Potassium, significantly higher content was obtained in the leaf samples of Ensete ventrocusom than E. brucei and E. abyssinica. The K content of E. ventricosum was 65% and 105% significantly higher ($p < 0.05$)

than the content of E. abyssinica and E brucei respectively. There was also a significant difference between E. brucei and E. abyssinica in their K contents and it was significantly higher in the latter than the former.

The Organic carbon (OC), C/N ratio, lignin and polyphenol contents of Ethiopian indigenous organic nutrient sources are presented in Table 9. There were significant differences among the three plant species in their OC, C/N ratio, lignin and polyphenol. *E. brucei* has a significantly higher OC than *E. abyssinica* and *E. ventricosum* but there was no significant difference between the latter two in their OC content. On the other hand, there was a significant difference in their C/N ratio and it was higher in *E. ventricosum* than *E. abyssinica* and *E. brucei* and there was no significant difference between the latter two plant species.

Table 9: Organic carbon, C/N ratio, and lignin and polyphenol contents of *E. brucei, E. abyssinica* and *E. ventricosum*

NO	Organicsource type	OC (%)	C/N	Lignin (%)	Total soluble Polyphenol (%)
1	*E. brucei*	43.3 a (43.3-43.4)*	12a	12.6a (12.4-12.8)	1.06b
2	*E. abyssinica*	41.0b (40.9-41.2)	11a	9.7 b (9.9-9.5)	2.04a
3	*E. ventricosum*	41.2 b (41.3-41.2)	16b	6.5c (6.6-6.5)	0.08c
	LSD	**0.23**	**1.9**	**0.34**	**1.0**
	CV(%)	**5.8**	**7.5**	**2.5**	**10**

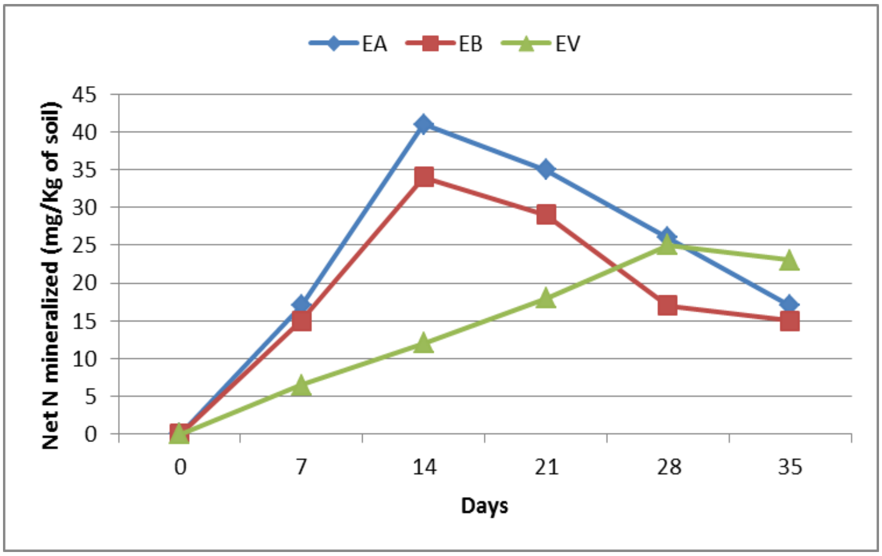
**Values in the parentheses are data ranges. Source: Abebe (2012)*

The lignin content was significantly higher ($p< 0.05$) for *E. brucei* and followed by *E. abyssinica* and least *for E. ventricosum*. With regards to polyphenol, however it was significantly lower in *E ventricosum*, followed by *E. brucei* and relatively higher for *E. abyssinica* (Table 9). In all the three plant species studied the lignin and polyphenol contents, however, were in the low range according to Palm and Mutto (1999).

3.3 Mineralisation Rate of *E. abyssinica, E. brucei* and *E. ventricosum*

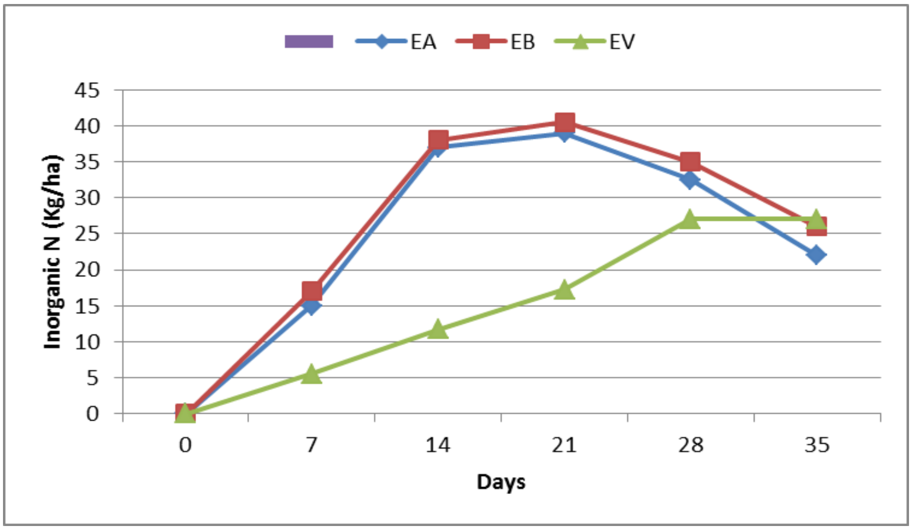
The net mineralisation rate of the three tree species (organic nutrient sources) studied under laboratory condition using soil samples from Hagreselam and Wolaita zones against time are presented in Figures 5 and 6 respectively. The maximum net N was released from *Erythina spp*. leaves in 14 days of incubation in both soils. But there was a decline in the net mineralisation rate

or in cumulative N released from *Erythrina spp* after two weeks and Net mineral N-released become the lowest after the end of five weeks.



EA = Erythrina abyssinica, EB = Erythrinia brucei, EV = Ensete venticosom (Source: Abebe (2012)

Figure 5: Net N mineralisation from E.abyssinica, E. brucei and Enset under HagereSelam soil.

