On indigenous production, genetic diversity and crop ecology of enset (*Ensete ventricosum* (Welw.) Cheesman)

Promotor: Prof. dr. ir. P.C. Struik
Hoogleraar in de Gewasfysiologie

Samenstelling promotiecommissie:
Dr. T. Berg (Agricultural University of Norway, Norway)
Prof. dr. A. Niehof (Wageningen Universiteit)
Dr. ir. L. Visser (Wageningen Universiteit and Research centrum)
Dr. ir. E. Westphal (Wageningen Universiteit)

On indigenous production, genetic diversity and crop ecology of enset (*Ensete ventricosum* (Welw.) Cheesman)

Admasu Tsegaye

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Dedicated to my elder brother Alemayehu Tsegaye,
who died during his PhD studies, without seeing his wishes fulfilled.

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Abstract

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The indigenous enset-farming complex of the south and southwestern highlands of Ethiopia has supported a higher population density than any other farming system. Enset (*Ensete ventricosum* (Welw.) Cheesman) has been cultivated as (co-)staple food for about 7–10 million people. Since the last three decades, however, because of population pressure, recurrent drought and diseases there has been degradation of natural resources and, thus, the system failed to sustain the population. In the study, described in this thesis, the indigenous enset production methods, farm-based enset biodiversity and the plant characteristics and environmental factors influencing productivity were analysed to identify yield potentials and constraints in Sidama, Wolaita and Hadiya. The ultimate goal was to develop improved agronomic practices and enhance the use of the existing genetic diversity to reduce the gap between the actual yield and yield potential.

Some indigenous cultivation methods vary among regions: initiation of suckers, frequency of transplanting, leaf pruning and planting patterns. Morphologically diverse enset clones were identified in Sidama (52), Wolaita (55) and Hadiya (59). Among 146 clones, a total of 180 AFLP fragments was scored of which 104 (58%) appeared polymorphic. The AFLP-based dendrogram showed more duplication groups than the farmers' characterisation method suggesting that farmers overestimate the genetic diversity. The correlation between the two methods was only weak. Yet, the comparison between the AFLP-based and farmers-based characterisation methods showed that some aspects such as absence of clear regional clusters and clustering of clones with various prefixes to a single group corresponded well. Duplications in the clones identified by both methods may be safely removed from a conservation programme. Variation in farmers' skill in discriminating between clones may suggest that the areas where the people's culture is closely associated with the crop, should receive high priority for collecting clones or serving as sites for *in situ* conservation.

Plant height and LAI of different clones increased faster at Awassa or Areka than at Sidama because of a higher leaf appearance rate associated with temperatures being closer to the optimum. This led to higher early interception of photosynthetically active radiation and higher dry matter production. The mean extinction coefficient was between 0.56–0.91 and radiation use efficiency (RUE) ranged from 1.43–2.67 g MJ^{-1}. Yield potential differences between clones existed, mainly because of differences in RUE. The average ratio actual yield : yield potential (0.24) suggest that much can be done to reduce the yield gap.

Transplanting suckers directly into permanent field shortens the period until maturity, provides a reasonable yield soon after removing the suckers from the mother corm and reduces the chance of attack by disease or pests. The partitioning of dry matter to the harvestable parts, the harvest indices at different states of processing and the losses caused by scraping or fermentation, however, became more advantageous as a result of repetitive transplanting. At flowering, harvest indices based on fermented enset products of once, twice and three times transplanted suckers were 0.20, 0.35 and 0.25, respectively. Leaf pruning or the interaction between leaf pruning and transplanting did not significantly affect dry matter partitioning, harvest index or processing losses.

The maximum fresh weights of kocho after fermentation from enset plants transplanted once, twice and thrice were respectively 25.9, 54.1 and 37.1 kg plant^{-1}. In terms of weight and energy, enset is the most productive crop in the country, sweet potato is second, taro is third and Irish potato is fourth. The cultivation of enset in densely populated areas under low-input conditions can sustain the population better than that of any other crop. Moreover, enset produces various by-products and the prolonged presence of a closed canopy has an ecological advantage similar to that of forest.

This study combines indigenous technical knowledge, agronomic, physiological and molecular studies. It has contributed significantly to the understanding of the production methods and the genetic diversity. It has also investigated some strategies to reduce the gap between the actual yield and yield potential. Furthermore, it has underlined the relevance of physiological studies by generating basic physiological parameters. The information gained in this study also helped to underline future research topics.

Keywords: Enset, staple, indigenous knowledge, genetic diversity, AFLP, characterisation, conservation, Leaf Appearance Rate, Radiation Use Efficiency, yield potential, transplanting, leaf pruning, fermentation, 'kocho', food security

Propositions

1. In conserving and using biodiversity of enset, women play a major role.
   (this thesis)

2. A combination of factors, including household resources, cultural background, population pressure, disease pressure, and agro-ecology influences the number of enset clones on a given farm.
   (this thesis)

3. Poor processing and fermentation techniques threaten food security in enset growing areas.
   (this thesis)

4. Places with diverse cultural background have rich biodiversity.

5. Indigenous communities often protect valuable enset clones not because they provide food or forage but because they have significance to the ecological situation.

6. *In situ* conservation of biodiversity requires poverty alleviation while maintaining traditional values.

7. In a country as huge and diverse as Ethiopia, management of diversity in any form is the biggest challenge.

8. Development support or research assistance for developing countries that does not incorporate capacity building for technology development will not alleviate poverty or contribute to food security and environmental sustainability.

Propositions belonging to the PhD thesis of Admasu Tsegaye:
On indigenous production, genetic diversity and crop ecology of enset (*Ensete ventricosum* (Welw.) Cheesman)

Wageningen, 22 April 2002.

Preface

This is a thesis on *Enset ventricosum*, a crop that is important for food security and environmental sustainability, but has been neglected by research and development work for a long period of time. I sincerely hope that this thesis will not only bring the potential of the crop to the attention of the scientific community and policy makers but that it also underlines basic strategies to increase food security and environmental sustainability in enset-growing regions.

First and for most I would like to especially mention Prof. P.C. Struik, my supervisor and promotor, without whom the accomplishment of the work would not have been possible. Prof. P.C. Struik was my teacher and supervisor when I was at Wageningen University in 1991. The way he taught and guided me during my MSc studies gave me love and aspiration for science and opened my eyes to start a PhD research project. During his two visits to my field experiments and the enset-growing regions he gave me enlightening directions on the relevance of enset physiological and biodiversity studies. His keen interest in the enset crop, the farming system and his new ideas inspired me time after time. Prof. Struik is an efficient and dedicated promotor, always fast in reading and returning the draft manuscripts. He also provided financial support to carry out the molecular analyses. Thank you.

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May God bless you all,

Admasu Tsegaye

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CHAPTER 1

General introduction

CHAPTER 1

General introduction

This introductory chapter first gives an overview of the geographical situation, population and agriculture of Ethiopia. It then provides some details on the history, origin, distribution, botany, ecology, propagation, cultivation, harvesting, processing, and use of the enset plant. Finally, it presents the problem description, framework and objectives of the study described in this thesis. Part of this introduction is based on Tsegaye and Westphal (2002).

Ethiopia

Geographical location and climate of Ethiopia

Ethiopia lies in eastern Africa between 3° and 15° N and 33° and 48° E, with an area of 1.223 million km^2. The country covers an altitude range of 116 m bsl to over 4620 m asl. Although the country is located 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 °C. But, the sparsely-populated lowlands typically have hot climates.

Population

Ethiopia is the second most populous country in sub-Saharan Africa with an estimated population of over 57 million. The highest concentration of people (around 80%) resides in the highlands where the climate is favourable. The peoples of Ethiopia have a historically interesting and traditional culture originating 3000 years ago (Stroud and Mekuria, 1992). There are about 75 ethnic groups of various sizes, many with their own language, culture, farming system and identity.

Agriculture

Agriculture is the main economic activity of Ethiopia. The country's diverse agro-ecological regions are suitable to grow almost everything that human beings want in the world. Although the country is richly endowed with huge manpower and arable land, much of its potential is not yet exploited. Out of the 60% of its landmass, which is known to have a potential for agricultural development, only about 15% is said to have developed.

The agriculture sector contributes for about 55% of the Gross Domestic Product, accounts for around 90% of the total foreign exchange earnings and employs about 85% of the economically active population (Central and Statistical Authority – CSA, 1997b). About 95% of the presently cropped land of the country is cultivated by private holders (Zekaria and Abebe, 1996). According to CSA (1997b), subsistence private peasant farming includes about 8 million small households with an average family size of 5.12 persons and a crop area of 1 hectare. The private subsistence peasants still practise centuries old traditional methods of production with a very low productivity. In addition, drought and uneven distribution of rain often threaten the agricultural sector of Ethiopia resulting in food insecurity and local famine in certain parts of the country.

Farming systems

There are four major farming systems in Ethiopia: pastoralism, shifting cultivation, the seed-farming complex, and the enset-planting complex (Westphal, 1975). Among these, the enset-planting complex is the indigenous farming system, which supports a denser population than any other farming system (Brandt *et al.*, 1997). This production system is dominant in the highlands of south and southwestern parts of Ethiopia where several important differences in cultural and social organisation between ethnic regions exist.

In the enset-based cultivation, enset (*Ensete ventricosum*; also called 'ensete' in English) traditionally ranked first in importance as cultivated food crop and it is an important staple food. The extent to which the staple crop is supplemented by other crops, however, may vary considerably, but all ethnic groups have a prominent interest in cultivating enset. Enset is the main food source among the Semitic speaking Gurage, the East-Cushitic speaking Sidama and related groups. It is not the only staple food, but exists side by side as a co-staple to other crops, whether tuber crops or cereals, among the Gamo, Hadiya, Wolaita, Gedio and Ari. The Oromo people of southwestern Ethiopia rely upon cereals as the most important crops, with enset and root crops of secondary importance. In some cases, root crops are of prime importance, cereals are of secondary importance, and enset is of minor importance among the Sheko in southwestern Ethiopia.

The enset plant (*Ensete ventricosum* (Welw.) Cheesman)

History

The economic as well as the cultural importance of enset was first observed by the Scottish traveller James Bruce during his travel to discover the source of the Nile in 1768–1773 (Bruce, 1790). Bruce (1790) reported that enset grows to a great perfection in Gonder, west of the Nile, and near Lake Tana, where there are large plantations to produce the food of the people inhabiting that province. Tackholm (1951) and Simmonds (1958) reported that enset was once an important food and fibre plant in upper Egypt, perhaps more wide-spread during the Neolithic wet period than it is now. For many years enset was considered a species under the genus *Musa*. Although its first discoverer, James Bruce, emphatically stressed *Ensete's* difference to the *Musa*, Horaninow in 1862 became the first to propose a distinct new genus for it under the name of *Ensete* (Baker and Simmonds, 1953). The species name *Musa ventricosum* was first detected by the Australian botanist F. Welwitsch in Angola in 1857 (Smeds, 1955). Cheesman (1947) made genetic and taxonomic investigations and related 25 African and a few Asian *Musa* species to the genus *Ensete*. Later, Simmonds (1960) and Baker and Simmonds (1953) reviewed Cheesman's work and documented *Ensete's* pertinent taxonomic characteristics.

Taxonomy

The genus *Ensete* Horan. (order Zingiberales, family Musaceae) currently contains about eight distinct species (Baker and Simmonds, 1953). Among these, *E. gilletii* De Wild. is native to western Africa from Sierra Leone to Angola, and it is ecologically adapted to drier locations than other species, *E. homblei* Beq. ex De Wild. is more like canna and banana and distributed in Congo, the Democratic Republic of Congo and Zambia, *E. superbum* Roxb. is native to India, *E. glaucum* Roxb. is distributed over a wide range from Burma to the Philippines and Java (Indonesia), and *E. ventricosum* is generally adapted to swampy and moist areas through central and eastern Africa. Moore (1957), Shank (1963) and Bezuneh *et al.* (1967) reported that among the species occurring in tropical Africa, *E. ventricosum* is widely cultivated only in Ethiopia for food and fibre, having been so used since the times of early Egyptian civilisation.

Origin and distribution

The wild form of *E. ventricosum* is common and widespread in tropical Africa from Kenya and Uganda, south to Mozambique, and west to the Democratic Republic of Congo and Cameroon (Baker and Simmonds, 1953; Simmonds, 1958). *E. ventricosum* is also native to the highlands of south and southwestern Ethiopia (Tackholm, 1951; Smeds, 1955, Simmonds, 1960; Vavilov and Rodin, 1997). In south and southwestern parts of Ethiopia farmers have countless numbers of varieties and there are even wild enset plants in forests, river gorges and near streams (Fig. 1).

Botanical description

E. ventricosum is a monocarpic, perennial herb, and 4–8 m tall (sometimes even up to 11 m). The plant consists of an adventitious root system, an underground stem structure known as corm, a pseudostem which is distinctly dilated at the base formed from leaf sheaths that extend from the base of the plant, leaves and an inflorescence (Fig. 2). The

Fig. 1. Wild enset plants from seed at 2800 m asl in the forest of Dawo region near Waka town. (Picture: Paul Struik)

pseudostem has a diversified coloration of green, red, purple, brown or a mixture of green and red and can grow to about 5 m tall. Leaves are oblong to oblanceolate-oblong, up to 7 m × 1 m, bright to darkgreen, with their midribs, petioles and margins sometimes pale to dark red or dark purple; rarely also the lower side is reddish (Edwards and Laye, 1997). Features of *E. ventricosum* that make it distinguishable from banana include the absence of stooling, the monocarpic habit, the enlarged basal portion of pseudostem, the smooth and nearly globose seeds, the relatively erect leaves and a chromosome number of 9.

Ecology

Ensete ventricosum occurs at altitudes from 1500–3100 m asl, but scattered plants can also be found at lower altitudes. For optimum growth, the plant requires an average rainfall of 1100–1500 mm per year and a mean temperature of 16–20 °C. Enset grows well in most soil types, provided they are sufficiently fertile and well-drained. The ideal soils are moderately acidic to alkaline (pH 5.6 to 7.3) with 2–3% organic matter (Bezuneh and Feleke, 1966).

Propagation and cultivation methods

The common method of propagation is by means of suckers originating from the immature corm of an enset plant. Although it is not common, seeds may also be used to

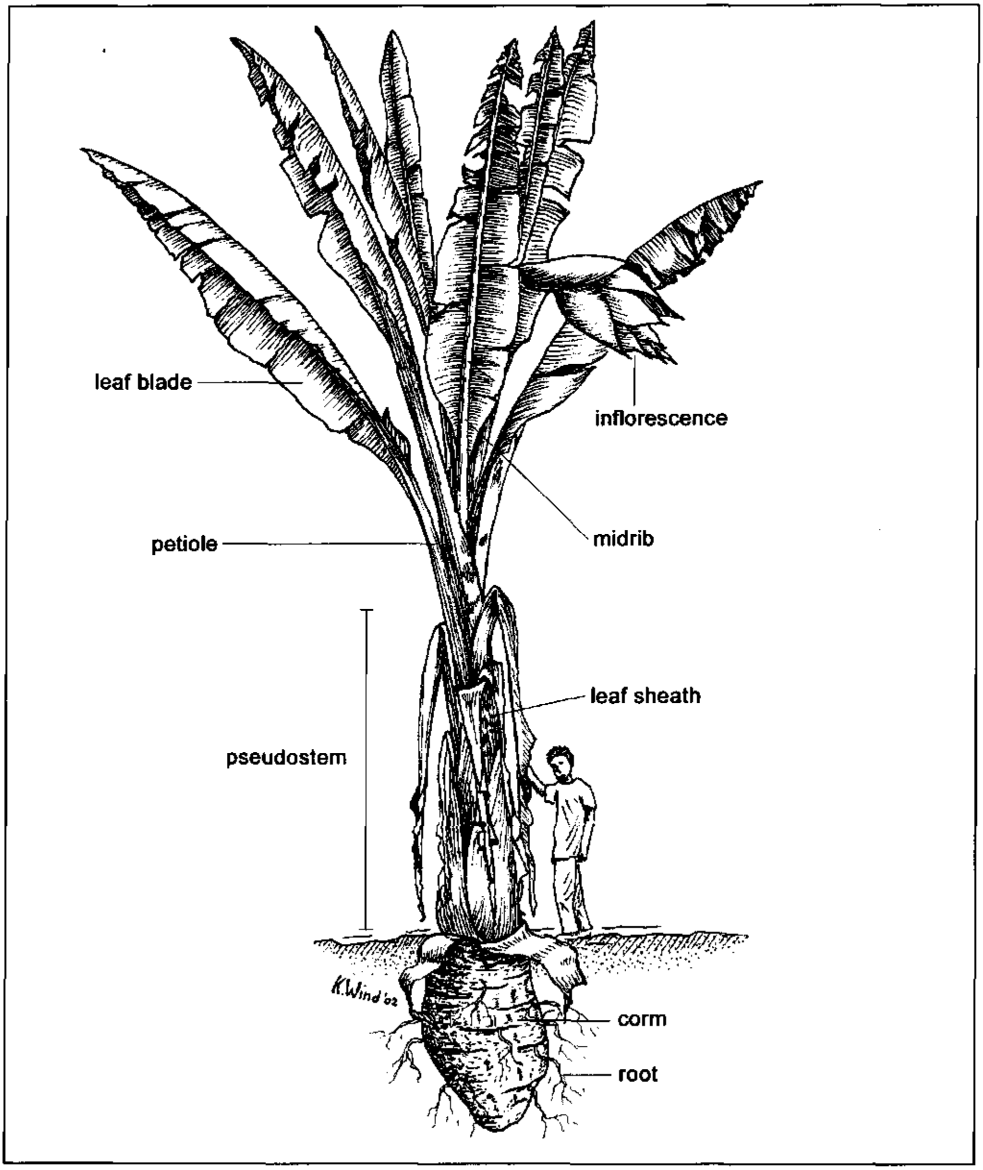

Fig. 2. *Ensete ventricosum*. Habit of flowering plant.

produce seedlings in some parts of southern Ethiopia. In the traditional cropping system, it is a common practice to transplant suckers several times in nursery beds before taking them into the permanent field. The suckers stay at each nursery for a period of one year. Under the traditional production system, depending upon the altitude and management practices, maturation takes 5–10 years.

Harvesting, products and storage

The optimal harvesting time of enset for food is just after the appearance of the inflorescence (Fig. 3). Harvesting includes cutting the leaf sheaths of the pseudostem into pieces, scraping the leaf sheaths pulp (parenchymatous tissue) from the cut pieces, pulverising the corm, mixing the pulverised corm with the scraped leaf sheaths pulp and fermenting the mixture for a certain period of time. The main food product obtained by fermenting the mixture is locally known as 'kocho'. Part of the starchy liquid called 'bulla' obtained by squeezing the mixture can also be consumed after it is allowed to settle for some days. The freshly cooked corm is locally called 'amicho' and can be consumed in a similar way as Irish potato. The plant can be harvested at any developmental stage if there is shortage of food. Thus, the plant is considered as a field bank for food.

Nutritional value

Rich in carbohydrates, enset products are of great nutritional significance. The nutritional value of enset products is comparable to other starchy products such as sweet potato, taro and yam. The fat and carbohydrate contents of enset products are even better compared to sweet potato and yam, but the protein content of enset is extremely low and therefore it cannot satisfy the protein requirements. The enset food contains more Ca and Fe than most cereals, tubers and root crops.

Fig. 3. Ten-years-old enset at Hagereselam, 2600 m asl. (Picture: Admasu Tsegaye)

Production and yield

Enset cultivation is concentrated in the highlands of south and southwestern Ethiopia. It is a regionally dominant staple food covering approximately 168,000 ha and is the main source of food for about 7–10 million people (CSA, 1997a). The main enset-growing areas are inhabited by the Gurage, Kembata, Hadiya, Wolaita, Sidama, Gedio, Gamo, Keficho, Oromo and related ethnic groups. Major enset-growing ethnic regions, area under enset, 'kocho' and 'bulla' production and average yield per plant are presented in Table 1.

Table 1. Major enset-growing zones, area under enset, 'kocho' and 'bulla' production and average yield per plant. Source: Adapted from CSA (1997a).