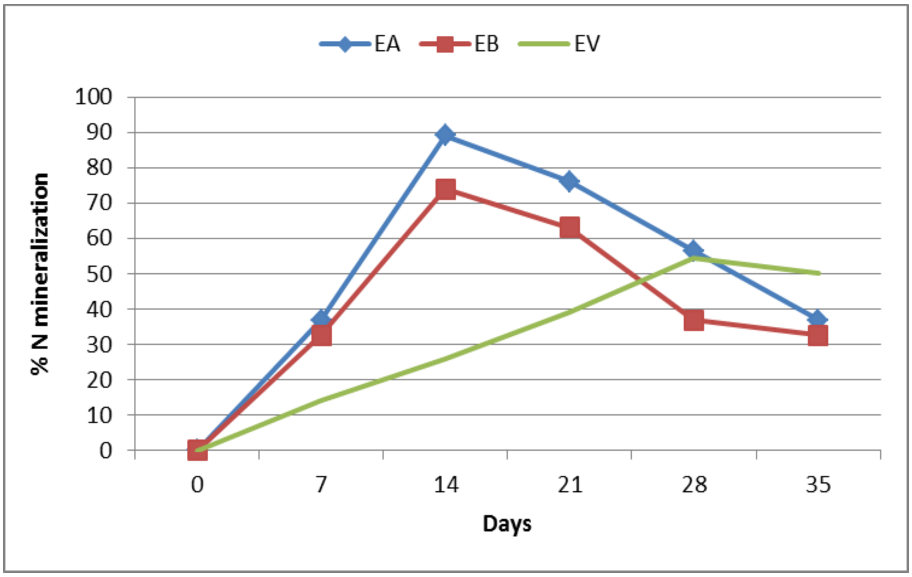


EA = Erythrina abyssinica, EB = Erythrinia brucei, EV = Ensete venticosom **(***Source: Abebe (2012)*

Figure 6: Net N mineralisation from E.abyssinica, E. brucei and Enset under Wolaita soil

The situation was completely different in the case of Enset, where the highest net mineralisation was achieved at the end of 28 days of incubation under both soil conditions. The net N mineralisation pattern of all the three materials was not affected by soil types used in the study.

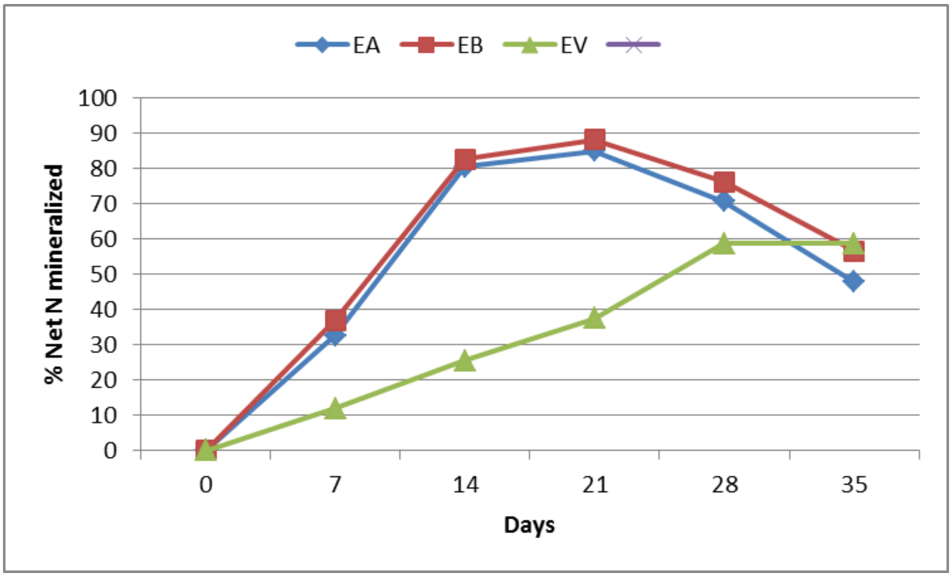
The percentage of N-mineralised from the three organic soils over time incubated with HagreSelam and Wolaita soils are presented in Figures. 7 and 8 respectively. A maximum of 85 % of N was released from E. spp leaves at the end of the 2 weeks (14 days) in both soils. However, there was a decreasing trend of N mineralised from litters of both Erythrina spp after two weeks in both soils.



EA = Erythrina abyssinica, EB = Erythrinia brucei, EV = Ensete venticosom Source: Abebe (2012

Figure 7: N mineralisation as percentage of initial plant N during decomposition of E.abyssinica, E. brucei and E. ventricosum under HagereSelam soil.

In the case of *Enset*, the maximum net N mineralisation was achieved at the end of the 28 days in both soils. Only 50 and 59 % of the added N in *Enset* litter was released at the end of the 28 days of incubation in HagereSelam and Wolaita soils respectively, in contrast to more than 80% N released from *Erythrina spp.*

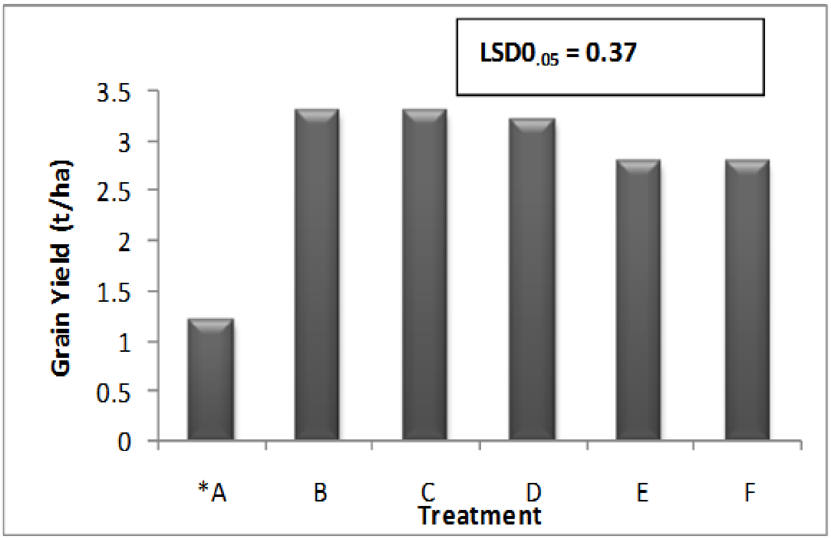


EA = *Erythrina abyssinica*, EB = *Erythrinia brucei*, EV = *Ensete venticosom*
Source: Abebe (2012)

Figure 8: Net N mineralisation as percentage of initial plant N during decomposition *E.abyssinica, E. brucei and E. ventricosum* under Wolaita soil.