Region	Area ('000 ha)	Production		Average yield	
		'Kocho' production ('000 kg)	'Bulla' production ('000 kg)	'Kocho' (kg plant^{-1})	'Bulla' (kg plant^{-1})
Oromia					
West Welega	0.32	2,436	3	17.38	0.02
Illubabor	0.63	5,303	165	20.07	0.62
Jimma	8.17	168,528	8,254	32.55	1.59
West Shewa	6.37	53,538	347	33.57	0.22
East Shewa	0.61	27,073	1,267	37.30	1.75
Arssi	2.35	61,271	2,960	17.44	0.84
Bale	5.79	162,431	8,705	22.38	1.20
Borena	30.04	632,300	6,074	43.36	0.42
Total	**54.28**	**1,112,880**	**27,775**	**33.46**	**0.84**
S.N.N.P.R.S[†]					
Gurage	20.19	73,655	3,612	20.03	0.98
Hadiya	13.18	182,107	9,207	28.75	1.45
Kembata	6.11	69,802	2,325	30.86	1.03
Sidama	37.10	1,221,229	49,205	33.34	1.34
Gedeo	7.34	122,311	298	28.47	0.07
North Omo	18.29	202,425	9,130	20.33	0.92
South Omo	1.34	18,673	-	27.28	-
Shekicho Keficho	6.36	222,848	8,462	22.99	0.87
Bench Maji	0.90	17,546	32	23.74	0.04
Yem	1.06	9,732	275	27.07	0.77
Amaro	1.29	23,314	2,135	32.18	2.95
Burji	0.26	1,927	120	16.30	1.02
Derashe	0.10	1,575	80	25.72	1.31
Total	**113.52**	**2,167,144**	**84,881**	**28.69**	**1.12**
Gambella	0.10	1,769	24	31.45	0.43
National Total	**167.90**	**3,281,793**	**112,680**	**30.15**	**1.04**

[†] Southern Nation, Nationalities and Peoples' Regional State.

Use

Enset is cultivated mainly for a starchy human food and livestock feed, although almost every part of the plant can be used in one way or another. The pseudostem, corm and stalk of inflorescence constitute the most important source of food for humans, whereas the whole part of the plant except the roots are used to feed livestock. Enset fibre has an excellent structure, and its strength is equivalent to the fibre of abaca, a world-class fibre crop (Huffnagel, 1961; Bezuneh *et al.*, 1967; Brandt *et al.*, 1997). The dried leaf sheaths and midribs are used as packing and wrapping material, in fences and house construction. The leaf blades are used as a plate for serving cooked foods, for wrapping several kinds of materials such as fermented enset, butter, coffee and chat to prevent them from drying too much. Local people also believe that enset has various medicinal properties. Enset is also being used as an ornamental plant in Ethiopia and elsewhere.

Enset has important ecological functions such as producing organic matter, creating a nutrient reservoir in the soil, controlling erosion, thus contributing to the stability and continuity of farming (Tesfaye, 1996; Asnaketch, 1997). Failure of rain can only stop the growth but not kill the plant, as it has a large accumulation of moisture in its pseudostem. As a result, famine rarely occurs in areas where enset is widely grown.

Problem description

Although enset has been cultivated as a main food and sustained the densest rural population for many years, it has been neglected by research, development and conservation efforts. Crops such as enset cannot be commercially marketed but have multipurpose use for subsistence farmers. They produce large quantities of dietary energy and have stable yields under conditions in which other crops fail. Yet, they have hardly come to the attention of the government and researchers. The majority of research, development and conservation in Ethiopian agriculture had been focused on cereal-based systems. However, in recent years it has been observed that the potential of such type of development is limited; it can only assist farmers working on fertile soils under favourable environmental conditions. To the majority of subsistence farmers who cultivate crops under unreliable environmental conditions, rather than leading to a significant improvement of their lives, this strategy has caused food insecurity, environmental degradation and loss of valuable genetic diversity. As a result, some enset-growing regions have experienced famine in recent years, something unknown to the past generations.

At present, as a result of population growth, in major enset-growing areas farmland holdings have decreased and enset cultivated at the traditional technical level of production has failed to feed the population that has been growing at an increasingly higher rate.

The crop has also a long maturity period. Pijls *et al.* (1995) noted that in the Gurage region the daily intake of enset was 0.80 kg d^{-1} $person^{-1}$ in 1971 but only 0.55 kg d^{-1} $person^{-1}$ in 1995. They suggested that the average hectareage, which was 0.16 ha per household, should be enlarged to 0.27 ha to supply the household food needs. However, there is little opportunity in densely-populated areas for expansion of cultivated land; thus further increase in agricultural production is only possible by an increase in productivity. Although the yield of enset is higher than the yield of cereals, even without the application of fertilisers and pesticides, it is far below the yield potential because of lack of knowledge on yield-determining, -limiting and -reducing factors and on ways to reduce their negative effects.

Disease and drought have also threatened enset. Bacterial wilt of enset incited by *Xanthomonas campestris* pv *musacearum* causes complete death of the plant within weeks after the first symptoms (Yirgou and Bradbury, 1974; Ashagari, 1985). During drought, when other crops failed to survive, people depended entirely on enset and harvested whatever they had in the field. This practice together with the occurrence of diseases caused serious genetic erosion. Although the country is rich in genetic diversity of this crop, identification of this diversity to provide materials that excel in poor as well as favourable environments have not yet been started.

Given the important contribution enset can make to the food security of densely populated areas in Ethiopia, and the potential that exists for expanding the production and use to other parts of the country, it has recently received more attention. However, there is a growing sense that the enset-based farming system is often poorly understood and faces many problems. The most important problems are associated with lack of knowledge on the various indigenous cultivation methods, on farm-based enset biodiversity, and on the agronomy of the crop, diseases and with the fact that the crop has a long growth cycle. A better understanding of genetic diversity and the impact of environmental factors on growth and development of the enset plant can help to develop improved agronomic practices and enhance the use of the existing genetic diversity to increase food security. Moreover, proper understanding and evaluation of the indigenous knowledge and traditional cultural practices can help to design and implement better adopted development programmes.

Research objectives

The objective of this study was to understand and analyse the indigenous enset cultivation methods, farm-based enset biodiversity and the plant characteristics and environmental factors that determine the growth and development of the enset plant. This basic information is needed to assess yield potential and identify the production constraints and their relative importance. The ultimate goal was to develop improved agronomic practices and enhance the use of the existing genetic diversity to bridge the gap between actual yield and yield potential in order to increase food security and environmental sustainability. The study therefore included the following elements:

- Description of indigenous enset production systems, farm-based biodiversity and production constraints in some major enset-growing ethnic and agro-ecological regions;
- Characterisation of enset biodiversity with DNA fingerprinting (AFLPs);
- Exploration of farmers' characterisation methods and comparison with DNA fingerprinting (AFLPs) to understand how farmers evaluate, utilise and conserve enset genetic diversity;
- Experimentation to investigate the yield potential using physiological parameters and weather data, and compare it with actual yield;
- Investigation of crop establishment methods in order to narrow the gap between the actual yield and yield potential; and
- Experimentation to compare 'kocho' yield of enset under different crop establishment methods with the yield of other main starch crops grown in Ethiopia.

Outline of the thesis

The general framework of this thesis is presented in Fig. 4. Chapter 1 provides the general information about the Ethiopian agriculture, describes the enset crop, its botany and role in south and southwestern parts of the country, and provides the problem description, the framework and the objectives of the research programme.

Chapter 2 describes the current indigenous knowledge on production methods and its production constraints. The farm-based enset biodiversity is investigated and its relationship with various household characteristics is evaluated in three different areas. The enset biodiversity from Sidama, Wolaita, Hadiya and Kaffa Shaka areas is then characterised with AFLPs to investigate genetic relationships among clones, identify duplicates and study regional variation in Chapter 3.

Chapter 4 compares farmers' characterisation methods with characterisation by DNA fingerprinting (AFLPs) to assess farmers' skill and knowledge of genetic diversity in order to develop a sound conservation strategy.

Chapter 5 investigates crop-physiological parameters that determine the growth of enset and how these parameters develop over time and affect the growth and yield under field conditions. Yield potentials were calculated for two different agro-ecological zones using the physiological parameters and weather data, and these yield potentials were compared with actual yields in the different regions.

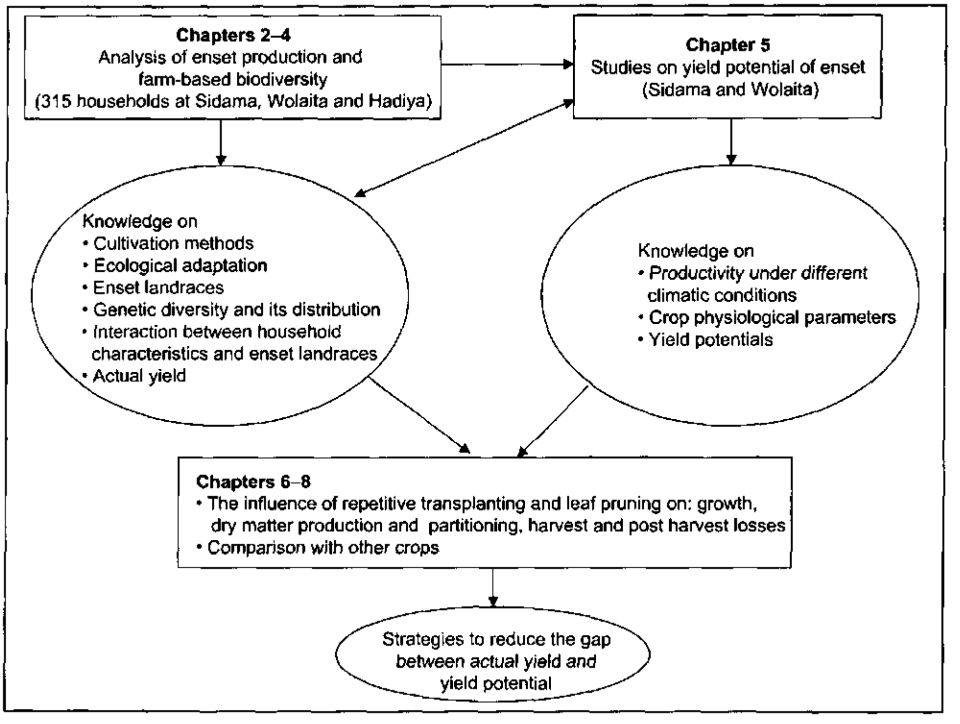

Fig. 4. General framework of the thesis.

Chapters 6 and 7 examine the influence of crop establishment methods on growth, dry matter production and distribution of enset plant, focusing on the effects on duration of the crop cycle, the partitioning of assimilate to the harvestable parts of the crop and the recovery of 'kocho' after fermentation.

Chapter 8 compares 'kocho' yield of enset in terms of weight and energy, under different crop establishment methods with the yields of other main starch crops grown in Ethiopia.

The thesis concludes with a general discussion (Chapter 9) in which the scientific achievements, its usefulness for enset cultivation and genetic conservation and its implication for improving enset production are discussed.

CHAPTER 2

Analysis of enset *(Ensete ventricosum* (Welw.) Cheesman) indigenous production methods and farm-based biodiversity in major enset-growing regions of southern Ethiopia

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CHAPTER 2

Analysis of enset *(Ensete ventricosum* (Welw.) Cheesman) indigenous production methods and farm-based biodiversity in major enset-growing regions of southern Ethiopia

Abstract

Enset production is declining, and it faces genetic erosion due to drought, diseases and population pressure. Participatory Rural Appraisal (PRA) and additional formal survey studies on 315 households were conducted over three consecutive years (1998–2000) in the Sidama, Wolaita and Hadiya ethnic regions of southern Ethiopia to assess traditional cultivation methods, analyse the production systems, and evaluate farm-based enset biodiversity. The regions differ in terms of cultural background, resources, farming systems, population density, and agro-ecology. Furthermore, the methods for initiating suckers and the frequency of transplanting vary among the three regions.

Diverse enset landraces were identified in the Sidama (52), Wolaita (55) and Hadiya (59) regions. Sidama farmers had the highest number of landraces per farm, 57% and 21% more than found on Wolaita and Hadiya farms, respectively. In all three regions, landrace diversity was influenced by household resources, cultural background, population pressure, and agro-ecology. There were significant differences in the average number of enset landraces and livestock between rich and poor households in the three regions. Rich farmers had more land and manure-producing livestock, and they planted more enset landraces than poor farmers. In all three regions, women proved to be more experienced in identifying enset landraces than men.

The number of enset landraces per farm was significantly correlated with other household characteristics for resource-rich Sidama farmers and with the number of livestock and area of farmland for resource-rich Hadiya farmers. This suggests that middle or poor farmers concentrate on annual crops, rather than growing the perennial enset plant. More research is needed to identify, characterise and conserve genetic diversity, and to improve the cultivation practices of enset. The cultural, socio-economic, and gender-associated aspects of enset cultivation need to be assessed to understand the dynamics of enset biodiversity.

Keywords: Enset, indigenous production, landrace, biodiversity, ethnic regions, household characteristics, wealth, gender

Introduction

There are four major farming systems in Ethiopia: pastoralism, shifting cultivation, the seed-farming complex, and the enset-planting complex (Westphal, 1975). Among these, the enset-planting complex is the most sustainable indigenous farming system that can support the densely populated highlands of the south and southwestern parts of Ethiopia.

Enset (*Ensete ventricosum* (Welw.) Cheesman) is one of the oldest cultivated plants in Ethiopia. Anthropologists, archaeologists, historians, and other scholars argue that domestication of enset in Ethiopia occurred as early as 10,000 years ago (Brandt *et al.*, 1997). The highlands of southern Ethiopia form the geographical centre of enset cultivation (Vavilov and Rodin, 1997), and the various ethnic groups in this region recognise and exploit many enset landraces.

Within the enset production systems, 7 to 10 million people cultivate the crop as a staple food, or as a co-staple with cereals and root and tuber crops. Enset produces a starchy food from its vigorous pseudostem, its corm, and from the stalk of its inflorescence. A mixture of scraped pseudostem pulp, the pulverised corm, and the stalk of the inflorescence is fermented in a pit, the resulting product locally called '*kocho*'. Although many different dishes are prepared from '*kocho*', a pancake-like bread and porridge are the most common. Furthermore, the corm can be cooked fresh and consumed in a way similar to Irish potato, sweet potato, or cassava. Enset also provides good quality fibre, and all plant parts, except the roots, can also be used for livestock feed. Local people also believe that particular enset landraces have various medicinal properties.

Livestock play an important role in maintaining soil fertility, in providing milk and meat, and as a source of cash in times of need. Farmers grow the enset crop closest to their house, where they can easily fertilise it with cow dung and house refuse, while they sow cereals, root, and tuber crops in areas further away from the house. Young enset plants are intercropped with annuals (such as maize, common bean, cabbage, taro, and Irish potato), and older enset plants with perennials (such as avocado, coffee, and citrus) (Tsegaye and Struik, 2000a).

Farmers say: "Enset is the enemy of hunger, and human and livestock life is impossible without it". However, there has been little research and development work on enset-production systems, despite its importance for food security and environmental sustainability. The Ethiopian government had mainly focused its agricultural research and development efforts on high-yielding annual crops that can be marketed. The attention of the government towards encouraging the adoption of these new technologies has resulted in a shift from enset- to cereal-based agriculture. As a result, some enset-growing regions have experienced famine in recent years, something unknown to past generations.

Recently, there has been increased awareness of the importance of enset for food security and environmental sustainability. For instance, some communities that had shifted from enset to cereal production have started to grow enset again, as their recent experience with famine has caused them to appreciate enset's ability to prevent hunger. In addition, enset-production systems are being promoted outside of the traditional enset region, not only in adjacent areas, but also in areas far to the north and east of Ethiopia, where the population has historically depended mainly on cereal crops.

The enset-based farming systems are very poorly known, particularly details about enset's production systems, cultivation methods, and genetic diversity. Average farm sizes have decreased with increasing population, and enset cultivation under traditional technologies and practices has failed to produce enough to feed the population. Enset has a long-growing cycle, and gives low yield in traditional production systems. As enset cultivation spans several different ethnic groups and agro-ecological zones, the production methods and processing procedures used for it vary greatly. In order to improve traditional enset-production systems, indigenous knowledge from the different enset-growing regions needs to be analysed and understood. Such an improved understanding of indigenous knowledge related to enset production can help to identify guidelines for selecting potentially interesting topics for scientific research (Bellón, 1991; DeWalt, 1994).

Diseases, insect pests, and drought have also threatened the enset-production systems. Though, there has been some characterisation of the genetic diversity in enset, the work to identify plant material with resistance to diseases and pests, or with the ability to excel in specific environments, has not yet begun.

The few sociological or survey studies available on enset-farming systems cover sample areas too small to be representative of the entire region (e.g., Spring *et al.*, 1996). Furthermore, the little research and development effort that has been addressed to enset has not been based on farmers' needs, and has thus failed to address their production constraints. Therefore, this research aimed to: (1) describe and evaluate current indigenous knowledge on production methods and production constraints; (2) identify the existing diversity and its potential use to improve the production systems; and (3) identify household characteristics that determine enset's production and biodiversity.

Materials and methods

Study areas

Participatory Rural Appraisal (PRA) and formal survey studies were conducted over three consecutive years (1998–2000) in three densely-populated enset-growing regions, inhabited by the Sidama, Wolaita, and Hadiya ethnic groups (see Fig. 1).

The Sidama people, who speak a Cushitic language, depend heavily on enset for food. Hagereselam (2600–2650 m asl), with a population density of 299 persons km^{-2}, was selected from Sidama. The Wolaita belong to the Omotic linguistic family, and cultivate enset as a co-staple, along with cereals, roots and tubers. The study site in Wolaita was Areka (1750–1820 m asl), which has a population density of 348 persons km^{-2}. The Hadiya people speak a Cushitic language, and also cultivate enset as a co-staple with cereal or pulse crops. From Hadiya, we selected Anna-lemmo (2220–2400 m asl) and Ambicho Gode (1900–2000 m asl) for the study, both with population densities of 278 persons km^{-2}.

Hagereselam, Areka, and Anna-lemmo/Ambicho Gode are, respectively, 150, 205 and 350 km from Awassa, the main town of the Southern Nations Nationalities and People's Regional State. Besides ethnicity, the three regions differ in cultural background, resources, farming systems, population density and agro-ecology.

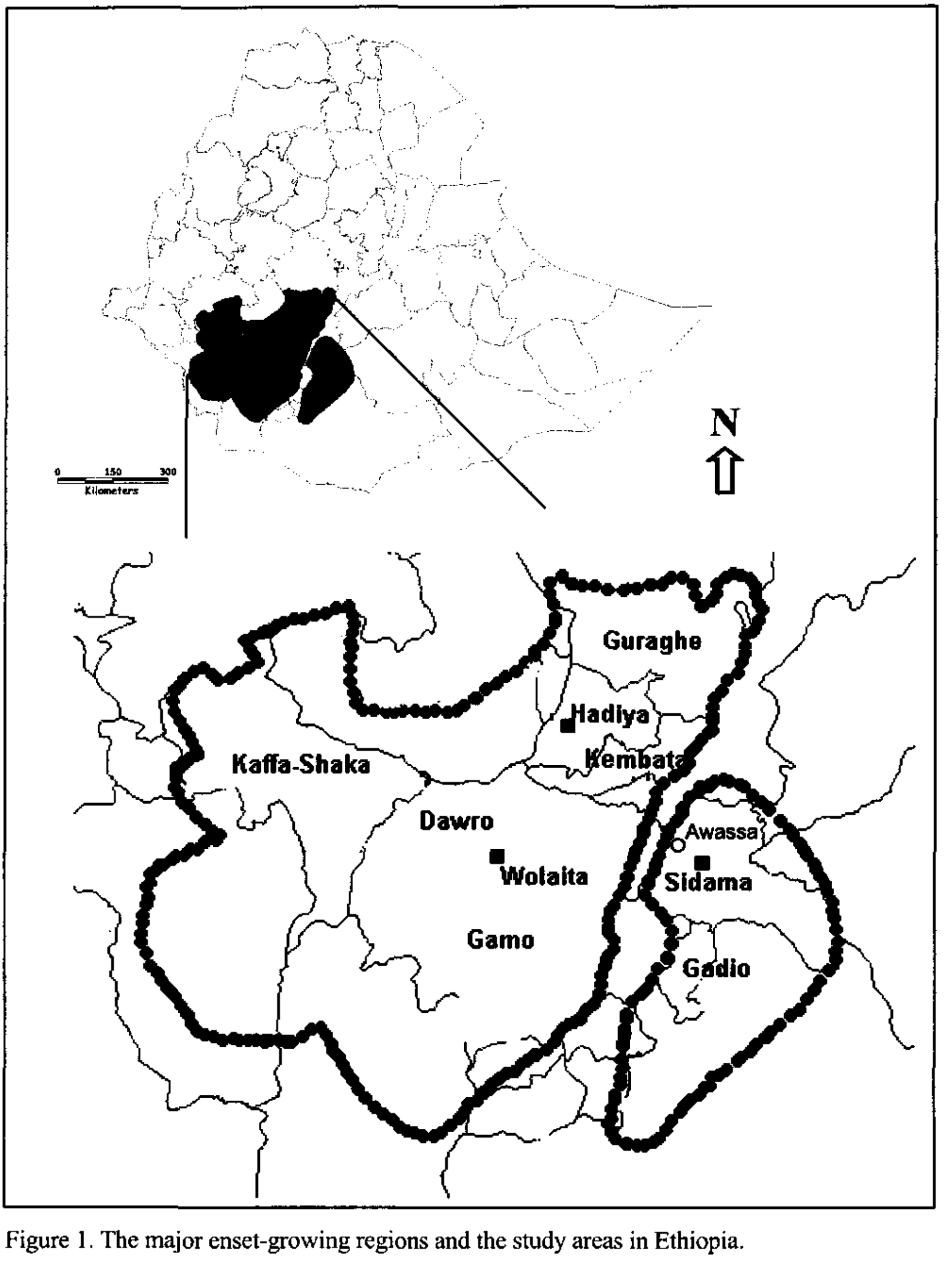

Figure 1. The major enset-growing regions and the study areas in Ethiopia.