4.4 Effects of Combined Application of Inorganic N Fertiliser and *E. brucei* Biomass on Wheat Performance and N-equivalence Value of *E. brucei*

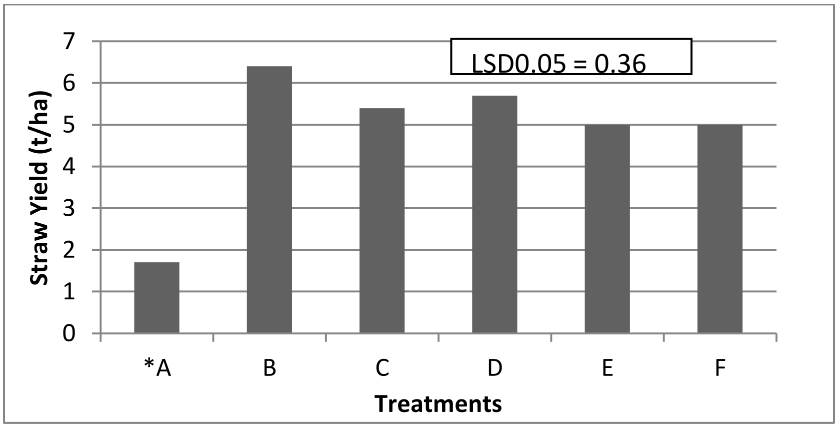
The data analysed over two seasons revealed that the grain and straw yield of wheat was significantly affected by N fertiliser, E biomass and their combinations (Figures.9 and 10). The E. brucei applied at 2.5 t DM ha-1 increased the grain and straw yields of wheat by 127% and 194% over the control group respectively. But the grain yield obtained from Erythrina biomass application was less by 20 % when compared with that which was obtained with recommended N (46 kg N ha-1).



*A= 0/0 inorganic/organic N, B= 100:0, C= 75:25, D= 50:50, E= 25:75, F= 0:100 inorganic/organic N. Source: First Authors's Field work (2010-2011)

Figure 9: The effects of combined application of inorganic N fertiliser and *E. brucei* biomass on the grain yield of wheat at Kokate over two years (2010-2011).

The highest grain and straw yield of wheat was obtained from sole N fertiliser (46 kg N ha^{-1}) and treaments which were composed of combined applications of inorganic N fertilisers and E. brucei biomass.



A= 0/0 inorganic/organic N, B= 100:0, C= 75:25, D= 50:50, E= 25:75, F= 0:100 inorganic/organic N Source: First Authors's Field work (2010-2011)

Figure 10: The effects of combined application of inorganic N fertiliser and E. brucei biomass on the straw yield of wheat at Kokate over two years (2010-2011).

Plate 5: Erythrina biomass treated wheat crop(left) and no fertiliser and no biomass treated (control) wheat(right), Kokate, Southern Ethiopia

The nitrogen equivalence value calculated on the N-response curve is shown in Figure 11. As indicated in the graph and calculated from regression equation, *E. brucei* biomass applied at 2.5 t DM/ha has nitrogen fertiliser equivalence value of 43 kg. This means approximately equal to one quintal of urea .

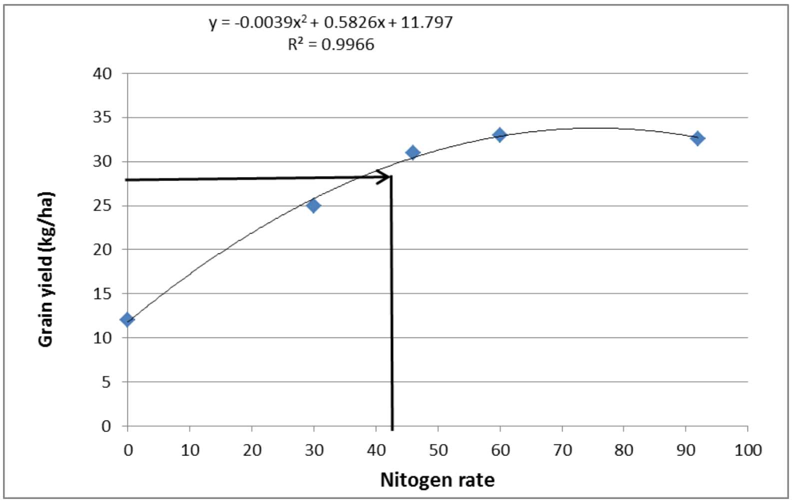


Figure 11: The effect of different rates of N fertiliser on the grain yield of wheat at Kokate, Southern Ethiopia
Source: First Authors's Field work (2010-2011)

It also means that the same amount of crop yield can be obtained by applying 2.5 t ha^{-1} of *Erythrina brucei* biomass on dry matter basis. The relative percent fertiliser equivalence value was also calculated and it was found to be 93%. This means that 93% of the recommended N fertiliser as urea for wheat crop production at Kokate area of Southern Ethiopia can be met with application of 2.5 t DM ha^{-1} of *E. brucei* biomass.

4.0 DISCUSSION

4.1 Soil Physicochemical Properties Used in the Mineralisation Study

The particle size distributions of the Kokote and Hagereselam soils have clayey textural class, in line with Ashenafi (2010) who reported that soils of Delbo Wogene watershed in Wolaita area have clay content ranging from 25 - 85%, throughout the profile.

The bulk density critical value for agricultural use according to Hillel, (1980) is 1.4 g/cm^3. Thus, the Wolaita and Hagereselam soil were less than the critical value. This implies that no excessive compaction and no restriction to root development (Werner, 1997) or both lies in good porosity for aerobic microorganisms. The Gravimetric water content of the soils at field capacity were (33 kPa) 46.20% , 42.74% while the amount at permanent wilting point (1500 kPa) were 31.55%, and 27.57 % respectively for Hagereselam and Wolaita soils. The volumetric plant available water content (AWC) of these soils was 14.65% and 15.17%. According to Beernaert (1990), available water content values are rated < 8 as very low, 8 – 12 as low, 12 – 19 as medium, 19 – 21 as high and >21% as very high. Accordingly, both soils available water content lies in medium range. Thus, optimal microbial activity occurs at near “field capacity” (Linn and Doran, 1984), as a result, both soils are in suitable range for aerobic microorganisms’ activity.

The pH of HagereSelam soil is strongly acidic and slightly acidic in Wolaita soils (Hoskins, 1997). The total nitrogen and OC contents were in the low ranges (Jones, 2001; Brook, 1993). The Olsen available P was in very low range in both soils acoording to Brook (1993).

4.2 Nutrient and Chemical Composition of Organic Nutrient Sources

The study has shown that *E. abbysibnica* and *E. brucei* ha leaf’ N contents are higher than 2.5%; indicating that they are high quality organic nutrient sources (Sangiga and Woomer 2009). The observed high N content in these plant species is expected as it is an N-fixing tree (Fasil, 1993; Negash, 2002). The average N content of *E. abyssinica*, as was revealed in this study, was appreciably higher than the average N content of leguminous cover and green manure crops reported in Gachene *et al*., (1999). The N content of *E. abyssinca* was compared to the N contents of different species of *leucaena* as reported by Kahsay and Thotill (1995), and higher than the N content of *Grilicida septum*, *cajanaus cajan*, *Cassia siamea*, *Dactyldenia barteri*,

Erythrina. Poeppingiana, *Ingga edulis* and *Alchornea cordifolia* (Nair, 1993).

However, the mean N content of *E. brucei* was found to be similar to the N content of leguminous cover crops reported in Gachene *et al*., (1999). But the finding of previous studies of *E. brucei* showed that it had N content of 4.83% (Wassie, 2012) which is much higher than the present N value of this plant. In the course of evaluating *E. brucei* as animal feed, Yinnesu and Nurfeta (2012) reported that it has a mean N content of 4.12%. The current lower value of N observed in this study is probably due to the fact that the N content of a particular plant could vary depending on the time of sampling, age of the plant and the variations in soil and climate conditions. This is substantiated by the fact that the plant sample from *E brucei* used for this study site were taken during the months of dry period in April 2011.

In the case *of Ensete ventricosum*, it had N content of 2.4% and this value is much higher than that of N content of Enset reported by Zebene (2003) to be 1.14%. The N content of Enset as revealed in this study and confirmed by Zebene (2003) and Nurfera *et. al*., (2009) is lower than the values of N recorded for most leguminous cover crops (Gachene *et al*., 1999). But, being a non N-fixing herbaceous indigenous food crop to Ethiopia, its N content could be considered to be high when compared with cereal residues and the likes of maize and wheat (McCartney, *et al*.,2006). The apparent relative high N content of *E. ventricosum* leaves could partially be explained. This is because it receives a high amount of organic residues such as household refuses, farmyard manure and compost in smallholder farms more than any other crops grown in the area (Elias, 2003).

With regards to Phosphorus (P), significantly higher amount was found in *E abyssinica* followed by *E. brucei* and the least in leaf litter of *E. ventricosum*. The P content of *E. brucei* and *E. abyssinica* is much higher than the P content (0.15 – 0.29 %) reported for leguminous tropical trees (Kahsay and Thotill, 1995; Palm *et al*., 2001) and the P contents of leguminous cover crops (Gachene *et al*, 1999). Kindu *et al*., (2009) reported that the P content of *Hagenia abyssinica*, an indigenous tree to Ethiopia was found to be higher than the P content of tropical trees. Yet, the P content of *Erythrina spp* studied had a higher P content than that of *Hagenia abyssinica*. The P content of *Erythrina spp* was higher than that reported for *Tithonia diversifolia* which is well known for its high P content (Nabahungu *et al*., 2011). The high content of P in the *Erythrina spp* could probably be attributed to P extraction and uptake ability from deeper part of P limited acid soil in southern Ethiopia where they are grown abundantly (Wassie and Shiferaw, 2009). One of the advantages of deep rooting perennial

agroforestry trees is that they take nutrients from the deepest part of the soil. Thus, they release it to the soil through their pruns when used as mulch or manure material which is not normally achieved with annual green manure crops (Larson and Frisvold, 1996).

The P content of Enset is lower than the P content of tropical trees but was similar to that found in the leguminous cover crops (Gachene *et al*., 1999; Kahsay and Thotill, 1995). On the other hand, the high P content observed in *E. ventricosum* is probably due to the high amount of organic fertiliser nutrients uptake that it receives in smallholder farms where it is grown as a high value food crop in the Southern Ethiopia region (Elias, 2003).

The potassium (K) contents of the three tree species (organic nutrient sources) were high but was still higher in *Enset* than in *Erythrina* spp. This could be due to the fact that, *Enset* being a high valued food crop grown in southern Ethiopia receives high amount of fertilisers in the form of organic material.

There were significant variations among the tree species (organic resources) studied in their carbon content and C/N ratios. The carbon content of the studied plant materials is lower than that reported for some tree legumes like *G. septum*, *Acacia* spp, *Cajanus cajan*, *Leucaena leucocephala* and *Albizia* spp. (Oyun, 2006).

The lignin and polyphenol contents of all the three plant species studied were below 15 and 5 % respectively, implying that both the lignin and polyphenol contents of the studied plant materials were all in the low range when compared with categories indicated in Gachengo *et al*., (2012). Compared with individual green manure trees, for example, *Gliricida septem;* which has polyphenol content of 14.9, the present materials have lignin content far lower than the value. The lignin and polyphenol contents of the plant species studied were also comparable to the lignin and polyphenol contents of legume cover crops reported in Gachene *et al*., (1999). Based on the N, lignin and polyphenol contents both *Erythrina spp* studied in this experiment are classified as high quality nutrient materials and rated as ‘quality class I‘ (Gachengo *et al*., 2012).

Enset has N content less than 2.5% nitrogen content which makes it a low quality organic nutrient source, compared to what was reported by Nurfeta *et al*., (2008). These authors reported that the N content of leaves of *Enset* sampled from Hawassa was 1.96%, higher C/N ratio and lower lignin and polyphenol content. Thus, based on such information, *Enset* can be rated as ‘quality class III’ plant material.

According to the decision guideline showing how to use organic material for soil fertility improvement as indicated by Sangiga and Woomer (2009), both *Erythrina spp* could directly be incorporated into the soil as organic fertiliser without prior composting or prior mixing with inorganic fertilisers. However, in the case of *Enset*, it can be used as organic fertiliser in the form of compost based on the same guideline.

4.3 Mineralisation Rate of *E. abyssinica, E. brucei* and *E. ventricosum*

In this study, it has been shown that *E. abyssinica* and *E. brucei* have the same N release pattern releasing most of their N content within two weeks of incoperation into the soil. Because these materials are high quality (Class-I), it is expected that they decompose faster and release N (Palm, 1995). The mineralisation rate of *Erythrina spp* obtained at the end of 2 weeks of incubation period was found to be four times higher than that reported for mineralisation rate of cowpea plant with N content of 2.9% during the same period of time (Franzluebbers *et al*., 1994). This may be due to the relatively higher amount of nitrogen present in the *Erythrina spp*. Moreover, differences in laboratory incubation condition could account for such a variation. The fast mineralisation of *Erythrina* biomass is in line with Rutunga *et al*., (2001), who reported that 52 - 80 % of N has been released from *Tephrosia* and *Tithonia* above the ground within 30 days after the biomasses were incorporated into the soil. The decline in the net mineralisation rate after two weeks in the case of *Erythrina spp* and after 4 weeks in the case of *Enset* is possibly due to the loss of N attributable to denitrification.