Wealth ranking

In each study area, 105 households were randomly chosen. Community leaders and eight key informants participated in a wealth ranking exercise where they were asked to identify indicators of household wealth or well-being, and to group neighbouring households according to their relative wealth. The key informants sorted a number of cards, each with one household name recorded on it, into three separate piles for rich, middle and poor households. This ranking system was used to establish the overall wealth distribution, and to calculate the proportion of each category in each village. The researchers visited all 315 farming households in the three study areas, and conducted group and individual discussions, gathering data using semi-structured interviews and PRA methods.

Cultivation methods

During the household surveys, the researchers were able to directly, and repeatedly, observe cultivation activities such as propagation, transplanting, leaf pruning, weeding, fertilisation, and the planting pattern, obtaining detailed and consistent descriptions. Some activities could not be observed and were therefore described by the farmers themselves. For each area, the compiled information on cultivation methods was presented to a group of representative farmers, for feedback and discussions to gain agreement on the common local methods of cultivation.

Household characteristics

Group discussions with farmers identified crop species, livestock, farm size, and family size as the most important household characteristics in their production system. In all three enset-growing study areas, a group of male and female key informants were asked to name all the enset landraces and crop species grown there. This information was used to develop and pre-test a formal questionnaire survey, which was conducted at household level. For each household, the survey recorded the number of enset landraces, the vernacular name of each landrace, other crop species, the number of livestock, the monthly share of consumption by main crops, family size, and farm size.

Data categorisation and analysis

In order to assess the diversity of enset within each wealth category, the names of all enset landraces grown in each region were listed, tallying landrace presence by household, to determine percentage occurrence of a landrace in each wealth category. The collected data were then analysed with descriptive statistics, treating each household as a replication and using a logarithmic transformation of household characteristics to account for non-normal distributions. The coefficient of determination (r^2) was computed to determine the linear relationships among the household characteristics.

Results

Wealth classification

Tables 1 to 3 present the wealth indicators, as defined by community leaders and key informants in the three ethnic regions. In Sidama and Hadiya, a large proportion of the population fell in the middle wealth category, whereas in Wolaita the proportion of resource-poor households was the highest. The combined proportion of rich and middle income households was 74%, 60% and 47% in Sidama, Hadiya, and Wolaita, respectively. In all three regions, wealthier farmers had more land and livestock, and produced more crops for sale, while poorer farmers had little land, few livestock and consumed agricultural products immediately after harvest. Poor farmers cannot afford to buy improved seeds, fertilisers, or herbicides. They lease their land and sell their labour to rich farmers.

Propagation

Sidama region. Enset is vegetatively propagated from the corm of an immature plant. Plants produce suckers mainly in March, but small numbers of suckers are also available in October. Farmers take a four-years-old enset plant, locally called '*simancho*', cutting it 100–150 mm above the junction of the pseudostem and corm. They scrape out the central part of the corm, until the growing bud is removed. The corm is placed in shade for 2–3 days to allow the wound to heal, and then planted in fallow land near the house at a spacing of about 0.8 m × 0.8 m. The size of the planting hole depends on the size of the corm. In most cases, soil and then animal manure and house refuse are placed on top of the planted corm. The suckers, locally called '*funta*', appear after 2–3 months and remain undisturbed for at least a year.

Wolaita region. As in Sidama, Wolaita farmers propagate enset vegetatively. To do this, they uproot an immature enset plant, and cut the pseudostem about 100–150 mm above its junction with the corm. The corm is then split into two equal parts, the central growing bud is removed, and the two halves are exposed to the sun for 2–3 days. The split corm is planted in a well-prepared hole near the house in December or January, before the beginning of the rainy season, and covered with soil and animal manure. Numerous new shoots, locally called '*osha hatta*', emerge from the corm after 2–3 months. These suckers are left in the same place for at least one year.

Hadiya region. Similar to the Sidama and Wolaita regions, enset is propagated vegetatively using the corm of an immature plant. Farmers uproot a three-years-old enset plant,

Table 1. Wealth ranking by community leaders and key informants at Hagereselam, Sidama region.

Wealth category	Wealth indicators	%
Rich	2–3 farm lands, each with wives and children	12
† (Duresa)	Large, beautiful, traditional houses in all farm lands	
	More than 40 dairy cattle	
	More than 10 oxen and many sheep and goats	
	More than 10 horses for transportation and hauling	
	Do not buy agricultural products from market	
	Own natural forest and do not sell the products, but give freely to people	
	More than 1 ha of enset plantation, with many flowering enset plants at each farm land	
	More than 1 ha of bamboo plantation at each farm land	
	Store large quantities of wheat and barley for sale	
	Provide children all necessary traditional requirements for marriage	
Middle	2 farm lands, each with wives and children	62
† (Mererima)	Beautiful traditional houses in both farm lands	
	About 30 livestock, including dairy cattle, oxen, sheep and goats	
	1-4 horses for transportation and hauling	
	0.5 ha enset plantation, with some flowering plants in both farm lands	
	0.5 ha bamboo plantation in both farm lands	
	Own natural forest	
	Do not buy agricultural products from market	
	Store wheat and barley for sale	
Poor	One farm land and a wife	26
† (Buticho)	Small traditional house, not properly roofed with bamboo	
	1-3 livestock	
	Sell agricultural products immediately after harvest	
	Small area of enset plantation	
	Do not have flowering enset plants	
	Consume enset plants before maturity	
	Sell labour to rich	
	Do not pay tax on time	

† Local names for rich, middle, and poor households.

Table 2. Wealth ranking by community leaders and key informants in Areka, Wolaita region.

Wealth category	Wealth indicators	%
Rich	Land area more than 1 ha	12
† (Durre)	Own house with a corrugated iron sheet roof	
	5–7 dairy cattle	
	2–3 oxen	
	1–2 mules for transportation	
	4 donkeys	
	Store agricultural products for sale	
	Do not buy agricultural products from market	
	Many coffee plants	
	More than 10 flowering enset plants	
	Send all children to school	
	Loan livestock out to poorer neighbours, who feed and shelter them	
	Many eucalyptus (*Eucalyptus globulus*) trees	
	Sell 3–15 fattened animals for traditional holidays	
	Lend money on credit	
	Hire daily labourers	
Middle	Land area 0.50–0.75 ha	35
† (Gdowwa)	Have large traditional house	
	2–3 dairy cattle	
	1–2 oxen	
	1 donkey	
	Cash savings	
	Store agricultural products for sale	
	Do not buy agricultural products from market	
	Enough enset plantation for family consumption	
	5–7 flowering enset plants	
	Small number of coffee plants	
	Small number of eucalyptus trees	
Poor	Land area 0.25 ha	53
† (Manko)	Small house, not well constructed	
	Feed and shelter dairy cow of richer, to obtain milk and manure	
	Do not have more than 2 sheep or goats	
	No oxen	
	No large enset plants in the field	
	Plant enset only for corm production	
	Do not have money to pay for medication or tax	
	Usually lease land to rich	
	Sell labour to the rich	

† Local names for rich, middle, and poor households.

Table 3. Wealth ranking by community leaders and key informants in Ambicho-Gode, Hadiya region.

Wealth category	Wealth indicators	%
Rich	Farm size more than 2 ha	10
† (Godancho)	3–4 houses, 1 large and the others small	
	Trading activity in town in addition to farming	
	Do not buy seeds for planting	
	Produce more than 1800–5000 kg wheat and pea per harvest	
	2 horses and mules	
	1 donkey	
	Pair of oxen	
	3 to 5 dairy cattle	
	Own 0.5 ha eucalyptus (*Eucalyptus globulus*) plantation	
	Own 0.25 ha chat (*Catha edulis*) plantation	
	More than 0.25 ha of enset plantation	
	About 30 flowering enset plants in the field	
	Lend money to others	
	May have more than one wife	
	Store wheat and barley for sale	
	Lease land from the poor	
	Hire labourers for farm activities	
	Slaughter sheep or goats when guest comes to their house	
Middle	Farm size 1–2 ha	50
† (Lembeancho)	2 houses; 1 large and the other small	
	Produce 1000–1800 kg wheat and peas per harvest	
	Do not buy seeds during planting	
	May have more than one wife	
	0.25 ha eucalyptus	
	0.25 ha chat	
	1 horse	
	Do not borrow money	
	3–7 livestock including cattle, sheep and goats	
	0.25 ha enset plantation, with 10–15 flowering enset plants	
	Produce wheat and barley	
Poor	Do not have mule	40
† (Buticho)	One wife	
	One small house, not well constructed	
	Usually go to town to sell labour	
	2 sheep or goats	
	10 eucalyptus trees	
	10 chat plants	
	Feed and shelter other people's cattle for milk and manure	
	No flowering enset plants in the field	
	Lease land to the rich	

† Local names for rich, middle and poor households.

locally called *'kiniba'*, and cut the pseudostem 100–150 mm above its junction with the pseudostem. To eliminate the central growing bud, the centre of the corm is bored and filled with dried mud, and stored in shade for 2–3 days if there is rain, or immediately planted at a spacing of 1.0 m × 1.0 m if there is no rain. The suckers that emerge after 2–3 months are called *'dubo'*, and remain in the same place for at least one year.

Transplanting

Sidama region. After almost a year the mother corm is uprooted and the suckers (*'funta'*) are separated from it. The leaves and the top part of the suckers are cut. The cutting of the leaves is thought to stimulate growth after transplantation. With the onset of the rainy season, Sidama farmers plant these suckers in their fields, with a narrow spacing of 0.75 m × 0.75 m. Plants that appear thin and unpromising are transplanted for a second time into another field; these suckers are locally called *'dukullo'*. The enset sucker or plant gains a new name for each year during the process of development from sucker into mature plant: '*awulo*' or '*kasha*' (one-year-old plant in the final field), *'qora'* (two-years-old), *'qatalo'* (three-years-old), *'simancho'* (four-years-old), *'malancho'* (five-years-old), *'itancho'* (six-years-old), and *'kalimo'* (flowering enset). For sucker production *'simanchoes'* are uprooted, whereas for immediate corm consumption *'malanchoes'*, are utilised.

Wolaita region. After the beginning of rains in mid-January or February, Wolaita farmers uproot the mother corm and separate the suckers (*'osha hatta'*). The leaves and the top part of the plant are cut. The suckers are then transplanted with a narrow spacing of 0.50 m to 0.70 m between rows and 0.30 m to 0.35 m between plants. The enset suckers, locally called *'bashaashwa'* at this stage, remain in the same field for 1–2 years, depending on soil fertility. In the second or third year, farmers transplant the enset suckers (*'bashaashwa'*) into a final field at a spacing of 1.0 m × 1.0 m. The enset plants are locally known as *'garrdwa'* at this stage, and remain in the same field until they reach maturity or are uprooted for food. The local term for a large enset plant nearing maturity is *'alla'*.

Hadiya region (see Fig. 2). Similar to the Sidama and Wolaita ethnic regions, Hadiya farmers transplant with the onset of the rainy season, uprooting the mother corm and separating the suckers ('*dubo*') from it. They also cut the leaves and top part of the plants. In the first year, small suckers are transplanted in groups of 3–5 into a single hole, while larger ones are transplanted in groups of two. Hole spacing is 0.5 m × 0.5 m. The groups of 3–5 suckers are usually transplanted to the middle rows. Suckers are locally called *'sima'* at this stage, and remain in the same place for one year. In the second year, suckers that were in groups of two are transplanted separately—these individual suckers are now called *'ogoja'*. Suckers that were in groups of 3–5 are transplanted in groups of 2–3, and called *'lammo'*. Spacing is now 0.8 m × 0.8 m, usually with *'lammo'* suckers planted in alternate rows with '*ogoja*' plants. These larger *'ogoja'* plants take the name '*erro*' after the third year, but are not transplanted then. The '*lammo*' suckers are

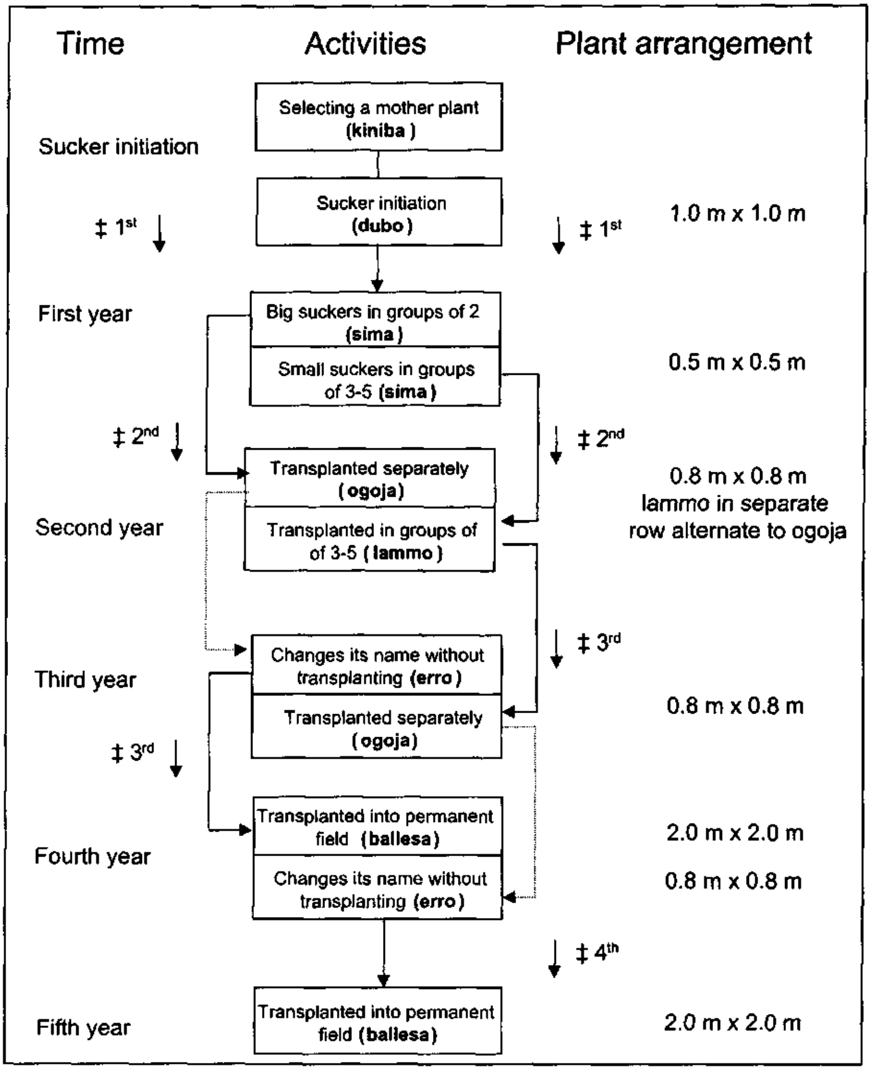

Fig. 2. Enset planting flow-chart in the Hadiya region. Words between brackets indicate the local name of suckers or plants in a particular phase. The enset plant requires 3–4 years to mature after transplanting to a permanent site. ‡ Indicates numbers of repeat transplantings.

transplanted at a spacing of 0.8 m × 0.8 m, and take the name '*ogoja*'. In the fourth year, the '*erro*' plants, which have been two years in the same place, are transplanted to a permanent site with a spacing of 2.0 m × 2.0 m. The smaller '*ogoja*' plants also remain undisturbed in the fourth year, but individuals are transplanted in the fifth year to another field with a spacing of 2.0 m × 2.0 m. The '*erro*' plants that are transplanted to a permanent site at a spacing of 2.0 m × 2.0 m, and are locally known as '*ballesa*'.

Weeding, leaf pruning and fertilisation

There are no clear differences among the three regions in weeding, hoeing, or fertilisation methods. Farmers do weeding and slashing by hand or with a sickle, and use a digging spade or fork to loosen the soil. Weeding and slashing happen more frequently in earlier growth stages or during the rainy seasons (May–October). Depending on the amount of rain and the age of the plant, weeding can occur 2–3 times a season. Deep hoeing is practised in the dry season to kill weeds such as *Cynodon dactylon* L. or *Cyperus rotundus* L.

Leaf pruning practices, however, vary between the regions. Wolaita farmers severely prune enset leaves for animal feed or sale, whereas Sidama farmers usually use thinned enset plants for animal feed, except during the dry season. In Hadiya, again except in dry seasons, severe leaf pruning is not practised.

Within the traditional production systems, animal manure plays an important role in maintaining soil fertility. The enset crops are grown closest to the house so that the enset field can easily be fertilised with livestock manure and house refuse. Farmers claim that they cannot produce enset without animal manure. A poor farmer, who cannot purchase an animal, borrows from a rich farmer to obtain manure and milk.

The rate, timing, and method of manure application vary among households, depending upon the growth stage of the plantation and the availability of manure. Although it proved difficult to determine the actual application rates, according to the informants and to our own observations, this rate decreases as the age of the plantation increases. When manure is available, farmers do a heavy application in the wettest months (June to August). Otherwise, they apply manure daily until all individual enset plants have received manure. Every day, fresh manure is collected from the house and piled between enset plants. After the manure starts to break down, they practice a circular ring application or spreading method. Also, animal urine is channelled to the plantation from the household.

Planting pattern

Farmers in Sidama start with a relatively dense plantation, without a definite pattern of planting, thinning this to eliminate the less promising plants. As a result, some plants never develop fully and have a stunted appearance. The advantage of this system is that the dense leaf canopy conserves soil moisture, suppresses weed growth, and reduces organic matter decomposition by reducing soil temperature. In addition, this type of planting pattern makes full use of the land. The main disadvantages are that other crops cannot be intercropped during the early stages of enset growth, and the thinned enset plants that are used for food are only half-grown. In Hadiya and Wolaita, we observed a clear planting pattern where plants are transplanted every one or two years.

In all the three regions, farms of households in the rich or middle wealth ranks were fenced and free from weeds. Enset plants at different stages of development were also planted in separate groups, forming a certain pattern. This was not the case on the farms of poor households. The severity of bacterial wilt seemed to be high in these farms, indicating that sanitary measures and fencing with trees or bamboo might help to reduce infection.

Enset biodiversity

The number of enset landraces identified in Sidama, Wolaita and Hadiya regions were 52, 55 and 59, respectively (Tables 4, 5 and 6). Each vernacular name represents a morphologically distinct enset landrace. The average number of enset landraces per farm was significantly higher in Sidama than in Wolaita or Hadiya (Table 7). The average number of distinct enset types per farm varied between 9 and 14 across the three regions. Farmers have multiple uses of these landraces, including food, fibre, fodder, fuel, medicine, and construction. Household consumption, however, was the most important use across all the regions.

In all the regions, households ranked as rich or average tended to grow more landraces than their poorer counterparts (Table 7). On average, poorer households had 30% and 20% fewer landraces on their farms than households in the highest and middle wealth rank, respectively.

The numerous landraces differ with respect to morphological characters (leaf, midrib, petiole and pseudostem colour), use value ('kocho', corm and fibre), quality of products, maturity period, vigour and reaction to bacterial wilt (Tsegaye *et al.*, 2002; Chapter 4).

Crop species

The number of crop species recorded in Sidama, Wolaita and Hadiya were 10, 25 and 14, respectively. Enset, wheat (*Triticum* sp.), barley (*Hordeum vulgare* L.), Ethiopian kale (*Brassica oleracea* L.), potato (*Solanum tuberosum* L.), pepper (*Capsicum* sp.), common bean (*Phaseolus vulgaris* L.), and pumpkin (*Cucurbita pepo* L.) were the most common in all three study areas, whereas fruits such as avocado (*Persea americana* Mill.), banana (*Musa* sp.), mango (*Mangifera indica* L.), orange (*Citrus sinensis* (L.) Osbeck), and

Table 4. Frequency of enset landraces (%) in Sidama region, Hagereselam, for each wealth category.