The results of mineralisation rate of plant materials obtained in the laboratory will not represent the mineralisation rate of the same plant material that will occur in the actual field condition.

However, even if the results from the laboratory incubation experiment do not represent the actual mineralisation in field conditions, the information will be very valuable as it gives an indication of how fast these plant materials will likely decompose under field conditions. Besides, the laboratory results will enable researchers compare the relative nutrient release pattern of the residues of different plant species.

4.4 Effect of *E. brucei* on the Yield of Wheat and its N-equivalence Value

The *E. brucei* biomass applied at 2.5 t DM ha^{-1} significantly increased the grain and straw yield of wheat in the study. This suggests that the nutrient

released from mineralising *Erythrina* biomass has been taken up by the wheat plant. This is substantiated by the finding in this study and earlier reports by Palm (1995) that the N content and the very low lignin and polyphenol contents of *E. brucei* are some of the indices of high quality plant material of organic source. There are a number of reports indicating that leguminous green manures and trees incorporated into the soil serve as nutrient sources and thus increase the yield of crops (Wassie *et al*., 2009; Omotayo and Chukwuka, 2009. Sileshi *et al*., 2008; Mugwe *et al*., 2007; Yadessa and Bekerea, 2003).

According to Yadessa and Bekere (2003), biomass of *Cajanus cajan* applied at a rate of 4 t ha^{-1} increased the grain yield of maize by over 86% compared to the control. In a similar study, Mombeyarara *et al*., (2011) reported that the effect of *Ipomoea stenosiphon,* a locally available plant material with N content of 2.3%, when applied at 75 kg/ha N equivalence on maize, increased the grain yield by 111% and 161% on two soils.

The grain yield of wheat obtained with *Erythrina* biomass incorporated soil was 20% less than that obtained with the recommended dose of N inorganic fertiliser, as opposed to our report that with *Erythrin brucei* biomass applied as N source produced the same as that obtained with the recommended inorganic fertiliser (Wassie, 2012). This may be due to poor synchronisation of the N released from *Erythrina biomass* with crop demand which could be explained by the effect of seasonal variation in climate and soil factors.

5.0 CONCLUSION

Both *Erythrina abyssinica* and *E. brucei* have N contents greater > 2.5%, lignin content <15% and polyphenol content < 5%. Based on these quality indices, they are rated as high quality (Class-I) organic sources that can be directly incorporated into the soil as a source of nutrients for growing crops.

These plant species also have P contents comparable to the P content of *tithonia* which is known for its high organic P content. Again, both *Erythrina spp* have fairly high amount of K in their leaves. This implies that they can be a good source of P and K in addition to N.

Enset, has an N content < 2.5% indicating it is low quality material with respect to nitrogen although the low lignin and polyphenol content upgrades its quality. Also, Enset has a higher C/N ratio. Given that it is a non N-fixing plants like cereals, it can be qualified as being of high quality, however, based on quality indices in the literature, it can be rated as belonging to class III materials. *Enset* was shown to contain relatively low amount of leaf P content but contains high amount of K as opposed to *Erythrina* spp.

Under the current study condition and location, *E. brucei* biomass applied at 2.5 t DM/ha has been shown to have an N-equivalent value of 43 $kgha^{-1}$ nearly one quintal of urea. This means that the biomass applied at this rate could produce the same yield as that produced by applying one quintal of Urea. This further implies that in areas where the tree is abundantly growing *E. brucei* as in most locations in southern Ethiopia, farmers can reduce the cost of inorganic N fertilisers by collecting *Erythrina brucei* biomass from around their homestead and farm boundary trees and incorporating it into the soil. Moreover, in addition to being nutrient sources, the use of such locally available organic fertilisers, have additional benefit of increasing the soil OM content which is the key for maintaining land sustainability

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6.0 RECOMMENDATIONS

Laboratory and field crop response studies proved that *E. brucei* is a high quality locally available source of organic fertiliser that can be used for improving soil fertility to enhance and sustain crop production in Ethiopia. Thus, there is a need for extension of this low-input technology to farmers to be used as organic inputs for soil fertility improvement.

E. abyssinica, is rated as being a good quality organic fertiliser source from the results of the laboratory experiment. But a further real time study in the field of different crops is recommended to determine the extent of benefits in terms of yield and soil quality improvement.

In the present study, only the nutrient contents in leaves of *Erythrina spp* and *Enset* were studied, however, further studies on the nutrient compositions of roots, stems buds and flowers should also be conducted.

The *Eerythrina spp* investigated in this study is N-fixing trees. But the N-fixation characteristics such as extent of N-fixation, nodulation pattern, the type bacteria that nodulates them are not well known. Thus, further studies in the N-fixation aspect of both *Erythrina spp.* are recommended.

Both *Erythina spp* have P and K content comparable to the P and K contents available in most green manure crops and trees. This is an added advantage to N to use them as organic P and K sources for crops. But further detailed field experiments are required to determine the values of these plants as a source of P and K nutrition of crops.

Enset plant, is not an N-fixing plant, it has a high nutrient composition especially, potassium compared to cereals. It can be a good source of organic fertiliser provided that further field experiment on the effect of *Enset* biomass on the yield of crops are studied and results are known.

Further economic analyses of organic nutrient sources especially *Erythrina spp* should be done against inorganic fertilisers that are imported annually into Ethiopia.

REFERENCES

Abebe, A. 2013. Chemical Characterization of *Erythrina abyssinica*, *Erythrina brucei* and *Ensete ventricosum* and their aerobic mineralization in Luvisols of Hagereselam and Cambisols Wolaita zones, Southern Ethiopia. MSc. Thesis, Hawassa University.

AHI. 2003. Restoring soil fertility in the east African highlands through participatory research, CIAT, Kampla, Uganda.

Anderson, J.M. and S.J. Ingram, 1996. Tropical Soil Biology and Fertility: A Handbook of Methods, 2nd edition. CAB International, Oxford, UK

AOAC. 1990. Association of Official Analytical Chemist, Official Methods of Analysis, 15th Ed., Washington DC, USA.