No	Vernacular name	Rich (12%)	Middle (62%)	Poor (26%)	Mean	Weighted average
1	Midasho	97	100	97	98	98.8
2	Genticha	100	94	91	95	93.9
3	Gulumo	100	100	80	93	94.8
4	Bira	89	89	77	85	85.9
5	Chacho	86	74	71	77	74.7
6	Addo	77	74	77	76	75.1
7	Kiticho	80	86	57	74	77.7
8	Derassa addo	74	57	69	67	62.2
9	Gossalo	54	68	63	62	65.0
10	Astara	68	54	34	52	50.5
11	Kule	54	54	49	52	52.7
12	Alaticho	47	49	47	48	48.2
13	Gedmo	37	63	29	43	51.0
14	Keshe/Kire	49	37	29	38	36.4
15	Uwesho	37	37	26	33	34.1
16	Mundurare	37	31	23	30	29.6
17	Haho	31	29	14	25	25.3
18	Micho	17	20	29	22	21.9
19	Bufare	23	17	23	21	19.3
20	Wanikore	29	20	14	21	19.5
21	Damala	17	17	14	16	16.2
22	Goticho	26	9	9	15	11.0
23	Borbodancho	23	17	3	14	14.1
24	Dobramo	11	17	9	12	14.2
25	Lemicho	17	9	11	12	10.5
26	Agena	20	6	6	11	7.7
27	Kincho	14	9	6	10	8.8
28	Gamachela	17	3	9	10	6.2
29	Adami	3	14	9	9	11.4
30	Made	3	14	11	9	11.9
31	Bullo	11	11	6	9	9.7
32	Siltite	14	6	6	9	6.9
33	Aydara	9	11	3	8	8.7
34	Molagna	11	14	0	8	10.0
35	Shewite	6	9	9	8	8.6
36	Birbo	6	6	9	7	6.8
37	Garircho	6	9	3	6	7.1
38	Chacho	0	6	9	5	6.1
39	Hamesesa	6	3	3	4	3.4
40	Nefo	6	3	3	4	3.4
41	Wubisho	3	0	6	3	1.9
42	Dergicha	6	3	0	3	2.6
43	Hekeche	3	3	0	2	2.2
44	Siriro	6	0	0	2	0.7
45	Gena	6	0	0	2	0.7
46	Garbo	3	3	0	2	2.2
47	Meleket	0	6	0	2	3.7
48	Kanda	3	0	0	1	0.4
49	Ambula	3	0	0	1	0.4
50	Arisho	3	0	0	1	0.4
51	Awulecho	0	0	3	1	0.8
52	Saranna	0	0	3	1	0.8

Table 5. Frequency of enset landraces (%) in Wolaita region, Areka, for each wealth category.

No	Vernacular name	Rich (12%)	Middle (35%)	Poor (53%)	Mean	Weighted average
1	Ankogena	80	94	60	78	74.3
2	Kuchia	86	74	74	78	75.4
3	Alagena	69	57	49	78	54.2
4	Kabaria	74	57	34	58	47.0
5	Nakaka	54	49	37	48	43.2
6	Shalakumia	54	51	31	45	40.8
7	Suitia	40	43	49	44	45.8
8	Wanadia	51	37	31	40	36.0
9	Peluwa	57	40	23	40	33.0
10	Aginia	57	37	23	39	32.0
11	Silkantia	34	37	40	37	38.2
12	Chichia	46	40	26	37	33.3
13	Gefetanuwa	37	20	29	25	26.8
14	Tuzuma	34	20	17	24	20.1
15	Sirarea	14	37	14	22	20.1
16	Dalulia	23	26	17	22	21.0
17	Zinkia	20	29	14	21	20.0
18	Bundwa	17	20	17	18	18.1
19	Arkia	26	9	6	14	9.5
20	Matia	17	11	11	13	11.7
21	Masmasa	17	6	6	10	7.3
22	Adnona	11	9	9	10	9.2
23	Halla	9	14	3	9	7.6
24	Mazia	17	6	3	9	5.7
25	Lembuwa	9	17	0	9	7.0
26	Godaria	9	11	0	7	4.9
27	Tenna	9	11	0	7	4.9
28	Benuwa	11	0	6	7	4.5
29	Pena	11	0	3	5	2.9
30	Doko	9	6	0	5	3.2
31	Lochingia	3	6	6	5	5.6
32	Katania	6	3	3	5	3.4
33	Bukunia	6	3	3	5	3.4
34	Banga	3	6	0	3	2.5
35	Kuania	3	6	0	3	2.5
36	Hawsakuwa	6	3	0	3	1.8
37	Budaro	0	6	0	2	2.1
38	Separa	6	0	0	2	0.7
39	Kekeruwa	0	0	3	1	1.6
40	Argama	3	0	0	1	0.4
41	Genesa	0	0	3	1	1.6
42	Afamma	0	3	0	1	1.1
43	Badadia	0	3	0	1	1.1
44	Achaka	0	3	0	1	1.1
45	Sanka	0	0	3	1	1.6
46	Shamaruwa	0	3	0	1	1.1
47	Tagacha	0	0	0	1	1.1
48	Mahia	0	0	3	1	1.6
49	Gonwassa	3	0	0	1	0.4
50	Mochia	3	0	0	1	0.4
51	Siskela	3	0	0	1	0.4
52	Chorore	3	0	0	1	0.4
53	Fara	3	0	0	1	0.4
54	Gishera	3	0	0	1	0.4
55	Guniashia	3	0	0	1	0.4

Table 6. Frequency of enset landraces (%) in Hadyia region, Ambicho Gode and Anna-lemmo, for each wealth category.

No	Vernacular name	Rich (10%)	Middle (50%)	Poor (40%)	Mean	Weighted average
1	Gimbo	100	97	96	98	96.9
2	Sapara	94	79	81	85	81.3
3	Siskela	88	82	78	83	81.0
4	Hayiwona	82	85	67	78	77.5
5	Disho	71	64	48	61	58.3
6	Gishera	68	55	48	57	55.5
7	Merza	53	61	37	50	50.6
8	Oniya	56	39	33	43	38.3
9	Unjama	38	45	37	40	41.1
10	Zobra	44	36	37	39	37.2
11	Shate	50	39	22	37	33.3
12	Manduluka	35	36	37	36	36.3
13	Torora	41	30	37	36	33.9
14	Astara	35	33	19	29	27.6
15	Beneja	32	18	19	23	19.8
16	Agade	29	18	19	22	19.5
17	Uskruz	21	24	18	21	21.3
18	Kombotra	29	21	11	20	17.8
19	Hiniba	29	21	4	18	15.0
20	Kaseta	26	12	15	18	14.6
21	Kiniwar	26	15	11	17	14.5
22	Orada	18	18	11	16	15.2
23	Gariya	24	18	4	15	13.0
24	Woshamaja	15	12	15	14	13.5
25	Bedadeda	24	12	7	14	11.2
26	Mesmesicho	26	9	0	12	7.1
27	Moche	12	9	15	12	11.7
28	Hanzena	12	18	4	11	11.8
29	Dirbo	24	9	0	11	6.9
30	Tebute	9	9	7	8	8.2
31	Gozoda	12	9	4	8	7.3
32	Sormanicho	15	3	7	8	5.8
33	Korina	3	9	11	8	9.2
34	Bekecho	9	9	4	7	7.0
35	Shewrad	12	3	4	6	4.3
36	Necho	12	6	0	6	4.2
37	Dego	6	6	4	5	5.2
38	Sokido	3	9	4	5	6.4
39	Mariye	6	3	4	4	3.7
40	Tessa	3	9	0	4	4.8
41	Eshamwesa	6	6	0	4	3.6
42	Lendwesa	3	3	7	4	4.6
43	Teigo	6	0	4	3	2.2
44	Woshemela	6	0	4	3	2.2
45	Memo	6	3	0	3	2.1
46	Tegaded	9	0	0	3	0.9
47	Onsessa	6	0	4	3	2.2
48	Bokucho	0	3	4	2	3.1
49	Jegireda	3	3	0	2	1.8
50	Anchere	0	0	4	1	1.6
51	Mekelesa	3	0	0	1	0.3

Table 6. Continued.

52	Genko	3	0	0	1	0.2
53	Arke	3	0	0	1	0.3
54	Gudere	0	3	0	1	1.5
55	Awuneda	0	3	0	1	1.5
56	Amcheroda	0	3	0	1	1.5
57	Sherafera	3	0	0	1	0.3
58	Wordes	3	0	0	1	0.3
59	Sumeka	3	0	0	1	0.3

passion fruit *(Passiflora edulis* Sims) were only common in Wolaita. There was a significant difference in the average number of crop species between the three regions, with Wolaita farmers growing substantially more types of crops than in Sidama or Hadiya (Table 7). The crops grown in the study areas are used to supplement the low protein and vitamin content of enset products and to generate cash from sales.

There was a significant difference in the average number of crop species between the three wealth categories in Wolaita, with the average rich household growing 47% and 22% more crop species than the average poor or middle household, respectively. In Sidama, poor households grew significantly fewer crop species than either rich or middle-ranked households, while in Hadiya region, there was no significant difference according to wealth rank (Table 7).

Livestock

The number of livestock per farm differed significantly between the three regions (Table 7), with fewer livestock in Wolaita than in Sidama or Hadiya. Livestock provide manure for enset and other important crops and milk to supplement the diet, and are an important source of cash.

Within each of the three regions, the number of livestock differed significantly among the three wealth categories (Table 7).

Farm size

A typical farm includes a rectangular compound or field, fenced by eucalyptus trees in Wolaita and Hadiya, and by bamboo in Sidama. In front of the house about 5–10% of the land is left as a front yard for grazing and for social activities such as funeral and wedding ceremonies.

The household farm size in Sidama was significantly larger than in Wolaita or Hadiya. Farm size also differed between the three wealth categories in the study areas (Table 7).

Family size

In Sidama, average family size was significantly higher than in Wolaita, though Hadiya family size was similar to the other locations (Table 7). Family members in Wolaita and Hadiya are mostly involved in crop production or non-crop production activities, while in Sidama, livestock herding and feeding are also important production activities.

Average family size differed significantly with wealth in Sidama and Wolaita, with wealthy households having more members (Table 7). In Hadiya, the family size of poorer households was lower than for those in the middle or wealthiest categories.

Table 7. Average number of enset landraces, crop species, livestock, family and farm size of each wealth category in Sidama, Wolaita and Hadiya ethnic regions.

Region/wealth category	Number of enset landraces	Number of crop species	Number of livestock	Farm size (ha)	Family size (number)
			Mean		
Sidama	13.9 (1.2)†	3.0 (0.6)	12.4 (1.1)	1.7 (0.4)	8.9 (0.9)
Wolaita	8.8 (0.9)	10.9 (1.0)	4.5 (0.7)	0.7 (0.2)	7.4 (0.9)
Hadiya	11.7 (1.1)	6.0 (0.8)	6.1 (0.8)	1.0 (0.3)	8.2 (0.9)
Mean	11.5 (1.1)	6.6 (0.8)	7.7 (0.9)	1.1 (0.3)	8.2 (0.9)
s.e. mean	(0.05)	(0.05)	(0.05)	(0.04)	(0.05)
			Sidama		
Rich (n=35)	15.6 (1.2)	3.2 (0.6)	22.3 (1.3)	2.6 (0.5)	11.7 (1.1)
Middle (n=35)	14.4 (1.2)	3.3 (0.6)	10.3 (1.0)	1.5 (0.4)	8.7 (0.9)
Poor (n=35)	11.6 (1.1)	2.5 (0.5)	4.6 (0.7)	0.7 (0.2)	6.3 (0.8)
Mean	13.9 (1.2)	3.0 (0.6)	12.4 (1.0)	1.7 (0.4)	8.9 (0.9)
s.e. mean	(0.07)	(0.05)	(0.11)	(0.06)	(0.09)
			Wolaita		
Rich (n=35)	10.8 (1.0)	13.1 (1.1)	7.0 (0.9)	1.0 (0.3)	9.4 (0.9)
Middle (n=35)	9.0 (0.9)	10.8 (1.1)	4.2 (0.7)	0.7 (0.2)	7.2 (0.9)
Poor (n=35)	6.6 (0.9)	8.9 (0.9)	2.3 (0.5)	0.4 (0.1)	5.6 (0.8)
Mean	8.8 (0.9)	10.9 (1.0)	4.5 (0.7)	0.7 (0.2)	7.4 (0.9)
s.e. mean	(0.11)	(0.07)	(0.08)	(0.03)	(0.09)
			Hadiya		
Rich (n=35)	13.3 (1.1)	6.3 (0.8)	9.7 (1.0)	1.3 (0.4)	9.2 (0.9)
Middle (n=35)	12.4 (1.1)	6.1 (0.8)	6.1 (0.8)	1.1 (0.3)	8.3 (0.9)
Poor (n=35)	9.4 (1.0)	5.7 (0.8)	2.5 (0.5)	0.7 (0.2)	7.0 (0.9)
Mean	11.7 (1.1)	6.0 (0.8)	6.1 (0.8)	1.0 (0.3)	8.2 (0.9)
s.e. mean	(0.09)	(0.05)	(0.09)	(0.04)	(0.09)

† Log(x+1) transformed data in parentheses.

Relations between household characteristics

Correlation coefficients among household characteristics were estimated in the three regions in order to determine patterns of relationships and to assess the impact of household characteristics on enset biodiversity. Only for the resource-rich households in the Sidama region was the number of enset landraces correlated with all assessed household characteristics (Table 8). For resource-rich Hadiya farmers, the number of enset landraces was significantly correlated with livestock number and with farm area. However, for the resource-rich group of Wolaita farmers, the number of enset landraces was not correlated with any of the measured household characteristics, though it was positively correlated with the number of crop species and negatively correlated with family size in resource-poor households. The absence of a correlation pattern in Wolaita suggests that farmers might be pursuing other off-farm activities – such as trading and handicraft – for their living because of the scarcity of farmland. As family size of resource-poor farmers increases, they may concentrate on few high 'kocho'-yielding enset landraces rather than growing diverse landraces with various properties.

Enset and gender

There is a clear gender division in enset cultivation practice. Men are involved in propagating, planting, and transplanting activities. Women are involved in manuring, hand-weeding, thinning, and landrace selection. In addition, the tedious work of harvesting and processing is exclusively left to women. It is taboo for men to assist during processing, or even to enter the enset field at this time. The farmers in all the study areas indicated that women have control over the enset field because it is an important source of daily food. Since women are the ones who take care of husbandry and post-harvest handling, they are able to identify all of the different genotypes. In some households, it was very difficult to identify the different landraces in the backyard farm in the absence of the housewife. The farmers in all enset-growing regions consistently indicated the importance of women by saying that "If women do not harvest and process enset, there would be no food produced from the plant and it would simply be an ornamental plant, as it is in other parts of the world".

Production consumption and marketing

The Central Statistical Authority (CSA, 1997a) estimated the area cultivated with enset to be about 37,000, 18,000 and 13,000 ha in Sidama, Hadiya and North Omo (where the Wolaita region is located), respectively. According to the same survey, these zones' annual production of 'kocho' is about one million, 190,000 and 200,000 t, respectively.

Table 9 presents the relative contribution of major farm products to total household consumption over the entire year. In the Sidama and Hadiya regions, enset accounted for

Table 8. Coefficient of determination (r^2) among household characteristics for each wealth category in Sidama, Wolaita and Hadiya ethnic regions (n=35).

	El	Cs	L	F	El	Cs	L	F	El	Cs	L	F
	Sidama rich				Wolaita rich				Hadiya rich			
Enset landrace (El)	-				-				-			
Crop species (Cs)	0.12*				0.03	-			0.04	-		
Livestock (L)	0.14*	0.01			0.04	0.03			0.09*	0.00		
Farm land size (F)	0.26**	0.00	0.00		0.02	0.15*	0.00		0.19*	0.16*	0.00	
Family size (Fs)	0.12*	0.04	0.18*	0.05	–0.05	0.00	0.02	0.07	–0.00	0.02	0.00	0.03
	Sidama middle				Wolaita middle				Hadiya middle			
Enset landrace (El)	-				-				-			
Crop species (Cs)	0.06	-			0.20**	-			0.08			
Livestock (L)	–0.01	0.01	-		–0.00	0.02			–0.00	–0.21**		
Farm land size (F)	0.00	0.03	0.45**	-	0.00	0.07	0.02		–0.03	0.00	–0.00	
Family size (Fs)	0.00	0.10	0.16*	0.27**	0.07	0.05	0.03	0.18*	–0.00	–0.02	0.02	–0.03
	Sidama poor				Wolaita poor				Hadiya poor			
Enset landrace (El)	-				-				-			
Crop species (Cs)	0.07	-			0.14*	-			0.09			
Livestock (L)	0.00	0.15*	-		0.02	0.03	-		0.02	0.01		
Farm land size (F)	0.02	0.08	0.05		–0.01	0.03	0.02		–0.02	–0.04	0.00	
Family size (Fs)	0.00	0.15*	0.52**	0.21**	–0.14*	–0.05	–0.00	0.08	–0.00	0.00	0.04	–0.00

* and ** significant at $P < 0.05$ and $P < 0.01$ levels of probability, respectively.

Table 9. Average proportion (%) of annual household consumption met by major crops for each wealth category in the three survey areas.

	Sidama			Wolaita			Hadiya		
Crops	Rich	Middle	Poor	Rich	Middle	Poor	Rich	Middle	Poor
Enset	85	88	89	19	27	30	60	54	68
Beans	1	2	1	5	4	8	1	3	1
Maize	1	-	1	29	16	17	5	5	1
Root crops	2	1	3	40	48	36	7	7	4
Cabbage	1	2	-	6	4	8	15	21	19
Wheat	5	3	4	-	-	-	7	5	7
Barley	5	4	2	-	-	-	5	5	-
Teff	-	-		1	1	1	-	-	-

Note: Root (and tuber) crops include sweet potato, yam, taro and Irish potato.

the largest share of crop produce consumed as food. In the Sidama region, enset's contribution to food needs in January and February is relatively low (about 50%) compared to other months, as other crops, such as barley and wheat, are harvested at this time. In Hadiya, the share of enset in the household food consumption was more or less constant throughout the year. In Wolaita, root and tuber crops such as sweet potato, yam, taro, and Irish potato were the most consumed products, followed by enset and maize.

In all three regions the households produce enset predominantly for home consumption, and only a very small proportion of enset products is sold in the local market.

Discussion

Cultivation methods

Cultivation methods, such as propagation and transplanting, varied mainly between the three ethnic groups, rather than between wealth categories within a given group, indicating that cultural background influenced cultivation methods. The Wolaita people claim that splitting the corm into two or four equal parts would produce too many suckers. Moreover, Wolaita and Hadiya farmers claim that repetitive transplanting results in more vigorous growth of pseudostem and corm, which are the main harvestable parts of the plant.

Wealth classification

The classification in wealth classes by the key informants was not always consistent with the quantitative information provided by the individual farmers. This becomes obvious when Tables 1–3 are compared with Table 7. Traditionally, farmers are very suspicious, and are reluctant to give accurate information about their livestock number, family, or farm size. Most farmers believe that counting their family and livestock may result in undesirable events, such as illness or death. Providing information about their farm size is also associated with redistribution of land and increases in land tax. However, we tried to minimise the inconsistency by hiring farmers' children from the study areas for enumeration and data collection.

The wealth indicators used to categorise households according to relative wealth or well-being were similar for all three regions. Resource-rich households in the three ethnic regions have common properties that distinguish them from their less well-off neighbours. This shows that differences in wealth categories between households in each location relate primarily to resources rather than to cultural background, ethnicity, or agro-ecology. Most of the wealth indicators for the Hadiya study area were similar to those mentioned by Spring *et al.* (1996).

Enset landraces

A combination of factors, including household resources, cultural background, population pressure, and agro-ecology influence the number of enset landraces on a given farm. An enset garden is thought to require heavy applications of organic matter to be able to maintain it during drought periods for food security (Elias *et al.*, 1998). Since better-off farmers have more resources, notably land, labour, and livestock (as a source of manure), they can plant more landraces for their specific characteristics, even when they are low yielding (Table 7). Poor farmers, however, do not plant a large number of enset landraces, as some types do not perform as well as others, or need at least 3–4 years to mature. In enset-growing regions, planting many different landraces in the backyard is a sign of status within the community.