ARC (Awassa Agricultural Research Centre). 2011. Progress report of natural Resources for the period 2010/2011. Hawassa, Ethiopia.

Ashenafi, A., Abayneh, E., and Sheleme, B., 2010. Characterizing soils of Delbo Wegene watershed, Wolaita Zone, Southern Ethiopia for planning appropriate land management. Journal of Soil Science and Environmental Management 1: 8, pp. 184-199.

Bationo, A., B. Wasawa, J. M. Okeyo, F. Maina and J. Kihara. 2011. Innovations as key to the green revolution in Africa: Exploring the scientific facts. Vol. 1. Springer, London

Beernaert, F., 1990. Simple and practical methods to evaluate analytical data of soil profiles. Maputo, Mozambique. Pp: 145-150.

Bishaw, B. and A. Abdulkadir. 1990. Agroforestry and Community Forestry for Rehabilitation of Degraded Watersheds on the Ethiopian Highlands. Ethiopian Tree Fund Foundation. etff.org/Articles/Agroforestry.html Accessed on 25/09/2010 at 14.29 Ghana Time.

Black, C.A, 1965. Methods of soil analysis. Part I, American Society of Agronomy. Madison, Wisconsin, USA. 1572p.

Brook, R. H. 1983. International course on soil and plant analysis: Lecture notes. Service Laboratory for Soil, Plant and Water Analysis, Soil

Science Department, Faculty of Agriculture, Minia University, Egypt.

Demil, T., 1994. Germination ecology of two endemic multipurpose species of *Erythrina* from Ethiopia. *For. Ecol. Manage.*, 65: 80–87.

Elias, E. 2003. Module 2 - Environmental roles of agriculture in Ethiopia. www.ftp.fao.org/es/esa/roa/pdf/2_Environment/Environment_EthiopiaNA.pdf, accessed on 06/11/2012 at 14.16 Ghana time.

Elias, E.,2002. Farmer's Perception of Soil Fertility Change and Management. SOS SAHEL and Institute of sustainable development, Addis Ababa, Ethiopia.

Fassil, A., 1993. Nodulation Nitrogen Fixation by Rhizobium and Bradyrhizobium Species of some Indigenous Tree Legumes of Ethiopia. Dissertation, University of Bayreuth, Germany.

Francis, A., E. Ngome, M. Becker, K. elvin and M. Mtei. 2011. Leguminous cover crops differentially affect maize yields in three contrasting soil types of Kakamega, Western Kenya, J Agric.and Rural Devet. In the Tropics and Subtropics.

Franzluebbers, K., R.W. Weaver, A.S.K. Juo and A. J. Franzluebbers. 1994. Carbon and nitrogen mineralisation from cowpea plant part in repeatedly dried and wetted soils. *Soil Biol. Biochem*. 26: 1379-1387.

Gachene, C. K. K., C. A. Palm and J. G. Mureith. 1999. Legume cover crops for soil fertility improvement in eat African region. Report of an AHI Workshop, TSBF, Nairobi, 18 - 19th Feb., 1999.

Gachengo, C., B. Vanlauwe, and C. Palm. 2012. Mineralization pattern of selected organic materials. http://webapp.ciat.cgiar.org/tsbf_institute/pdf/ nut_mgt_paper_5.pd, Accessed on 2012 at 15.25 Ghana time.

Gitarai, J.N, S.K. Karumba and K Muaniki.2000. Performance of green manure legumes in two contrasting sites at Embu and Mbeere district of Mount Kenya region. Legume Res Netw Pro Newsletter. 4: 2-4.

IFPRI. 2010. Fertilisers and soil fertility potential in Ethiopia: Constraint and opportunities for enhancing the system, working paper, Washington.

Jama, B., C. A. Palm, R.J. Brush, A. Niamng, C. Gachengo, G. Nzigueba and B. Amandalo. 2000. Tithonia diversifolia as a green manure for

soil fertility improvement in western Kenya: A review. *Agroforestry Systems* 49: 201–221.

Jones, B. J. Jr. 2001. Laboratory guides for conducting soil tests and plant analysis, CRC press, London.

Hillel, D., 1980. Fundamentals of soil physics. Harcourt Brace Jovanivich Publisher, Academic Press, Inc. San Diego. 413p.

Hoskins, B. R. 1997. Soil testing hand book for professionals in agriculture, nutrient and residual management, 3rd ed. University of Marine, Orono,, Maine.

Kahsay, B. and J.C. Thotill, 1995. Performance, feed quality and P response of *Leucaen* and *Calliandra* species grown as hedge row on acidic Nitisol at Soddo, Ethiopia. *Trop. Grassl.*, 29: 1–8.

Keeny, D. R. and D. W. Nelson. 1982. Nitrogen: Inorganic forms, PP. 684-654. In: A. L. Page and D. keeny (eds.). Methods of soil analysis, Part 2. Chemical and microbiological properties of soil analysis. Agronomy Monograph, No. 9. ASA, Madison.

Kena, K., Y. Tadesse and B. Tesfa, 1992. Influence of fertiliser and its related management practice on maize grain yield in major maize producing areas of Ethiopia. *In*: Benti, T. and J.K. Ramsom (eds.), *Proceedings of the First National Maize Workshop of Ethiopia*, pp: 95–104. 5–7 May 1992, IAR/CIMMYT, Addis Ababa, Ethiopia.

Makumba, W and A. Phiri. 2003. Evaluation of *Gricilida septum* and *Tephrosia candida* as a source of N for vegetable production in a biomass transfer. http://www.cabi.org/GARA/FullTextPDF/2008/20083327052.pdf. (Accesssed ,May 30th,2011)

Kindu, M, G. Glatzel and M. Sieghardrt. 2009. Haggena abyssinica (Bruce) J.F. Gmel: A preffered tree for fodder and soil fertility improvement in Galessa watershed, central Ethiopia. *Ethiopian Journal of Natural Resources.* 11: 277-291

Larson, B.A., and G.B. Frisvold. 1996. Fertilisers to support agricultural development in sub-Saharan Africa: What is needed and why. *Food Policy* 21:509 - 525.

Legesse, N. 2002. Review of research advances in some selected African tree with special reference to Ethiopia. *Ethio. J. Biol. Sci.,* 1: 81-126.