Farmers have multiple uses for the enset plant and thus select enset landraces to fit their different needs and constraints. The selection criteria for household use include the quality and quantity of food products, maturity period, disease and drought tolerance, forage and fibre quality, medicinal value, ease of scraping, rapidity of fermentation, quality of corm, and productivity on marginal soils. Since one landrace can never fulfil all criteria, farmers tend to keep a diverse range of enset types on their farm (Table 7). Farmers' interest in maintaining multiple varieties with contrasting traits to fit different needs and constraints, rather than concentrating on a single variety with a particular trait, has also been reported for maize in southern Mexico (Bellón, 1996; Brush, 1995).

The significant correlation of on-farm diversity of enset landraces with all the household characteristics of resource-rich Sidama households, and with livestock numbers and farmland size of resource-rich Hadiya households (Table 8), may suggest that middle- or poor-resource farmers concentrate on other annual crops rather than the perennial enset plant. Most resource-limited farmers are short of food at some point in the season, and cannot afford to wait until the enset plant matures. Resource-rich Wolaita households are comparable with middle level Sidama or Hadiya households. Thus, it is likely that the Wolaita farmers, irrespective of wealth category, select few enset landraces, and also participate in trading, handicraft and other off-farm income generating activities.

The Sidama people grow more enset landraces on their farms, on average, than the Wolaita or Hadiya people (Table 7). The Sidama speak a Cushitic language, and have been adapted to the cultivation, processing, and food habit of enset culture for a long period of time (Stanley, 1966). They grow enset as a staple food in dense plantations, and are highly dependent upon cattle to produce manure for fertilising enset fields, and to supply cash to meet household needs and obligations. Though the Hadiya belong to the same ethno-linguistic family, their culture and language are quite different from the Sidama. The Wolaita people are Omotic, and are characterised by their own distinctive language and culture. Enset is a co-staple with cereals and other tuber crops for both the Wolaita and Hadiya peoples (Westphal, 1975; Brandt *et al.*, 1997). These ethnic groups also differ somewhat in their end-uses of enset. The Wolaita people commonly select enset landraces for their corm, whereas the Sidama and Hadiya people grow enset for the 'kocho' yield (starch from the mixture of scraped pseudostem and pulverised corm). Jain (2000) also reported the influence of cultural background on plant species diversity and the uses of plant species for different purposes.

Farm, family size and enset landrace

The national average farm and family sizes in Ethiopia were reported to be 1.09 ha and 5.17 persons, respectively (Zekaria and Abebe, 1996). The average Sidama farm size exceeds the national average by 73%, while average Wolaita and Hadiya farms are, respectively, 27% and 26% smaller. As a result, the Sidama farmers keep a large number of livestock and grow more enset. Increasing population pressure in the Wolaita and Hadiya regions has lead to more extensive cultivation to feed the growing population. This, in turn, leads to reduced numbers of livestock, and thus reduced cash flow from the sale of animal products, and less manure to maintain soil fertility for enset cultivation. These conditions have forced farmers to grow fewer enset landraces. This study confirms the statement by Clincotta *et al.* (2000) that increased population pressure in biodiversity-rich areas increases the risk of plant species extinction.

Crop species

Wolaita is characterised by low soil fertility and erratic rainfall, and drought periods are common. When droughts destroy their other crops, the Wolaita people must depend entirely on enset, and harvest whatever they have in the field. This practice, together with the occurrence of bacterial wilt disease, has caused serious genetic erosion of enset. The Wolaita farmers plant a higher diversity of annual crops than the Sidama or Hadiya people, probably as a risk avoidance strategy (Table 7). In this ethnic region, annual, short cycle root and tuber crops are the most important food source throughout the year (Table 9). The tendency of small farmers to cultivate diverse crop species with different maturation periods and products, as a means of coping with heterogeneous and uncertain ecological conditions, has also been reported by Clawson (1985), Scoones (1996), and Netting and Stone (1996). The average number of crop species of the resource-rich farmers in Wolaita (13.1) is similar to the findings (14.4) of Asfaw and Woldu (1997) in the same area.

Enset and gender

Women play a major role in enset landrace selection. Since the processing of enset is laborious and tedious, neighbouring women conduct this activity in work-groups for each household in turn. During such group work the hostess cooks enset corms for the group to consume at the end of the day. In addition, women are very busy every day preparing different kinds of meals from the different products of enset. All these activities allow women to easily identify the clones, and to know the specific characteristics and uses of each landrace.

Conclusions and recommendations

- There is variation in cultivation methods among the different ethnic groups, more than among households within a single group. The cultural and socio-economic determinants responsible for this variation, as well as the advantages and disadvantages of the different cultivation methods, need to be investigated.
- Women control the enset fields and are also responsible for harvesting and processing. They have a well-developed knowledge of the enset crop and its biodiversity. Therefore, a gender-sensitive analysis is needed to fully understand the dynamics of enset biodiversity.
- The enset-production system involves intercropping with diverse crop species as well as landrace mixtures. To improve the production system and increase productivity per unit area, compatible crops for intercropping and the best mixtures of enset landraces need to be investigated.
- The phenotypic variation of enset landraces expressed under farmers' conditions is enormous. Farmers have managed this diversity for centuries with limited influence from outside. Research should analyse how cultural and socio-economic factors influ-

ence the way farmers create, manage, utilise, and conserve this diversity. Moreover, this genetic variation needs to be assessed using morphological, agronomic, and molecular traits, in order to develop a strategy to conserve and utilise the existing genetic diversity.

- The diversity of enset landraces on-farm is largely influenced by a combination of household resources, cultural background, and agro-ecology.
- Livestock production is an important component in enset-based farming systems. Thus, future research and development studies on enset need to include a strong component that alleviates constraints to livestock productivity.
- The enset-growing areas are densely populated and have rarely experienced famine. Compared to other crops in the area, enset's high yields under low input conditions, tolerance of climatic and environmental fluctuation, storability for long periods of time, multipurpose use, and the cultural value attached to it make enset attractive to farmers in these regions.

CHAPTER 3

AFLP analysis of enset (*Ensete ventricosum* (Welw.) Cheesman) clonal diversity in south and southwestern Ethiopia for conservation

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CHAPTER 3

AFLP analysis of enset (*Ensete ventricosum* (Welw.) Cheesman) clonal diversity in south and southwestern Ethiopia for conservation

Abstract

Enset (*Ensete ventricosum* (Welw.) Cheesman) is a major multi-purpose crop in Ethiopia, which has been identified as the centre of origin and diversity of enset. During the last decades the local farming systems in which enset is maintained have become endangered. Conservation of vegetatively propagated crops such as enset is complex and relatively expensive. Consequently, an assessment of clonal diversity is essential in order to maximise conservation efforts. In the present study, 146 clones from five different regions in southern and southwestern Ethiopia were characterised with AFLPs to investigate genetic relationships among clones, identify duplicates, and study regional variation. A total of 180 bands was scored of which 104 (58%) appeared polymorphic. Twenty-one duplication groups consisting of 58 clones were identified. Duplicates were related to different utilisation purposes of clones and to the changing of vernacular names after exchange of clones between communities. Despite large variation in agro-ecological conditions among regions, only 4.8% of the total genetic variation was found between regions, whereas 95.2% was found within regions. This finding may be explained by regular long distance exchange of clones. Furthermore, it suggests the existence of substantial levels of phenotypic plasticity in enset. The results of the study allow for a substantial and well-based reduction of the number of clones qualifying for conservation. In addition, the exchange between regions suggested by this study indicates that unexplored additional diversity, if existing, should mainly occur in divergent farming systems.

Keywords: Enset, AFLP, genetic diversity, conservation

Introduction

Enset (*Ensete ventricosum* (Welw.) Cheesman) is a perennial monocarpic crop belonging to the family Musaceae. For thousands of years it has been used as a food crop in Ethiopia (Smeds, 1955), where it was once domesticated. Enset is an important (co-) staple crop for over 20% of the Ethiopian population living in the southern and south-western parts of the country, including many ethnic groups (Brandt *et al.*, 1997). It is a diploid (2n=18) species that phenotypically resembles the banana plant, but the edible parts of the plant are formed by the pseudostem and the underground corm rather than by the fruit. Natural forests in the region harbour wild relatives of the domesticated enset. Enset is predominantly vegetatively propagated, although some farmers practice regeneration by seed. Unlike banana, enset will only rarely produce voluntary suckers unless intentionally induced to do so.

Characterisation of clones by morphological markers is rudimental (e.g., Endale,

1997) and a well-established taxonomic classification and descriptor list are lacking. In addition, few attempts have been made to document and analyse clonal identity using farmers' classification. In these cases, clonal names reported in the literature are associated with only limited phenotypic data provided by farmers (e.g., Shigeta, 1991). Local knowledge is the main source of passport and agronomic data for the genetic resource collections maintained by the Institute of Biodiversity Conservation and Research in Addis Ababa, the Institute of Agricultural Research at Areka and the Debub University in Awassa.

Most of the genetic diversity of enset is traditionally maintained *in situ* by farmers. Unfortunately, many valuable clones have been lost because of various human and environmental factors (Gebremariam, 1996), which may have reduced the total available genetic diversity of the crop. Lack of knowledge about the genetic diversity of this crop species complicates the conservation, improvement, and utilisation of enset by farmers, conservationists, and breeders.

Although assessment of morphological variation present in enset is feasible, its use is rather limited because of the small number of phenotypic markers and the fact that they are influenced by environmental conditions. Therefore, in this study, molecular methods have been applied to characterise germplasm diversity in enset as a complementary approach.

Molecular genetic markers are usually unaffected by the environment and can often be generated in large numbers (Vosman *et al.*, 1999). The amplified fragment length polymorphism (AFLP) technique applied in this study combines the use of restriction enzymes and the polymerase chain reaction (PCR) (Vos *et al.*, 1995). AFLP fingerprinting profiles can be generated without prior knowledge of genome sequences, and therefore be applied to DNAs of any origin. AFLP fingerprinting usually results in informative profiles due to the high number of genomic fragments that can be analysed in a single assay (Lin *et al.*, 1996; Powell *et al.*, 1996). AFLPs have been applied successfully to characterise germplasm of various crops, including *Musa* spp., which are close relatives of enset (Engelborghs *et al.*, 1998).

In our study, AFLPs have been employed to characterise 146 enset clones from southern and southwestern Ethiopia. Specifically, we aimed to assess genetic relationships among the clones, identify duplicated accessions and investigate regional variation. Implications of our results for enset conservation efforts in Ethiopia are discussed.

Materials and methods

Plant material

Leaf samples from 146 enset clones were collected on farm from southern and southwestern Ethiopia in 1999 (see Table 2 in Chapter 4 for the complete list of clones). A representative set of clones were collected from the available diversity maintained in farmers' fields. Vernacular names were obtained from the enset farmers who provided the germplasm. Samples were collected from the Chena (n = 36) and Decha (n = 29) districts of the Kaffa-Shaka zone in southwestern Ethiopia (located 70 kilometres apart) and from the Sidama (n = 30), Hadiya (n = 45) and Wolaita (n = 6) zones in southern Ethiopia (see Fig. 1 in Chapter 2). The Kaffa-Shaka zone is located about 450 km from the closest other zone where samples were collected.

Pieces of young leaf tissue were harvested for each clone and stored in 50-ml tubes containing a saturated NaCl-CTAB preservation buffer following the procedures of Rogstad (1992). Upon return to the laboratory two weeks later, the CTAB was washed off thoroughly with distilled water. About 50 to 100 mg of leaf tissue was then transferred to 2-ml-Eppendorf tubes and stored at –80 °C awaiting further analysis.

DNA isolation

Tissue samples were vacuum dried overnight and mechanically ground using a 'Retch' shaking mill and about 5 glowed glass beads per Eppendorf tube. Since DNA analyses in enset had not been described before, three different DNA extraction procedures as described by Fulton *et al.* (1995), Rogstad (1992), and the Qiagen spin column extraction method (Dneasy™ Plant Mini Kit, Qiagen, Leusden, The Netherlands) were tested in order to determine the optimal protocol. No amplification using PCR could be accomplished with DNA obtained by the microprep protocol of Fulton *et al.* (1995). The other two protocols both resulted in DNA that enabled proper amplification, but slightly better results were obtained from DNA isolated with the Qiagen spin column method. This method was therefore adopted to isolate genomic DNA from all samples. Extracted DNA samples were stored at 4 °C. DNA concentrations were estimated by comparing 2 μl of each sample with 20, 40, 60, 80, and 100 ng of phage lambda DNA on a 0.8% agarose gel.

AFLP protocol

In general, the AFLP protocol followed the procedures described by Vos *et al.* (1995). Briefly, about 300 ng of total genomic DNA was digested to completion using 5 units of *Eco*RI and 5 units of *Mse*I. AFLP adapters for both restriction enzymes were then ligated to the fragments. Selection of *Eco*RI-*Eco*RI and *Eco*RI-*Mse*I fragments from the total fragment pool, by the use of biotinylated *Eco*RI adapter and magnetic beads, was not applied. Subsequently, template DNA was preamplified using primer pairs based on the sequence of the adapters, and 3′ extended with one selective nucleotide ("A" for the *Eco*RI primer and "C" for the *Mse*I primer). Successful amplification was verified by electrophoresis of a portion of PCR products on a 2% agarose gel. Diluted preamplification product was then used as template in a second amplification reaction, using primer pairs variably extended with a number of selective nucleotides at the 3′ end. The *Eco*RI primer was radiolabelled with ^{33}P prior to PCR. Labelled PCR products were separated on 6% denaturing polyacrylamide gels (Biozym, Sequagel-6) and exposed to X-ray film (Kodak, XOMAT AR) for several days. Goldstar *Taq* DNA polymerase (Eurogentec) was used for PCR and all amplification reactions were performed on a Perkin Elmer 9600 thermocycler. Cycling conditions were as follows: 1 cycle of 30 s at 94 °C, 30 s at 65 °C and 60 s at 72 °C; 12 cycles in which the initial annealing temperature of 65 °C was lowered by 0.7 °C each cycle; 23 cycles in which the annealing temperature was held constant at 56 °C. More details about the experimental procedures are given by Arens *et al.* (1998).

Following preamplification of the samples, 12 different primer combinations (E+AA, E+AC, and E+AG in combination with each of M+CCA, M+CCT, M+CGG, and M+CTC) were tested on six clones (vernacular names: 'Chele bocho', 'Choro', 'Neche nobo', 'Gesh ariko', 'Neche epo' and 'Ketano') in order to identify suitable primer pairs. This test panel of six clones was selected based on expected dissimilarity. Four primer combinations were selected for analysis of the total sample based on resulting fingerprinting profiles that could be scored unambiguously for multiple variable AFLP fragments. As a control for the reproducibility of the patterns, four replicate tissue samples from a single individual were included in all experimental steps in order to estimate the frequency of artefact bands on the autoradiograms.

Data analysis

Autoradiograms (approximate size range of the fragments: 50 to 500 bp) were manually scored and segregating bands were recorded as polymorphic AFLP fragments. The number of polymorphic and monomorphic fragments was determined for each primer pair. Clones were only designated identical when all AFLP fragments generated with the four primer pairs fully matched. Band sharing data were used to calculate genetic similarities between samples based on Jaccard's coefficient. The similarity values were used to graphically represent genetic relationships between the clones by the unweighted pair-group method using an arithmetic average (UPGMA) clustering algorithm (e.g., Nei, 1987) and principal co-ordinate plots (PCO). Matrices of Jaccard's similarity coefficients based on different primer pairs were tested for significant correlation (1,000 permuted data sets) by a Mantel test (Mantel, 1967). These analyses were carried out using the Genstat 5 software package (release 4.1). To investigate regional variation, an analysis of molecular variance (AMOVA) was used to compute molecular variance components for AFLP phenotypes within and between geographical regions. These analyses were carried out using version 1.55 of the software package WINAMOVA (Excoffier *et al.*, 1992), after preparing the input files for the analysis of dominant data using Mark Miller's AMOVA-PREP software program (http://herb.bio.nau.edu/~miller/). Monomorphic loci were included in all data analyses.

Results and discussion

AFLP variation in enset

Out of the twelve primer combinations that were analysed on a test panel of six clones, four primer pairs (E+AA/M+CCA, E+AA/M+CCT, E+AG/M+CCA and E+AG/M+CCT) that generated optimally clear AFLP profiles with multiple polymorphic bands that could be scored unambiguously were selected to analyse the total sample (Fig. 1). A total of 180 AFLP fragments was scored among the 146 clones. One hundred and four fragments (58%) were polymorphic (Table 1).

The level of polymorphism observed for each of the four primer pairs was similar, with values ranging from 0.52 to 0.61 (Table 1). Mantel tests revealed significant correlations between all pairs of primer combinations tested (range of correlation coefficients: $r = 0.12$ to 0.27, $P < 0.001$ in all cases). Thus, with respect to the observed level of variation and the genetic similarities among clones, consistent results were obtained with the four primer pairs investigated. Identical AFLP profiles were observed among four replicate tissue samples for each of the four primer pairs, indicating that the results obtained were not substantially affected by the generation of artefact bands.

Identification of duplicate clones

Within the 146 clones, 21 duplication groups consisting of 58 clones were identified based on the AFLP data (Table 2). In other words, 37 clones, or 25% of the collection consisted of duplicated clones. Duplication of clones may have at least two different origins.

Table 1. Number of bands scored and degree of polymorphism for the primer combinations E+AA/M+CCA, E+AA/M+CCT, E+AG/M+CCA and E+AG/M+CCT among the 146 enset clones analysed in the present study.

	Primer Combination				
	E+AA/ M+CCA	E+AA/ M+CCT	E+AG/ M+CCA	E+AG/ M+CCT	Total
Total number of bands scored	49	35	48	48	180
Number of polymorphic bands	30	20	29	25	104
Degree of polymorphism	0.61	0.57	0.60	0.52	0.58

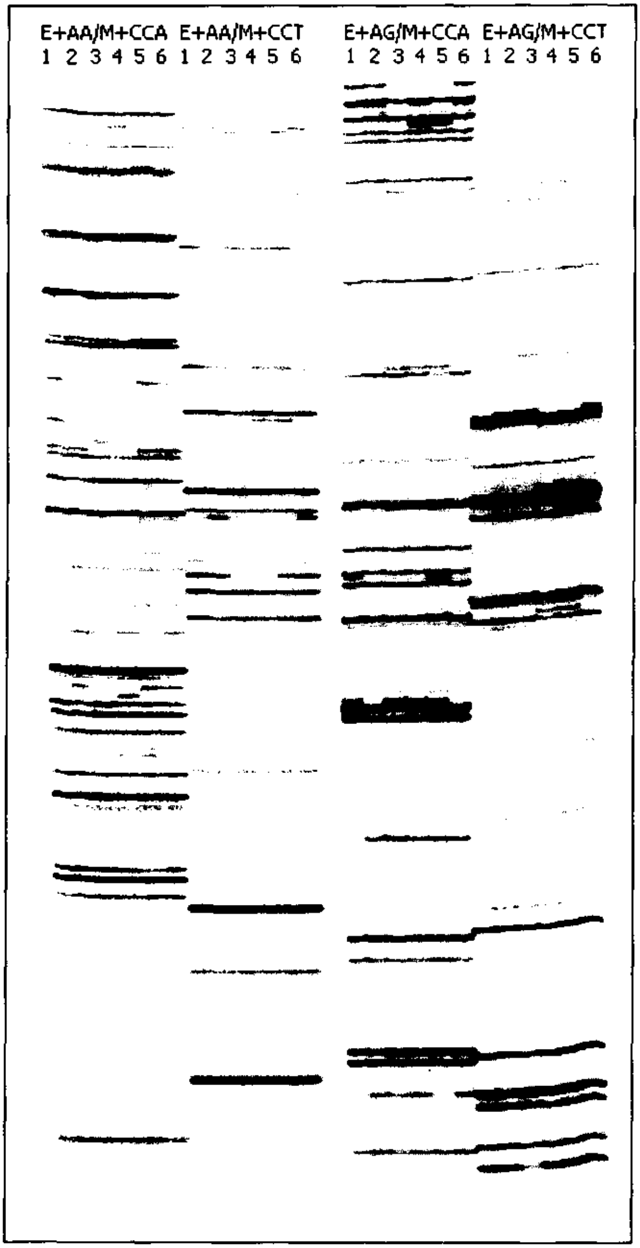

Fig. 1. Part of the AFLP autoradiograms of six enset clones analysed in the present study for the primer combinations E+AA/M+CCA, E+AA/M+CCT, E+AG/M+CCA and E+AG/M+CCT. These primer combinations were selected from of a group of 12 that were tested on the six enset clones. Vernacular names of these clones are 'Chele bocho' (1), 'Choro' (2), 'Neche nobo' (3), 'Gesh ariko' (4), 'Neche epo' (5) and 'Ketano' (6). Approximate size range of the fragments shown in the figure is 300 to 100 bp from top to bottom.

Table 2. Duplication groups (1 to 21) of enset clones based on identical AFLP fingerprinting profiles obtained for the primer combinations E+AA/M+CCA, E+AA/M+CCT, E+AG/M+CCA and E+AG/M+CCT. Enset clones are denoted by their vernacular name, with their geographic origin in Ethiopia given in parentheses (C=Chena, D=Decha, H=Hadiya, S=Sidama and W=Wolaita). Clones are categorised in three groups based on similar or related vernacular names (A), duplication within zones (B) and duplication between zones (C).

Group	Enset clones
(A) *Duplication groups consisting of clones with similar or related vernacular names*	
1	Chele ariko (C), Tuti ariko (C)
2	Bajo (D), Yahi bajo (D), Woiro (D)
3	Ganji bocho (C), Chele bocho (D)
4	Aei nobo (C), Anami nobo (C), Chele nobo (C), Gebi nobo (C), Machi nobo (C), Neche nobo (C), Goshno (C), Omo (C), Chongo (D)
5	Ketano (C), Katino (D), Akibero (C), Kachichi (C), Choro (D)
6	Bekecho (H), Bokucho (H)
(B) *Duplication groups comprising single zones*	
7	Ofichi (C), Shelako (C)
8	Shimo (C), Chamero (D)
9	Gayo (D), Wango (D)
10	Geno (D), Utino (D)
11	Kekero (D), Utro (D)
12	Agade (H), Mariye (H)
13	Beneja (H), Kombotra (H)
14	Manduluka (H), Orada (H)
15	Oniya (H), Torora (H), Wordes (H)
16	Woshamaja (H), Zobra (H)
17	Gamechela (S), Warukore (S)
(C) *Duplication groups comprising different zones*	
18	Hichewi (C), Kapicho (C), Chichia (W)
19	Tayo (D), Birbo (S), Made (S)
20	Bedadeda (H), Dirbo (H), Hayiwona (H), Shewite (S)
21	Eshamwessa (H), Shalakumia (W)

Firstly, a number of identical clones appeared to have similar or related vernacular names, i.e. the clones in groups 1 to 6 (Table 2A). In most cases, these duplications can be ascribed to different use purposes for the same clone (group 1 to 4). According to our own observations, farmers can consciously use different names for identical clones based on variation in the pseudostem size, time until maturity, or other phenotypic characteristics. According to a related custom, in Kaffa-Shaka and the neighbouring North Omo zone, farmers characterised several clones as 'male' or 'female', with no apparent relationship to the genotype of the plant. This habit appeared to reflect the qualities desired by male and female farmers. For example, the 'male' 'Nobo' is a large, vigorous, and strong plant and results in a high yield, whereas its taste is less preferred. The 'female' 'Nobo' is thin, less vigorous, and preferred for its taste (Alemu and Sandford, 1996; Habtewold *et al.*, 1996; Negash, unpublished data). Clones with similar or related vernacular names may also result from the use of different dialects among communities, such as the clones 'Ketano' and 'Katino' in group 5 and the clones 'Bekecho' and 'Bokucho' in group 6 (Table 2A).

Secondly, the majority of duplications displayed unrelated vernacular names and can probably be ascribed to the changing of vernacular names after the exchange of clones within zones (Table 2B) or between zones (Table 2C). According to the information supplied by farmers, exchange of planting materials is intense and vernacular names may be altered after some period of adaptation of the exchanged clone, corresponding to the farmers' own preferences and languages. Consequently, identical clones have been named differently by various communities. This might have contributed to duplication of clones included in this study that did not exhibit similar vernacular names. Although the majority of duplicate clones were collected within districts and zones rather than between zones, identical genotypes were also observed across largely varying agro-ecological systems, geographical distances, and language groups (Table 2C). This finding indicates that exchange of clones among farmers has not been restricted to single zones or similar environmental conditions. Traditional migration or exchange of clones among regions irrespective of geographical distances in order to increase the diversity of individuals for utilisation has been reported to occur frequently among enset farmers (Tsegaye, 1991; Tsegaye and Struik, 2000a).

Although full identity between clones can only be ascertained when the entire genomes of individuals are compared, a limited number of primer pairs is often found to be sufficient for cultivar discrimination (e.g., Schut *et al.*, 1997; Cervera *et al.*, 1998). In our study, two AFLP primer combinations appeared to be sufficient to distinguish the majority of enset clones. The number of clones distinguished increased only slightly after extending the set with a third and fourth primer pair, respectively (Table 3). Although the maximum number of clones that can be distinguished with 104 polymorphic AFLPs is 2.03×10^{31}, further extension of the number of primer combinations may reveal polymorphisms between clones that were found identical in the present study. An example is given by the clones 'Ketano' and 'Choro', that despite reported phenotypic differences appeared identical based on four primer pairs (Table 2: duplication group 5). Coincidentally, both clones were involved in the testing of the 12 different primer pairs in the initial phase of the study. Re-examination of the fingerprinting profiles revealed one or two polymorphic fragments between these clones for three out of the eight additional primer

Table 3. Cumulative number of enset clones that could be distinguished based on the AFLP data from single primer combinations (one primer pair: E+AA/M+CCA, E+AA/M+CCT, E+AG/M+CCA and E+AG/M+CCT), and from combined sets of two, three and four primer pairs. The range given in the columns under two and three primer pairs represents the upper and lower values depending on the choice of the second and third primer group respectively.

Primer pairs	One primer pair	Two primer pairs	Three primer pairs	Four primer pairs
E+AA/M+CCA	69	101–103	105–107	109
E+AA/M+CCT	72	97–101	106–107	109
E+AG/M+CCA	86	101–103	105–107	109
E+AG/M+CCT	59	97–102	105–106	109

pairs tested (E+AC/M+CCT, E+AC/M+CGG and E+AG/M+CGG). However, a genetic resources program aiming at optimisation of conservation efforts will usually not be jeopardised by the loss of some closely related clones.

Regional variation of enset in Ethiopia

The Southern Nations Nationalities and Peoples' Regional State (SNNPRS) is the major enset growing regional state in Ethiopia. The zones in which clones were collected represent the major enset-based farming systems and agro-ecological zones in this state. In total, enset is cultivated on an estimated 110,000 hectares in the SNNPRS, which is two-thirds of the total area under enset in the country (CSA, 1997a), the remainder being located in the neighbouring states of Oromiya and Gambella. Thus, the clones analysed in this study probably represent a major part of the total genetic diversity in the crop. The agro-ecological conditions in the sampled zones vary in altitude (meters above sea level: Hadiya, 2220–2400; Kaffa-Shaka, 700–3400; Sidama, 2600–2650; Wolaita, 1750–1820), annual rainfall (average in mm: Hadiya, 1500; Kaffa-Shaka, 1400–1600; Sidama, 1350; Wolaita, 1440), average temperature (minimum and maximum mean air temperature in °C: Hadiya, 9.1 and 22.3; Kaffa-Shaka, 15 and 26; Sidama, 6.7 and 19.2; Wolaita, 14.8 and 25.7) and soil type (Hadiya, sandy loam; Kaffa-Shaka, clay loam; Sidama, clay loam; Wolaita, silt loam).

Regional differentiation appeared to be limited as no clear clustering of genotypes from a single district or zone could be detected by UPGMA cluster analysis (results not shown). Absence of regional differentiation was also revealed by a principal co-ordinate plot of all the enset clones studied (Fig. 2). The two principal axes, together, explained only 17% of the total variation, indicating the limited genetic differentiation according to geographic origin among the clones investigated in this study. Mean similarity values among clones between regions ranged from 0.83 to 0.85 and were comparable to those (range 0.83 to 0.86) found within regions (Table 4). An analysis of molecular variance revealed that only 4.8% of the total genetic variance is distributed between the five regions studied, whereas 95.2% can be found within regions. Even in the light of historical long distance exchange, this result was rather unexpected based on the large variation in agro-ecology and the comparatively large geographic distances between the different regions within Ethiopia. Identical enset clones apparently perform quite well under very different growing conditions. A possible explanation for this finding is phenotypic plasticity. Enset is known for its ability to adapt to different agro-ecological conditions, with appropriate elevations ranging from 1500 to 3100 meters above sea level (Endale *et al.*, 1996). It is unknown whether this coverage of a wide range of altitudes involves genetic or phenotypic adaptation. A detailed study on the adaptive behaviour of enset clones under varying environments may resolve this issue.

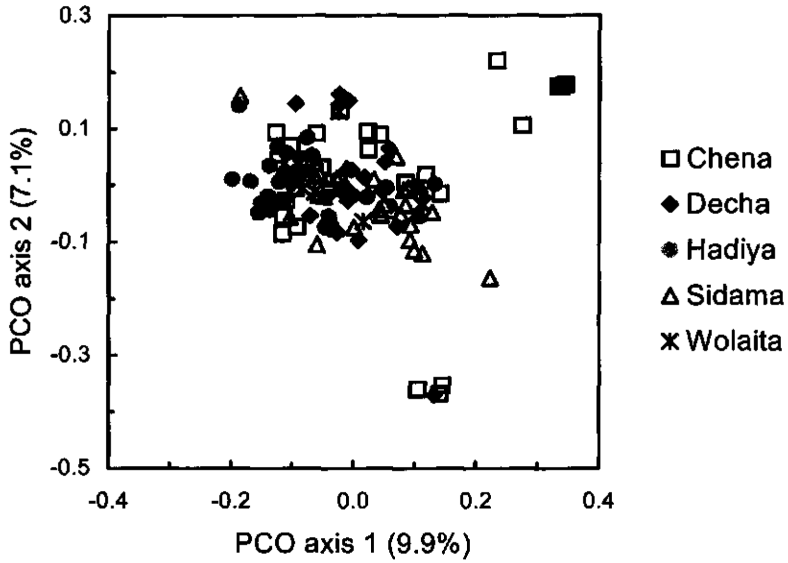

Fig. 2. Principal co-ordinate (PCO) plot of the 146 enset clones investigated in the present study. The plot is based on Jaccard's similarity coefficient using the AFLP data for the primer combinations E+AA/M+CCA, E+AA/M+CCT, E+AG/M+CCA and E+AG/M+CCT. The percentage of the total variation explained by each axis is given in parentheses in the figure. Clones are denoted by symbols, representing their different geographic origin (Chena, Decha, Hadiya, Sidama or Wolaita) in Ethiopia.

Table 4. Mean Jaccard's similarity coefficients based on the AFLP data from the primer combinations E+AA/M+CCA, E+AA/M+CCT, E+AG/M+CCA and E+AG/M+CCT, providing an indication on the genetic relationships of clones within and between regions. Mean values within and among the five regions (Chena, Decha, Sidama, Hadiya and Wolaita) studied are presented on the diagonal and below the diagonal, respectively. Standard deviations are given between parentheses.

Regions	Chena	Decha	Sidama	Hadiya	Wolaita
Chena	0.84 (0.05)				
Decha	0.83 (0.05)	0.83 (0.05)			
Sidama	0.84 (0.03)	0.83 (0.04)	0.85 (0.03)		
Hadiya	0.84 (0.04)	0.84 (0.04)	0.85 (0.03)	0.86 (0.03)	
Wolaita	0.84 (0.04)	0.83 (0.04)	0.85 (0.03)	0.84 (0.03)	0.85 (0.02)

Implications for the conservation of enset in Ethiopia

Lack of empirical knowledge about the genetic diversity of a crop hampers the efficient conservation and utilisation of its genetic resources. No genetic data on the clonal variation in enset have so far been available. Our results indicate that AFLP analysis can be successfully applied to study clonal diversity in enset. In addition to this genetic analysis, studies on agro-morphological diversity and utilisation of enset clones by farmers are described in Chapter 4. In brief, farmers' classification of agro-morphological diversity and use value correlated positively, but weakly, with the molecular data. In particular, farmers identified considerably fewer duplications (11 duplication groups consisting of 23 enset clones), of which the majority was identified also by molecular genetic analysis. Major characteristics by which farmers distinguished the enset clones were leaf colour, pseudostem colour, midrib colour, fibre quality, time to maturity, corm use, and medicinal value. In agreement with the molecular analysis regional clustering of the diversity was virtually absent. Together with a detailed study of the local knowledge of farmers, molecular and agro-morphological data provide the necessary information to develop an efficient strategy for the management of genetic resources of enset.

Conservation of enset genetic resources *ex situ* as seed in cold storage is difficult or even impossible. Seeds cannot be obtained easily and if so, they are difficult to store because of their bulky size and are hard to germinate. Moreover, conservation of seeds has limited value for utilisation in view of the preferred clonal propagation of the crop. Therefore, genetic resources of the crop can only be conserved either *in situ* (on-farm) or *ex situ* (*in vitro*, or in field genebanks). Since these approaches are capital-intensive and enset has been a neglected crop due to its geographically limited use, optimal effectiveness of an enset conservation program is of major importance. Knowledge about clonal diversity allows the selection of clones prioritised for conservation, by removing duplications and optimising genetic diversity, and hence optimising the cost-benefit ratio in maintaining the crop's germplasm. Absence of regional differences in diversity strongly suggest that the identified clones largely represent dominant diversity in the major enset growing regions in Ethiopia. Additional diversity qualifying for conservation programs might be found in strongly divergent agro-ecosystems and culturally different ethnic groups. Additional collecting missions should focus on such areas. Duplications in the clones identified by both the molecular analysis and farmers' classification (Chapter 4) may be safely removed from a conservation program. Moreover, duplication according to molecular analysis probably indicates close relationships between the clones involved, thus allowing a substantial structural reduction of up to 25% of total conservation costs, and justifying this type of analysis from an economic perspective.

Our results indicate that there is considerable diversity in the crop, despite the reported loss of several important clones from farmers' fields. Our findings are comparable to those reported for *Musa* (Engelborghs *et al.*, 1998). A more extensive investigation including divergent production areas not yet covered would extend the current overview of enset genetic diversity in Ethiopia and allow its effective conservation.

CHAPTER 4

Comparison of enset (*Ensete ventricosum* (Welw.) Cheesman) characterisation based on farmers' knowledge and on AFLPs for effective conservation and utilisation of genetic resources in Ethiopia

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CHAPTER 4

Comparison of enset (*Ensete ventricosum* (Welw.) Cheesman) characterisation based on farmers' knowledge and on AFLPs for effective conservation and utilisation of genetic resources in Ethiopia

Abstract

Enset is a vegetatively propagated (co-)staple crop in Ethiopia. Farmers' characterisation methods and DNA fingerprinting (AFLP) were compared to assess how farmers evaluate, utilise and conserve enset genetic diversity. This is needed to provide basic information to develop effective conservation and utilisation strategies. Farmers' characterisation was conducted on 142 clones out of 146 used for molecular analysis from Sidama, Hadiya and Kaffa-Shaka regions. Twelve common characteristics frequently used by farmers for characterising enset clones were identified.

A weak but positive correlation coefficient was observed between genetic similarity values based on farmers' and AFLP characterisation. The AFLP based dendrogram showed a higher percentage of duplication groups than the farmers' characterisation method. This result suggests that farmers overestimate the genetic diversity of enset.

The regional variation in farmers' skill in discriminating between clones that are genotypically different and can be used for various purposes was assessed. Farmers in regions where enset is being used as sole or main staple and therefore the culture is closely associated with the crop are skilful in discriminating enset clones. This farmers' knowledge is essential in developing an effective collection, evaluation and conservation strategy. This study also suggests that leaf colour, pseudostem colour, midrib colour, fibre quality, maturity, corm use and medicinal use are relevant descriptors.

Keywords: Enset, indigenous knowledge, farmers' characterisation, AFLP, genetic diversity, conservation, utilisation

Introduction

The genus *Ensete* Horan. (order Zingiberales, family Musaceae) contains about 6–8 distinct species equally divided between Africa and Asia (Moore, 1957; Simmonds, 1962). The genera *Musa* and *Ensete* have long been kept together under the same genus, but Cheesman (1947) pointed out that *Ensete* differed from the true banana in being monocarpic and in having a basic number of nine haploid chromosomes. Among the *Ensete* species, *Ensete ventricosum* (Welw.) Cheesman is a crop of considerable economic and social importance in Ethiopia. It is usually vegetatively propagated by producing new shoots (suckers) on an immature corm. Incidentally, seeds are also used for reproductive propagation in some parts of the country.

The wild form of *E. ventricosum* is common and widespread in southern parts of

Ethiopia. The expedition headed by Vavilov in 1923 to the country and subsequent studies of the collected materials have led to the conclusion that Ethiopia is the centre of origin of *Ensete ventricosum* (Vavilov and Rodin, 1997).

E. ventricosum is primarily grown as an important starchy, staple-food crop. Because of its conservative dry matter partitioning, it can be harvested over a long period of time (Tsegaye and Struik, 2001b; Chapter 7). The mixture of scraped pseudostem pulp, the pulverised corm and stalk of the inflorescence is put in a pit for fermentation and the resulting product is locally called '*kocho*' and cooked as porridge or baked into bread. Part of the starchy liquid called '*bulla*' obtained by squeezing the mixture can also be consumed after it is allowed to settle for some days. The fresh cooked corm is locally called '*amicho*' and can be consumed in a similar way as Irish potato or cassava. As a by-product, enset fibre has an excellent structure, and is used for making utensils. Local people in enset-growing areas also believe that enset has various medicinal qualities.

Currently, enset is used as a staple food for about 7–10 million people, in the southern parts of Ethiopia and its use is expanding towards other parts of the country (Tsegaye and Struik, 2000b; Chapter 6). Its flexibility as a food bank, the relative tolerance of this plant to prolonged soil moisture stress, its contribution to sustain the soil environment to be productive for generations and its higher yield compared to other crops in the region make it attractive to farmers.

In spite of the relative importance of enset in the diet and the customs of the people, enset germplasms have been poorly investigated. In the past three decades, because of drought, diseases, population pressure and expansion of settlement areas genetic erosion in some enset-growing areas occurred. Important genetic diversity includes genetic characteristics that make the plants tolerant to bacterial wilt and adaptable to drought and heat.

In recent years, there has been increasing interest to collect, characterise and conserve enset clones grown in different regions. However, the existence of different vernacular names based upon morphological traits and other phenotypic characteristics has created problems in identifying, classifying and conserving clones while avoiding duplication. Each region has its own languages and thus a unique set of names for different clones. Fifty-two, 55 and 59 enset types with different vernacular names were identified in Sidama, Wolaita and Hadiya regions, respectively (Tsegaye and Struik, 2001a).

Detection of genetic variation and determination of genetic relationships between plant populations are important to develop efficient strategies for conservation and utilisation of plant genetic resources (Powell *et al.*, 1996). Methods for detecting and assessing genetic diversity include an analysis of morphological and agronomic traits as well as DNA profiling techniques. The results of molecular or biochemical studies should be considered as complementary to morphological and agronomic characterisation (Karp *et al.*, 1997).

Anthropologists, archaeologists, historians, and other scholars have developed theories that argue for domestication of enset in Ethiopia as early as 10,000 years ago (Brandt *et al.*, 1997). As a result, it is likely that farmers have developed their own way of characterisation and selection criteria. Understanding farmers' characterisation methods based on morphological and agronomic characteristics and use value might help to understand how farmers value, use and conserve genetic diversity. This will be a useful tool to develop an effective conservation and utilisation strategy. It will also provide grass root information to develop a descriptor list that will be pertinent for identification and evaluation of enset clones in different regions. Results of characterisation of the collected clones using AFLPs was reported in Chapter 3. The objective of this chapter on genetic diversity of enset is to evaluate farmers' methods of characterisation and compare the results with the outcome of AFLP analysis. Implications of the results for evaluation, conservation and utilisation of enset genetic diversity in Ethiopia are discussed.

Materials and methods

Study areas

The major enset-growing ethnic regions and study areas in southern Ethiopia are shown in Chapter 2, Fig. 1. In these study regions, three different ethnic groups (Sidama, Hadiya and Kaffa-Shaka) with different cultures, languages and farming systems exist.

Enset germplasm

A total of 146 enset clones were used for molecular analysis. The clones from Sidama (n=30), Wolaita (n=6) and Hadiya (n=45) were collected in 1997–1998 and are maintained by the Debub University, Awassa College of Agriculture, whereas the clones from Kaffa-Shaka (Chena and Decha districts) (n=65) were collected in 1998 and are maintained there on farm by the Biodiversity Institute.

Farmers' methods of characterisation were carried out on 142 out of 146 enset clones. One enset clone from Sidama and three from Hadiya used for molecular analysis were not used in farmers' characterisation study, as insufficient information was gathered from farmers about these clones. Chena and Decha districts in Kaffa-Shaka are close and inhabited by the same dominant ethnic group. Thus, farmers' characterisation methods of these places were analysed together. Because the number of enset clones from Wolaita was small (n=6) and the collection areas were adjacent to Sidama, Wolaita and Sidama clones were pooled.