Linn, D.M. and Doran, J.W. 1984. Effect of water-filled pore space carbon dioxide and nitrous oxide production in tilled and non-tilled soils. *Soil Sci. Soc. Am J.,*48: 1267-1272.

Makumba, W. and A. Phiri. 2008. Evaluation of *Gliricidia sepium* and *Tephrosia candida* leaves as a source of N for vegetable production in a biomass transfer. Annual Report - Soil and Agricultural Engineering Commodity Group, 2007/08. Presented during the DARS Annual Planning meeting held at Andrews Holiday Resort, Mangochi, 14-19th September, 2008 2008 pp. 2-8

McCartney, D. H., H. C. Block, P. L. Dubeski and A. J. Ohama. 2006. Review: The composition and availability of straw and chaff from small grain cereals for beef cattle in western Canada. *Can. J. Anim. Sci*. 86: 443–455.

Mombeyarara, T., H.K. Murwira and P. Mapfumo. 2011. The potential of Ipomoea stenosiphon as a soil fertility ameliorant in the Semi-arid tropics. Pp. 481-490. In: A. Bationo, B. Waswa, J.M. Okeyo, F Maima and J. Khara (Eds). Innovation as a key to the green revolution in Africa.: Exploring the scientific facts. Vol. I, Springer, London

Mugendi, D. N, B. S Waswa, M. W Mucheru-Muna and JM Kimetu. 2011. Startegies to adapt, disseminate and scale out legume based technologies. Pp. 85-116. In Bationo, A., B. Wasawa, J. M Okeyo, F. Maina, J kihara and U Mukwunye (eds). Fighting poverty in Sub-Sahara Africa: The multiple roles of legumes in integrated soil fertility management. Springer, London.

Mugwe, J., J. Mugendi-Kungu and M. Mucheru-Mun, 2007. Effect of plant biomass, manure and inorganic fertilisers on maize yield in the central highlands of Kenya. *African Crop Sci*. J., 15: 111–126

Mureithi, G. J, C.K.K Gachene and J. L. W. Charles K K Gachene and J. L.WWanmuongo. 2004. Legume cover crops research in Kenya: Experiences of the legume research network project highlights of phases I research activities (1994-2000), KARI Technical Note Series. No. 12, Nairobi.

Mutuo, P. and C. Palm, 1999. Combined Organic-Organic Nutrient Sources: Experimental Protocol for TSBF-Afnet, Soil Fertility and SWNM, TSBF Program. Nairobi, Kenya

Nabahungu, N.L, J.G. Mowo, A. Uwiragiye and E. Nsengumuremyi. 2011. Use of Tithonia biomass, maize residue and inorganic phosphate in climing bean yield and soil properties in Rwanda. Pp. 335-341. In: A. Bationo, B. Waswa, J.M. Okeyo, F Maima and J. Khara (Eds). Innovation as a key to the green revolution in Africa.: Exploring the scientific facts. Vol. I, Springer, London.

Nair, P. K. R. 1993. An Introduction to Agroforestry, ICRAF, Kluwer Academic Publisher, London.

Nandwa, S. M, S. N. Obanyi and P. L. Mafongoya. 2011. Ago ecological distribution of legumes in farming systems and identification of biophysical niches for legumes growth. Pp. 1-26. . In Bationo, A., B. Wasawa, J. M Okeyo, F. Maina, J kihara and U Mukwunye (eds). Fighting poverty in Sub-Sahara Africa: The multiple roles of legumes in integrated soil fertility management. Springer, London.

Na-songkhla, B., 1997. Erythrina variegata L. In: Faridah Hanum, I. and L.J.G. Van Der Maesen (eds.), Plant Resources of South-East Asia No. 11 Auxiliary Plants, pp: 130–132. Prosea Foundation, Bogor, Indonesia

Nurfeta, A., A Tolera, L.O Eik and F. Sundstøl. 2008. Feed value of enset (*Ensete ventricosum*), *Desmodium intortum* hay and untreated or urea and calcium oxide treated wheat straw for sheep Journal of Animal Nutrition. 93:94-104.

Okalebo, J. R., Othieno, C. O., Woomer, P. L., Karanja, N. K., Semoka, J. R. M., Bekunda, M. A., Mugendi,D. N., Muasya, R. M., Bationo, A. & Mukhwana,E. J. (2006). Available technologies to replenish soilfertility in East Africa. *Nutrient Cycling in Agroecosystems*, 76, 153–170

Olsen, S. R., C. V. Cole, F. S. Watanabe and L. A.Dean.1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA circular 939. 1-19p.

Omotayo, O.E. and K.S. Chukwuka, 2009. Soil fertility restoration techniques in sub-Saharan Africa using organic resources. *African J.Agric. Res.*, 4: 144–150.

Oyun, M.B. 2006. Chemical characterization of selected tree legumes as indices for their litter quality. *J.App. Sci.*, 6: 2321-2324.

Palm, C.A, C.N. Gachengo, R.J, Delve, G Cadisch and K.E Giller. 2001. Organic inputs for soil fertility management in tropical agro ecosystem: application of organic resource database. Agriculture, ecosystems and environment. 83:27-42

Palm, C.A. 1995. Contribution of agroforestry trees to nutrient requirements of intercropped plants.*Agrofor. Sys*. 30: 105-124

Parr, J. F and D. Colacicco . 1987. Organic Materials as Alternative Nutrient sources. Pp. 81-99. Helsel, Z.R. (Ed.), Energy in plant nutrition and pest control. Elsevier Science Publishers B.V., Amsterdam.

Pound, B & E. Jonfa. 2005. Soil Fertility Practices in Wolaita Zone, Southern Ethiopia: Learning from Farmers, Farm Africa, Waterside press, London.

Rutunga, V., N. K. Karanaja and C. K. K. Gachene. 2001. Decomposition of biomass obtained from six months old Tephrosia vogelii, Tithonia diversifolia and natural vegetation fallow at Maseno, Kenya. *Agric. Hortic* 19: 49-62.

Sertus, S. and T. Bekele. 2000. Procedures for soil and plant analysis. National Soil Research Center, EARO, Technical Paper No.74, Addis Ababa, Ethiopia.110 p.

Sangiga, N and P.L. Woomer. 2009. Integrated soil fertility management in Africa: Principles, practices and development process. Tropical soil biology and fertility program of the CIAT, Nairobi. 263pp.