AFLP procedure

AFLP analysis basically followed the procedures of Vos *et al.* (1995). See for details in Chapter 3.

Farmers' characterisation

A Participatory Rural Appraisal (PRA) study was carried out in all study regions to collect and characterise enset clones. No standard descriptors pertinent for the identification and description of enset clones were available at the time of the study. At the community level, a group of knowledgeable male and female key informants were interviewed in an open-ended manner to investigate their traditional knowledge of characterisation of clones. At the household level, 105 household surveys were conducted both in Sidama and Hadiya, and 240 households in Kaffa-Shaka to study the identification methods in details. In both community and household surveys, the characteristics, which were frequently used by the farmers for characterisation of enset clones, were first documented. Then, farmers and researchers discussed the characteristics in an open-ended manner and qualitative evaluation of morphological characteristics, use values and agronomic characteristics were coded numerically to allow statistical analysis. Lighter colours or lower values of any other characteristic were given lower scores. Enset clones that grew up to 4, 4–6 and above 6 meters were considered to be poor, medium and high in vigour, respectively. The enset clones that flowered within 3–4, 4–6, and more than 6 years were considered early-, medium- and late-maturing types, respectively. Quantitative characteristics were avoided as differences in agro-ecology, management and developmental stage can lead to differences in measurement of different plant parts. The scores of the 12 different characteristics used by farmers for characterisation are given in Table 1.

Data analysis

AFLP data. Autoradiograms in the polyacrylamide gels were manually scored based on presence (1) or absence (0) of bands. The number of polymorphic and monomorphic fragments was determined for each primer pair. Jaccard's coefficients of similarity were calculated for all pairwise comparisons between clones and a dendrogram was created by cluster analysis using Unweighted Pair Group Method based on arithmetic Averages (UPGMA) of the Genstat 5 Release 4.1.

Farmers' data. The frequencies of the 12 different characteristics as a percentage of the number of clones in each region were evaluated using descriptive statistics. Chi-square analysis was used to assess variation in frequencies between regions for different

Table 1. The classification for 12 different characteristics used for characterisation of enset clones.

No	Characteristic	Scores
1	Leaf colour	Green (1), red (2)
2	Midrib colour	Yellow (0), green (1), red (2), brown (3)
3	Petiole colour	Green (1), red (2), purple (3), brown (4), pink (5), black (6)
4	Pseudostem colour	Green (1), red (2), purple (3), brown (4), pink (5), black (6)
5	'Kocho' quality	Low (1), medium (2), high (3)
6	'Bulla' quality	Not good (1), good (2)
7	Corm use	Not used (1), used (2)
8	Fibre quality	Low (1), medium (2), high (3)
9	Medicinal use	Not used (1), used (2)
10	Vigour	Poor (1), medium (2), high (3)
11	Maturity	Early (1), medium (2) , late (3)
12	Disease reaction	Susceptible (1), moderately tolerant (2), tolerant (3)

characteristics. Spearman's rank correlation coefficients were computed among characteristics. Principal component analysis was performed using the correlation matrix to define the pattern of variation and select most useful characteristics.

Comparison of farmers' characterisation and AFLP. Three data sets were prepared: 142 clones × all 12 characteristics included, 142 clones × colours of four plant parts, and 142 clones × 8 characteristics including use values and agronomic characteristics. Similar data sets were created for each region separately to compare farmers' characterisation of each region with AFLP results. Because different scales were used for the characteristics, data were first standardised to a mean of 0 and a variance of 1. Jacquard's coefficient of similarity was calculated for all pair-wise comparisons between clones and a dendrogram was created by cluster analysis using UPGMA. The dendrograms based on farmers' characterisation and AFLPs were then tested for significant correlation (1,000 permuted data sets) by the Mantel (1967) correspondence analysis.

Results

Farmers' characterisation

During the group discussions with key informants and the household surveys, 12 common characteristics frequently used by farmers for distinguishing enset clones were identified. These include four morphological characteristics (leaf, midrib, petiole and pseudostem colours), use value, quality of products, maturity period, vigour and reaction to bacterial wilt (causal agent: *Xanthomonas campestris* pv *musacearum*). The characterisation of enset clones based on the 12 characteristics is listed in Table 2.

The frequencies of the four colour traits as percentage of the number of clones in each region are presented in Table 3. In all three regions at least 97% of the clones had green leaves. There was a significant variation in frequencies of midrib, petiole and pseudostem colours between regions (Table 3). Green and red were the major midrib colours in Sidama or Hadiya, whereas red was the major one in Kaffa-Shaka. A high proportion of yellow midribs only occurred in Kaffa-Shaka. Petiole colour was more variable in Sidama than in Hadiya or Kaffa-Shaka. Green was the major pseudostem colour in all regions but other colours occurred frequently depending on regions. Brown, black or red spots or streaks on green surface of pseudostem were also common in all regions (data not shown).

Farmers also differentiate enset clones based on quality of the products: 'kocho', 'bulla', 'amicho' (corm-based product) and fibre. Enset clones that yield white paste dough of fermented pulp and 'bulla' were selected for 'kocho' or 'bulla' production. Clones that produce strong and long fibre were considered good for fibre production. Only specific clones that produce friable and sweet corms were selected for 'amicho' production. In the Sidama region, the proportions of clones with high quality 'kocho' and good 'bulla' were higher than in Hadiya or Kaffa-Shaka. In Sidama, more enset clones with high fibre quality were present than in Hadiya or Kaffa-Shaka.

In the Hadiya region, the proportion of enset clones grown for medicinal purposes was higher than in Sidama or Kaffa-Shaka (Table 4). Enset clones with red leaf colour were considered to be useful for medicinal purposes in all the three study areas. According to the farmers, corm or other parts of a particular enset type can serve as a medicine to cure cirrhosis or venereal diseases, to induce abortion, to mend fractured bone and to drive off placenta of livestock after giving birth.

Farmers also distinguish clones by the time they take to reach harvest stage (vigour) or to flower (maturity). In Sidama, the proportion of vigorous enset clones was higher than in Hadiya or Kaffa-Shaka. The proportion of early-maturing enset clones was higher in Kaffa-Shaka than in Sidama or Hadiya (Table 4). The proportion of bacterial wilt tolerant enset clones was higher in Sidama than in Hadiya or Kaffa-Shaka.

Correlation between characteristics

Spearman's rank correlation coefficients between all characteristics revealed interesting positive and negative relationships (Table 5). Scores for leaf colour were significantly correlated with scores for petiole colour, pseudostem colour and medical use, whereas they were negatively correlated with scores for 'bulla' quality. Scores for midrib colour

Table 2. List of enset clones with their local names, geographic sources, morphological characteristics, use value and other specific phenotypic characteristics. For the meaning of the scores see Table 1. P.stem = pseudostem.

			Morphological characteristics (colour)				Use value/quality products					Other characteristics		
Code	Local name	Geographic source	Leaf	Midrib	Petiole	P.stem	'Kocho' quality	'Bulla' quality	Corm use	Fibre quality	Medicinal use	Vigour	Maturity	Disease reaction
S1	Kule	Sidama	1	1	6	6	3	2	2	3	1	3	1	1
S2	Made	Sidama	1	2	4	2	3	2	1	3	1	3	3	3
S3	Birbo	Sidama	1	2	2	4	3	2	2	1	1	1	1	1
S4	Wubisho	Sidama	1	2	4	4	3	2	1	1	1	1	1	1
S5	Gena	Sidama	1	2	4	1	3	2	2	1	1	3	2	3
S6	Astara	Sidama	1	2	4	4	3	2	2	1	2	2	3	1
S7	Micho	Sidama	1	1	1	1	3	2	1	3	1	3	1	1
S8	Garbo	Sidama	1	2	4	4	3	2	2	2	1	2	1	1
S10	Shewite	Sidama	1	2	1	1	3	2	2	3	1	3	3	3
S11	Addo	Sidama	1	1	1	1	3	2	2	3	1	3	2	1
S12	Arisho	Sidama	1	2	5	5	1	1	1	1	1	1	3	3
S13	Ayedara	Sidama	1	1	1	1	3	2	2	3	1	3	1	3
S14	Derassa addo	Sidama	1	1	1	1	3	2	1	3	1	3	3	2
S15	Alaticho	Sidama	1	1	1	1	3	2	1	3	1	2	1	3
S16	Gulumo	Sidama	1	2	1	1	3	2	1	3	1	2	3	1
S17	Gamechela	Sidama	1	1	1	1	2	2	2	2	1	2	3	1
S18	Wamikore	Sidama	1	1	1	1	3	2	2	3	1	2	3	1
S19	Chacho	Sidama	1	1	2	1	3	2	1	2	2	2	3	1
S20	Bufare	Sidama	2	2	4	4	1	1	2	1	1	1	3	3
S21	Agena	Sidama	1	2	4	1	3	2	1	3	1	3	1	3
S22	Haho	Sidama	1	2	1	1	3	2	2	3	1	3	3	3
S23	Kincho	Sidama	1	1	1	1	2	2	1	2	1	1	3	2
S24	Kire	Sidama	1	1	1	1	3	2	1	3	1	2	1	1
S25	Awincho	Sidama	1	1	1	1	2	2	1	2	1	2	3	2
S26	Gedeme	Sidama	1	1	1	1	3	2	1	3	1	3	2	1
S27	Kiticho	Sidama	1	2	1	1	3	2	1	3	1	3	3	3
S28	Genticha	Sidama	1	2	1	1	3	2	1	3	1	3	3	1
S29	Gossalo	Sidama	1	1	1	1	3	2	2	3	1	2	2	1
S30	Nifo	Sidama	1	1	1	1	3	2	2	3	1	2	1	2
W1	Shalakumia	Wolaita	1	1	1	1	3	2	2	1	1	2	2	2
W2	Kucha	Wolaita	1	1	2	1	3	2	2	1	1	2	3	3
W3	Alagene	Wolaita	1	2	2	1	3	2	1	3	1	3	3	1
W4	Ankogene	Wolaita	1	1	1	1	3	2	1	3	1	3	3	3
W5	Halla	Wolaita	1	1	1	1	2	2	1	3	1	2	2	3

Table 2. Continued.

			Morphological characteristics (colour)				Use value/quality products					Other characteristics		
Code	Local name	Geographic source	Leaf	Midrib	Petiole	P.stem	'Kocho' quality	'Bulla' quality	Corm use	Fibre quality	Medicinal use	Vigour	Maturity	Disease reaction
W6	Chichia	Wolaita	1	1	1	1	3	2	2	1	1	1	1	1
H1	Separa	Hadiya	1	2	2	1	3	2	2	2	1	2	2	2
H3	Siskela	Hadiya	1	1	1	1	2	2	1	3	1	3	1	2
H4	Shetadena	Hadiya	1	1	1	1	2	2	1	1	1	2	3	1
H5	Astara	Hadiya	1	2	1	4	2	2	2	1	2	2	3	1
H6	Merza	Hadiya	1	2	4	4	3	2	1	3	1	3	2	3
H7	Gimbo	Hadiya	1	2	4	4	3	2	2	2	1	3	2	3
H8	Tebute	Hadiya	1	2	1	1	1	1	1	3	1	2	3	3
H9	Woshemja	Hadiya	1	1	1	1	2	2	1	2	1	1	1	1
H10	Zobra	Hadiya	1	2	4	1	3	2	2	2	1	2	3	2
H11	Agade	Hadiya	1	2	4	4	3	2	2	2	2	2	3	2
H12	Haywona	Hadiya	1	2	1	1	2	2	2	2	2	2	3	1
H14	Tegaded	Hadiya	1	2	1	1	3	2	2	2	2	3	2	3
H15	Necho	Hadiya	1	1	1	1	2	1	2	1	2	1	3	2
H16	Benja	Hadiya	1	1	1	1	2	2	1	3	1	1	1	2
H17	Hiniba	Hadiya	1	2	2	1	2	2	1	1	1	1	1	1
H18	Landwesssa	Hadiya	1	2	1	1	1	1	1	3	1	3	3	3
H19	Mesmescho	Hadiya	1	1	1	1	3	2	2	2	1	2	1	3
H20	Eshamessa	Hadiya	1	1	1	1	3	2	2	2	1	3	3	3
H21	Dirbo	Hadiya	1	2	2	4	3	2	1	3	1	3	3	3
H22	Sokido	Hadiya	1	1	4	4	1	1	1	1	1	1	3	1
H23	Shewira	Hadiya	1	1	1	1	2	2	2	1	1	2	3	1
H24	Bedadessa	Hadiya	1	1	1	1	3	2	1	3	1	2	3	1
H25	Gishira	Hadiya	1	1	1	1	3	2	1	2	2	2	2	2
H26	Gariye	Hadiya	1	1	1	1	2	2	2	1	2	2	3	1
H27	Manduluka	Hadiya	1	2	1	4	3	2	1	2	1	3	3	1
H28	Disho	Hadiya	1	1	4	4	2	2	1	3	1	2	1	2
H29	Moche	Hadiya	1	1	1	1	2	1	1	2	1	3	3	1
H30	Oreda	Hadiya	1	1	1	1	1	1	2	1	2	1	3	1
H31	Teigo	Hadiya	1	1	1	5	1	1	2	1	2	1	3	1
H32	Oniya	Hadiya	1	1	1	1	2	2	1	2	1	2	3	1
H33	Kombotra	Hadiya	1	2	4	4	1	2	2	1	2	2	3	1
H35	Kekelessa	Hadiya	2	2	4	4	1	1	1	1	2	1	3	3
H36	Woshemeja	Hadiya	1	2	2	2	3	2	1	3	1	1	1	1
H37	Torora	Hadiya	1	1	2	1	2	2	2	1	1	2	2	1
H38	Hanzena	Hadiya	1	1	1	1	2	2	1	1	1	2	3	1

Table 2. Continued.

			Morphological characteristics (colour)				Use value/quality products					Other characteristics		
Code	Local name	Geographic source	Leaf	Midrib	Petiole	P.stem	'Kocho' quality	'Bulla' quality	Corm use	Fibre quality	Medicinal use	Vigour	Maturity	Disease reaction
H39	Unjama	Hadiya	1	2	4	4	2	2	1	3	1	3	3	3
H40	Kaseta	Hadiya	1	2	1	1	2	2	1	1	1	1	1	1
H41	Mariye	Hadiya	1	2	2	2	1	2	1	2	1	3	3	3
H42	Gozoda	Hadiya	1	2	2	4	1	2	2	1	1	2	2	1
H43	Uskuruz	Hadiya	1	2	2	4	1	1	1	1	1	1	3	1
H44	Kinwar	Hadiya	1	0	1	1	1	1	2	1	2	1	3	1
H45	Bekucho	Hadiya	1	1	2	4	1	1	1	3	1	1	3	3
D2	Chele Bocho	Kaffa-Shaka	1	2	1	4	2	1	1	2	1	2	2	2
D3	Shoto	Kaffa-Shaka	1	2	2	2	2	2	1	2	1	2	2	1
D4	Achecho	Kaffa-Shaka	1	2	1	2	1	2	2	1	1	1	1	1
D5	Kekero	Kaffa-Shaka	1	2	1	1	1	1	2	1	1	1	1	1
D6	Bajo	Kaffa-Shaka	1	0	1	1	3	2	1	2	1	3	3	2
D7	Kochitato	Kaffa-Shaka	1	2	2	2	3	2	1	3	1	3	3	1
D8	Korimo	Kaffa-Shaka	1	2	1	2	1	2	2	1	1	1	1	1
D9	Utro	Kaffa-Shaka	1	1	1	1	1	1	2	1	1	2	2	1
D10	Agene	Kaffa-Shaka	1	2	3	3	1	2	2	1	1	1	1	1
D11	Tarelo	Kaffa-Shaka	3	1	1	1	2	2	2	3	1	2	2	1
D12	Woiro	Kaffa-Shaka	1	0	1	1	2	2	2	3	1	1	1	1
D13	Chamero	Kaffa-Shaka	1	3	1	1	2	2	2	2	1	2	2	1
D14	Tayo	Kaffa-Shaka	1	2	1	2	2	2	2	2	2	2	2	1
D15	Shetako	Kaffa-Shaka	1	1	1	1	2	1	1	2	1	3	3	1
D16	Wango	Kaffa-Shaka	1	2	1	2	2	2	2	2	1	2	2	1
D17	Kalo	Kaffa-Shaka	1	3	4	4	1	2	2	1	1	1	1	1
D18	Chongo	Kaffa-Shaka	1	3	4	4	1	2	1	2	1	1	1	2
D19	Choro	Kaffa-Shaka	2	2	2	2	2	2	1	2	1	2	2	1
D20	Utino	Kaffa-Shaka	1	1	1	1	2	2	2	2	2	2	2	1
D21	Bongo	Kaffa-Shaka	1	3	2	4	1	2	2	1	1	1	1	1
D22	Geno	Kaffa-Shaka	1	2	1	1	2	2	1	2	1	2	2	1
D23	Gayo	Kaffa-Shaka	1	2	2	2	2	2	2	3	1	2	2	2
D24	Epecho	Kaffa-Shaka	1	2	1	1	1	2	1	3	1	2	2	2
D25	Yahi bajo	Kaffa-Shaka	1	0	1	1	3	2	1	2	1	3	3	2
D26	Madi	Kaffa-Shaka	1	2	3	3	1	2	2	1	1	1	1	1
D27	Shuri	Kaffa-Shaka	1	2	2	3	1	2	2	1	1	1	1	1
D28	Nech Yesh	Kaffa-Shaka	1	0	3	3	2	2	2	2	1	2	2	1
D29	Ginkayo	Kaffa-Shaka	1	2	2	4	3	2	2	3	1	3	3	1
D30	Katino	Kaffa-Shaka	1	2	2	2	2	2	2	2	1	2	2	1

Table 2. Continued.

			Morphological characteristics (colour)				Use value/quality products					Other characteristics		
Code	Local name	Geographic source	Leaf	Midrib	Petiole	P.stem	'Kocho' quality	'Bulla' quality	Corm use	Fibre quality	Medicinal use	Vigour	Maturity	Disease reaction
C1	Neche nodo	Kaffa-Shaka	1	0	1	1	2	2	1	3	1	3	3	3
C2	Gesh ariko	Kaffa-Shaka	1	1	1	1	2	2	2	1	1	2	2	1
C3	Anami nobo	Kaffa-Shaka	1	0	1	1	3	2	1	3	1	3	3	3
C4	Kopri	Kaffa-Shaka	1	2	2	3	1	2	1	1	1	1	1	1
C5	Machi nobo	Kaffa-Shaka	1	0	1	1	3	1	1	3	1	3	3	3
C6	Waji beli	Kaffa-Shaka	1	2	2	2	1	1	2	1	1	1	1	1
C7	Chele ariko	Kaffa-Shaka	1	2	1	1	2	1	2	1	2	2	2	1
C8	Kapiccho	Kaffa-Shaka	1	2	1	1	1	1	2	1	1	1	1	1
C9	Eche ariko	Kaffa-Shaka	1	1	1	1	2	1	2	1	1	2	3	1
C10	Mocho	Kaffa-Shaka	1	1	1	1	1	1	1	1	1	1	1	1
C13	Ketano	Kaffa-Shaka	1	2	2	2	2	2	2	2	1	2	2	1
C14	Aei nobo	Kaffa-Shaka	1	0	1	1	3	2	1	3	1	3	2	3
C15	Bedado	Kaffa-Shaka	1	2	2	4	3	2	1	2	1	3	2	2
C16	Chekero	Kaffa-Shaka	1	2	1	4	2	2	2	2	1	2	2	2
C17	Garamanji	Kaffa-Shaka	1	3	2	4	2	2	2	1	1	2	1	1
C18	Tuti ariko	Kaffa-Shaka	1	2	1	1	2	2	2	1	1	2	1	1
C19	Bensano	Kaffa-Shaka	1	0	1	2	2	2	1	2	1	2	2	1
C20	Omichi	Kaffa-Shaka	1	2	1	4	1	2	2	1	1	2	2	1
C21	Gebe nobo	Kaffa-Shaka	1	0	1	1	3	2	1	3	1	3	3	3
C22	Deki	Kaffa-Shaka	1	0	1	1	2	2	2	1	1	2	1	1
C23	Chele nobo	Kaffa-Shaka	1	0	1	1	2	2	1	3	1	3	2	3
C24	Shelako	Kaffa-Shaka	1	0	1	1	2	1	1	3	1	2	2	3
C25	Offichi	Kaffa-Shaka	1	2	2	4	1	2	2	1	1	1	1	1
C26	Bakamo	Kaffa-Shaka	1	2	1	1	2	2	2	1	1	2	1	1
C27	Mavha dame	Kaffa-Shaka	1	1	1	1	1	2	2	1	1	1	1	1
C28	Gosheno	Kaffa-Shaka	1	2	1	4	2	2	2	2	1	2	1	1
C29	Shimo	Kaffa-Shaka	1	3	1	1	1	2	1	1	1	1	1	1
C30	Kebo	Kaffa-Shaka	1	2	2	2	2	2	2	1	1	2	1	1
C31	Bumbo	Kaffa-Shaka	1	0	1	1	2	2	2	2	1	2	1	1
C32	Omo	Kaffa-Shaka	1	2	2	2	1	2	1	2	1	2	2	1
C33	Hichewi	Kaffa-Shaka	1	0	1	1	1	2	2	1	1	2	1	1
C34	Gabati	Kaffa-Shaka	1	1	1	1	1	2	2	1	1	1	2	1
C35	Akibero	Kaffa-Shaka	2	2	2	4	2	2	1	1	1	2	1	1
C36	Kechichi	Kaffa-Shaka	1	2	1	1	2	2	2	1	1	2	2	1
C37	Adelibocho	Kaffa-Shaka	1	0	1	4	3	1	1	2	1	3	3	2
C38	Ganjibocho	Kaffa-Shaka	1	2	1	4	2	1	1	2	1	2	3	2

Table 3. Frequencies (%) of leaf, midrib, petiole and pseudostem colours as percentage of the number of clones in the three enset-growing regions.