SAS, 2000. *User's guide, Statistics, Version 8.1 Edition*. SAS Inst, Inc., Cary, North Carolina, USA.Sileshi, G., F.K. Akinnifesi, O.C. Ajayi and F. Place, 2008. Meta-analysis of maize yield response to planted fallow and green manure legumes in sub-Saharan Africa. *Plant Soil*, 307: 1–19.

SLU (Sustainable Land Forum), 2006. Indigenous Agro Forestry Practices and their Implications on Sustainable Land Use and Natural Resources Management: The Case of Wonago Woreda Research Report No. 1. Addis Ababa, Ethiopia.

Stoorvogel, J.J., and E.M.A. Smaling. 1990. Assessment of soil nutrient depletion in sub-SaharanAfrica: 1983-2000. Rep. no. 28. Vol. l-4. Winand Staring Ctr., Wageningen, the Netherlands.

TSBF.1993. Tropical soil biology and fertility. Hand Book of Methods, J.M Anderson and J.S.I Ingram (Ed), CAB, Wallington, UK.

Tsegaye, A. 2007. Effect of repetitive transplanting and leaf pruning on growth and dry matter partitioning of Enset (*Ensete ventricosum* welw. Cheesman) ,*Jounal of Agronomy* 6: 45-52.

Walkley, A. and I.A. Black. 1934. An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. *Soil Sci*. 63:251-263.

Wassie, H, B. Shiferaw and K. Kelsa, 2009. Integrated Soil Fertility Management Options for Sustainable Crop Production: Review of Research Findings from Southern Regional State of Ethiopia. Pp. 163–175 In: ESSS (ed.), Improved Natural Resource Management Technologies for Food Security, Poverty Reduction and Sustainable Development: Proc. 10th Conf. Ethiopian Soc. Soil Sci. 25–27 March, 2009 EIAR, Addis Ababa, Ethiopia.

Wassie, H. and B. Shiferaw. 2009. Mitigation of soil acidity and fertility decline challenges for sustainable livelihood improvement: Evidence from southern Region of Ethiopia. *In*: Atlaw, A., Y. Saba, M. Alemu and K. Minale (eds.), *Proc. National Conf. Sustain. Land Manag. Poverty Alleviation, Co-organised by Environ. Econ. Policy Forum for Ethiopia at Ethiopian Develop. Res. Institute, Sus. Land Use Forum (SLUF)*, pp: 131–143. Oromia Agricultural Research Institute (ORARI) and College of Agriculture at Hawassa University, Addis Ababa, Ethiopia.

Wassie, H. 2012. Appraisal of *Erythrina brucei* as a source for soil nutrition on Nitisols of South Ethiopia. *Int. J. Agric. Biol.*, 14: 371–376.

World Bank. 2008. Ethiopia: National Fertiliser project, Staff appraisal report, Washington Dc.

Werner, MR., 1997. Soil Quality characteristics during conversion to organic orchard management. *Appl. Soil Ecol*., 5: Pp 151-167.

Yadessa. A and D. Bekere, 2003. Effect of biomass transfer of *Cajanus cajan* with or without inorganic fertiliser on BH-600 hybrid variety at Bako, Western Oromia. Pp. 45-50. In: Tilahun, Amede and E. Zewde (eds.), Challenges of Land Degradation of Agriculture in

Ethiopia:Proceedings of the 6th ESSS Conference, pp. Feb 28–March 1, 2002, ESSS, Addis Ababa, Nigeria.

Yinnesu, A and A. Nurfeta. 2012. Effects of supplementing *Erythrina brucei* leaf as a substitute for cotton seed meal on growth performance and carcass characteristics of Sidama goats fed basal diet of natural grass hay. *Tropical Animal Health Production*, 44:445-451.

Young, A 1989 Agroforestry for soil management. 2nd edn. CABI Publishing, Wallingford, UK. p 320

Zebene, A. 2003. Tree species diversity, topsoil conditions and arbuscular mycorrhizal association in the Sidama traditional agroforestry land use, southern Ethiopia, PhD Dissertation, Upsala, Sweden. www. pub.epsilon.slu.se/214 Accessed on 13/11/2012, 5:30 Ghana time

Internet sites :

http://www.kew.org/plants-fungi/Ensete-*ventricosum*.htm
http://www.fao.org/docrep/X5327e/x5327e11.htm
http://en.wikipedia.org/wiki/Ensete_ventric

APPENDICES

Appendix 1: Total Nitrogen content of *E. brucei* and *E. venricosom* in different sites of Wolaita zone

	E.bruceie			*E.ventricosum*	
Site	Masl	Replication	T.N %	Replication	T.N %
Delbo Atwero	2236	1	3.77	1	1.16
		2	3.85	2	1.16
		3	3.93	3	1.23
Doga	1975	1	3.47	1	2.62
		2	3.31	2	2.77
		3	3.35	3	2.85
Gacheno	1884	1	3.00	1	3.16
		2	2.85	2	2.93
		3	2.70	3	3.00
Kokote	2154	1	3.94	1	2.46
		2	3.93	2	2.62
		3	3.92	3	2.62
Shone	1996	1	2.70	1	2.46
		2	2.85	2	2.62
		3	2.77	3	2.54

Appendix 2: Total Nitrogen content of *E. abyssinica* and *E. ventricosum* in different sites of Sidama zone

Site	masl		*E. abyssinica*	.	*E.ventricosum*
		Replication	% T.N	Replication	% TN
		1	5.16	1	3.00
Bultima	1941	2	5.08	2	3.16
		3	5.16	3	3.16
		1	3.16	1	2.23
Tubito	2234	2	3.31	2	2.08
		3	3.31	3	2.16
		1	4.31	1	2.93
Kila	2483	2	4.47	2	3.00
		3	3.85	3	3.10
		1	3.70	1	2.70
Aridessa	2686	2	3.62	2	2.70
		3	3.70	3	2.62
		1	3.85	1	2.77
Hagereselam	2767	2	4.00	2	2.23
		3	4.08	3	2.39

Appendix 3: Chemical characterization of EA, EB and EV

ONR	Rep	ADF	Lignin	Cellulose	Total Organic Carbon
		%			
E. abyssinica	1	31.00	9.90	1.00	43.42
	2	30.20	9.50	1.10	43.30
	3	30.50	9.70	1.20	43.36
E. brucei	1	35.00	12.80	2.00	40.93
	2	33.30	12.40	1.60	41.19
	3	34.80	12.70	1.80	41.16
E. *ventricosum*	1	30.90	6.60	0.60	41.13
	2	31.00	6.50	0.40	41.15
	3	31.00	6.50	0.56	41.14

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