Plant part	Colour	Region		
		Sidama (n=35)	Hadiya (n=42)	Kaffa-Shaka (n=65)
Leaf	Green	97	98	97
	Red	3	2	3
		$\chi^2 = 0.05$ ns		
Midrib	Yellow	0	2	25
	Green	57	48	14
	Red	43	50	52
	Brown	0	0	9
		$\chi^2 = 39.0^{***}$		
Petiole	Green	63	57	66
	Red	11	22	26
	Purple	0	21	5
	Brown	20	0	3
	Pink	3	0	0
	Black	3	0	0
		$\chi^2 = 35.3^{***}$		
Pseudostem	Green	77	60	49
	Red	3	5	21
	Purple	0	33	8
	Brown	14	0	22
	Pink	3	2	0
	Black	3	0	0
		$\chi^2 = 44.6^{***}$		

*** Indicates significant at $P < 0.001$.

ns Non-significant.

were positively correlated with scores for petiole and pseudostem colour. Scores for petiole colour were highly correlated with scores for pseudostem colour.

Scores for 'kocho' quality were positively correlated with scores for 'bulla' and fibre quality, vigour, maturity and disease reaction, whereas they were negatively correlated with those for corm use and medicinal use (Table 5). Scores for vigour were significantly, positively correlated with scores for 'kocho' quality, fibre quality and disease reaction. Scores for fibre quality were significantly correlated with those for 'kocho' yield and disease reaction, whereas they were negatively correlated with scores for corm and medicinal use. These findings are in agreement with farmers' claims. During the household survey farmers mentioned that vigorous clones produce quality 'kocho',

Table 4. Frequency (%) of enset clones in the three enset-growing regions based upon the use value and some specific characteristics.

	Region				
Characteristics	Sidama (n=35)	Hadiya (n=42)	Kaffa-Shaka (n=65)	Mean	χ^2
'Kocho' quality					
Low	6	29	34	23	45.5***
Medium	11	40	51	34	
High	83	31	15	43	
'Bulla' quality					
Not good	6	26	12	15	6.9*
Good	94	74	88	85	
Corm					
Not used	51	57	40	49	3.2 ns
Used	49	43	60	51	
Fibre quality					
Low	23	40	45	36	11.4*
Medium	26	34	35	32	
High	51	26	20	32	
Medicinal use					
Not used	94	71	95	87	15.6***
Used	6	29	5	13	
Vigour					
Poor	17	31	27	25	6.0 ns
Medium	40	43	51	45	
High	43	26	22	30	
Maturity					
Early	31	26	60	39	34.2***
Medium	20	17	32	23	
Late	49	57	8	38	
Disease reaction					
Susceptible	49	52	74	58	11.4*
Moderately tolerant	14	19	15	16	
Tolerant	37	29	11	26	

* Indicates significant at $P < 0.05$.

*** Indicates significant at $P < 0.001$.

ns Non-significant.

'bulla' and fibre, whereas clones with sweet edible corm produce less quality fibre. They also reported that clones that produce quality fibre are relatively tolerant to the bacterial wilt disease.

Table 5. Spearman's rank correlation coefficients (r) among different characteristics (n=142).

Characters		Lc	Mc	Pc	Ps.c	K	B	C	F	Md	V	M
Lc	(Leaf colour)	-	-									
Mc	(Midrib colour)	0.14	-									
Pc	(Petiole colour)	0.22**	0.46**	-								
Ps.c	(Pseudostem colour)	0.21**	0.48**	0.66**	-							
K	('Kocho' quality)	−0.14	−0.19**	−0.05	−0.22*							
B	('Bulla' quality)	−0.17*	0.11	0.05	−0.13	0.33**						
C	(Corm use)	−0.09	0.12	0.01	0.05	−0.13	0.16*					
F	(Fibre quality)	−0.14*	−0.22**	−0.13	−0.19*	0.53**	0.11	−0.41**				
Md	(Medicinal use)	0.19**	0.04	0.05	0.09	−0.08	−0.15*	0.18*	−0.22**			
V	(Vigour)	−0.12	−0.19*	−0.13	−0.19*	0.62**	0.17*	−0.22**	0.59**	−0.16*		
M	(Maturity)	0.02	−0.09	−0.07	−0.44**	0.23**	−0.25**	−0.23**	0.16*	0.22*	0.38**	
D	(Disease reaction)	0.07	−0.11	0.06	−0.07	0.29**	−0.17*	−0.31**	0.46**	−0.08	0.41**	0.32**

* Indicates significant at $P < 0.05$.

** Indicates significant at $P < 0.01$.

Table 6. Principal component co-ordinate scores, eigenvalues, total variance, and cumulative variance for the first four principal components for all characteristics.

Characteristics	PC1	PC2	PC3	PC4
Leaf colour	−0.13	0.32	−0.16	0.01
Midrib colour	−0.26	0.22	0.37	−0.03
Petiole colour	−0.16	0.49	0.36	−0.00
Pseudostem colour	−0.25	0.46	0.25	0.05
'Kocho' quality	0.41	0.01	0.27	−0.32
'Bulla' quality	0.08	−0.28	0.57	−0.22
Corm use	−0.26	−0.23	0.16	−0.46
Fibre quality	0.46	0.09	0.12	0.15
Medicinal use	−0.15	0.14	−0.29	−0.65
Vigour	0.46	0.11	0.14	−0.19
Maturity	0.22	0.31	−0.31	−0.38
Disease reaction	0.32	0.34	−0.07	0.17
Eigenvalues	3.08	1.98	1.57	1.17
% of total variance	25.67	16.47	13.04	9.78
% cumulative variance	25.67	42.14	55.18	64.96

Principal component analysis

The first four principal components, with eigenvalues greater than unity, together explained 65% of the total variation among the 142 enset clones for the 12 phenotypical characteristics studied (Table 6). The first two principal components accounted for 42% of the total variation. An examination of characteristics with the highest factor loading showed that vigour, fibre yield and 'kocho' yield (all use value or agronomic characteristics) were the most important characteristics contributing to the first principal component. In the second principal component, pseudostem colour, petiole colour and leaf colour significantly contributed. Characteristics that appeared important to the third and fourth components were medicinal use and 'bulla' yield, respectively. In case of AFLP analysis the first four principal components explained 50.4% of the total variation among the 142 enset clones. The first two components accounted for 31% of the total variation.

Comparison of farmers' characterisation methods and AFLP

Dendrograms constructed using farmers' characterisation and AFLP methods are given in Figs. 1 and 2, respectively. In the dendrogram, based on farmers' characterisation within 142 clones 11 duplication groups consisting of 23 enset clones were identified,

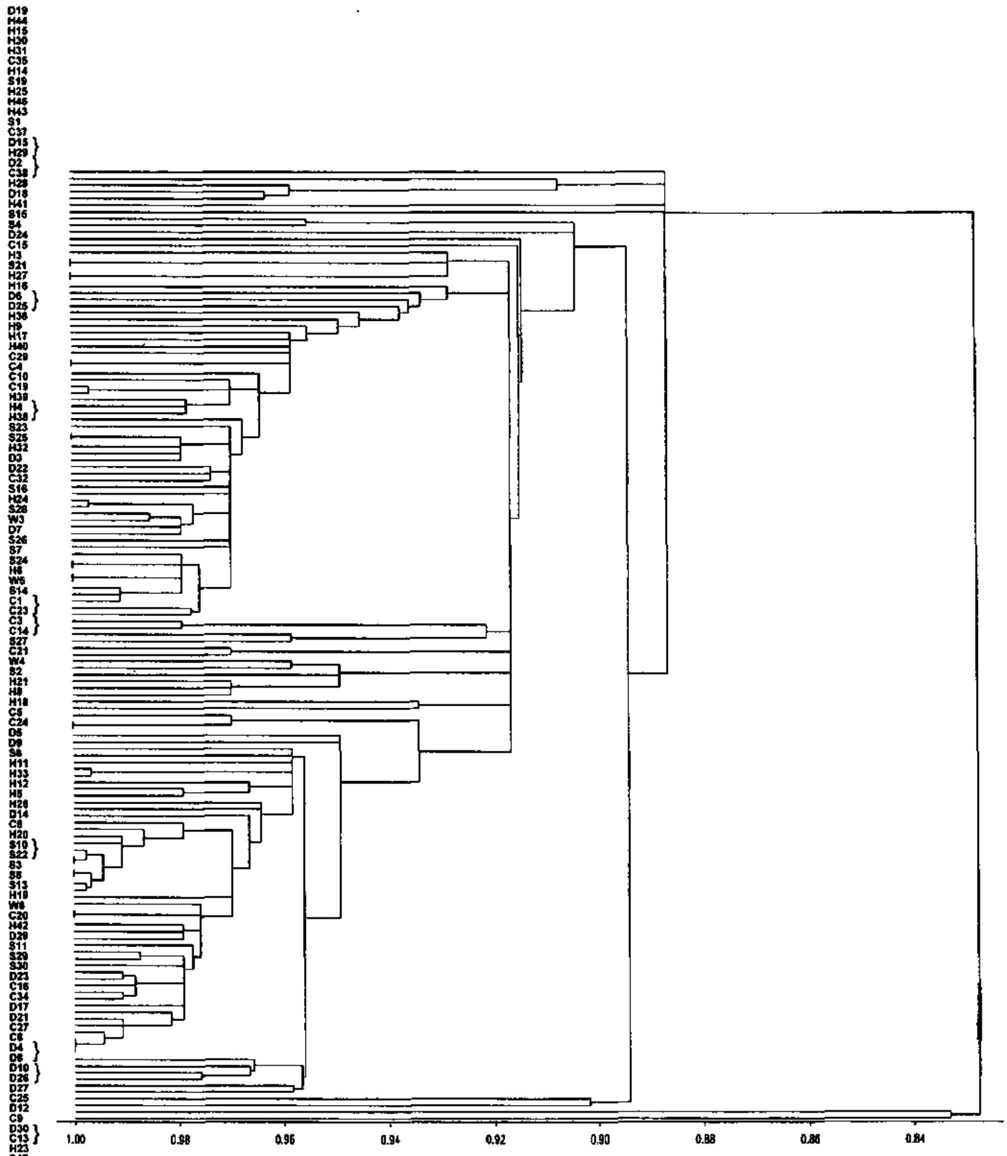

Fig. 1. UPGMA dendrogram of the 142 enset clones based upon 12 common characteristics frequently used by farmers for distinguishing enset clones. Clones are denoted by symbols, representing their different regions (S, Sidama; H, Hadiya; W, Wolaita; C, Chena and D, Decha districts in Kaffa-Shaka). The different lines reflect the results of the clones in the same order. Genetically similar are represented by a single line and if they are combined it is shown in the list by an accolade.

Fig. 2. UPGMA dendrogram of 142 enset clones based upon AFLP analysis with four primer combinations. Clones are denoted by symbols, representing their different regions (S, Sidama; H, Hadiya; W, Wolaita; C, Chena and D, Decha districts in Kaffa-Shaka). The different lines reflect the results of the clones in the same order. Genetically similar are represented by a single line and if they are combined it is shown in the list by an accolade.

meaning a redundancy of 12 enset clones or 8% of the total collection. In the AFLP based dendrogram, within the same 142 clones, 20 duplication groups consisting of 55 clones were identified, meaning a redundancy of 35 clones or 25% of the total collection. The following clones were clustered together in both dendrogrames: 'Chele ariko' and 'Tutu ariko'; 'Anami nobo' and 'Aei nobo'; 'Chele nobo' and 'Neche nobo'; 'Katino' and 'Ketano'; 'Bajo' and 'Yahi banjo'; 'Chele bocho' and 'Ganji bocho'.

A correlation test was performed on the farmers' characterisation and AFLP based genetic similarity values. The correlation coefficient was extremely low when all farmers' characterisation methods were included. A better correlation ($r = 0.05$) with P-value = 0.06 was observed when only the colour of plant parts was considered. Use values and other specific phenotypic characteristics of enset clones were negatively correlated to the AFLP-based genetic similarity values.

When ethnic regions were considered separately, farmers' characterisation based genetic similarity values of the Hadiya region in particular were negatively correlated ($r = -0.11$) with AFLP-based genetic similarity values. Correlations were positive and better but still weak ($r = 0.09$ with P-value = 0.04, $r = 0.07$ with P-value = 0.09) for Sidama and Keffa-Shaka regions, respectively.

Discussion and conclusion

Frequencies of leaf colours were fairly constant among regions and the major colour was green (Table 3). This result is in agreement with leaf colour evaluation of enset by Endale (1997). Although the colouration patterns of petiole and pseudostem were diversified, basically they showed more or less similar colours (Table 3). Only the most diverse traits would suffice for germplasm record.

Endale (1997) coded 19, 9 and 17 different colour types of pseudostem, midrib and petiole, respectively. It is very difficult to distinguish small differences consistently such as those between dark green or light green or between green with black strip or green with black dots, because such colour differences might also be affected by environmental factors. Thus, we limited the coding of pseudostem, petiole and midrib colours in our study to two, six and four scores, respectively.

The wide variation between regions in agronomic characteristics and use of enset for various purposes was manifested by the high chi-square values (Table 4). A high proportion of enset clones was grown for their high quality 'kocho' or 'bulla' in the Sidama region, whereas farmers in Kaffa-Shaka grew a high proportion of enset clones for corm production. This is related to the difference in food culture, socio-cultural preferences for different enset products and farming systems of the regions. According to Westphal (1975), Brandt *et al.* (1997) and observations of the authors enset is the staple food and main crop in Sidama, it is a co-staple with cereals in Hadiya and root crops are of primary importance in Kaffa-Shaka regions. As a result, the Sidama farmers select for high quality 'kocho' and 'bulla' yield, whereas the Kaffa-Shaka farmers give priority to corm use. The high proportion of enset clones for medicinal purposes in Hadiya region compared to Sidama and Kaffa-Shaka is probably related to unavailability of modern medicines in the area because of its inaccessibility. The high proportion of bacterial wilt tolerant clones in Sidama might not be a result of the genetic make up of the clones but due to less infestation of the disease probably because of environmental factors. The Sidama study area is located in the upland where the temperature is very low and unfavourable for bacterial wilt infestation compared to Hadiya and Kaffa-Shaka.

Farmers' characterisation of enset clones based on use value and agronomic traits is expected to be somewhat ambiguous because it is based in part on subjective descriptions. This method of characterisation, however, is interesting because the skills with which farmers recognise, select, and manage a given amount of diversity may have important implications for evaluation, conservation and utilisation of the genetic diversity.

Comparison of the results of cluster analysis based on AFLP and farmers' characterisation revealed that AFLP has a distinct advantage in diversity analysis in enset. The AFLP based dendrogram showed a higher percentage of redundancy with more duplication groups, whereas the farmers' characterisation method showed a low percentage of redundancy with few duplication groups. The total variation accounted for by the two principal components was higher for farmers' based characterisation compared to AFLP analysis. These results indicate that the diversity of enset clones recognised by farmers tends to overestimate the genetic variability. This result is contrary to the general farmers' behaviour of underestimating the actual diversity of potato reported by Quiros *et al.* (1990) in Peru and of cassava reported by Sambatti *et al.* (2001) in Brazil. The wide variation represented by the farmers could be partly because of the subjective description of farmers in different regions, but it might also indicate the wide range of skill and knowledge among enset farmers.

The most common cause of duplication in enset-growing regions is calling the same genotype by more than one name rather than calling different genotypes by the same name because of exchange of planting materials and differences in language among several ethnic groups. Most clones with a different suffix or prefix were found to be genetically similar. Farmers in upland or lowland areas but speaking the same language also call the same genotype by more than one name. As the low temperature and high precipitation in the uplands is favourable for the enset, more enset cultivation can be found in the uplands. Suckers for planting are mostly propagated in the uplands and carried for sale into the lowlands. Most of the time suckers from the upland might get new names when they are planted in the lowland. For example, AFLP analysis revealed that in the Hadiya region, the clones 'Beneja', 'Zobra', 'Orade', 'Dirbo', 'Onia', 'Mariye' collected in the lowlands are known by the names 'Kombotra', 'Woshemeja', 'Manduluka', 'Badadeda' or 'Hayiona', 'Torora' and 'Agade', in the uplands, respectively. This result would be a useful guideline to sample enset clones for further genetic analysis and/or conservation.

The AFLP and farmers' characterisation derived dendrograms appear very different from each other (Figs. 1 and 2). The similarities are absence of clear regional clusters and the clustering of some of the clones with various prefixes to a single name. This result shows that there is some degree of correspondence between AFLP and farmers' based characterisation. Lack of strong regional differentiation observed by both clusters indicates that the diversity is rather evenly distributed over the regions probably due to clone flow between regions. It is a common phenomenon for farmers to exchange their clones between different households, communities and regions to get clones for varying biophysical and socio-economic conditions. Since one clone can never fulfil all the needs of a household, in most cases, a household maintains 9–14 different types of enset clones in its own field (Tsegaye and Struik, 2001a; Chapter 2).

The low but positive correlation coefficient between AFLP and farmers' method of characterisation is due to the subjective description of traits by farmers in different enset-growing regions. A better but still weak correlation coefficient between colour of plant parts and AFLP data indicates that farmers can better discriminate clones by referring to the colour of plant parts than use value or other specific characteristics. Boster (1985) and Sambatti *et al.* (2001) also reported the use of colour of plant parts by farmers to properly discriminate between cassava cultivars. They also mentioned that utilising colour of plant parts to identify different clones is especially important for crops whose economically important organ is hidden from daily view, as it is also the case for enset.

The better correlation coefficient between AFLP and farmers' characterisation method in Sidama and Kaffa-Shaka compared to Hadyia might indicate that there is variability among regions in farmers' skills to recognise genetic differences. In this respect the Sidama farmers seem to have a good skill and knowledge in discriminating between enset clones. The AFLP analysis resulted only in two duplication groups from the Sidama collections compared to 7 and 11 duplication groups from Hadiya and Kaffa-Shaka collections, respectively. Because Sidama farmers completely depend on enset as their staple food, they might have acquired a wide range of skills and knowledge to accurately characterise enset clones. In regions where enset is used as a supplementary food crop or of minor importance, farmers may have more difficulties in identifying clones. The regions at which enset is being used as a staple food and where peoples' culture is highly associated with the crop need to be given due attention when developing effective collection, evaluation and conservation strategies.

The use of AFLP for enset characterisation has some advantages over farmers' characterisation methods. The AFLP marker technique is preferred for its efficiency to detect genetic differences among clones of the same species (Cervera *et al.*, 1998), and its overall utility for detecting genetic variation (Powell *et al.*, 1996; Milbourne *et al.*, 1997) and its reproducibility (Jones *et al.*, 1997). It is clear that farmers' classification is highly qualitative and it is based on farmers' subjective description. The characteristics are also limited in number and the environment influences phenotypic traits.

Very few studies have been carried out to study the relationship between farmers' characterisation and molecular markers or isozymes. The use of isozyme electrophoresis as a classification tool indicated that farmers identification corresponds with a high degree of accuracy to the actual biological diversity of Andean potato fields (Quiros *et al.*, 1990). Ayele *et al.* (1999) and Messele (2001) reported a low correlation on dendrograms from AFLP and morphological qualitative data. Bertuso (1999) also reported a weak but positive correlation between AFLP and farmers' characterisation. We did not expect a very high correlation between AFLP and farmers based method of characterisation. The comparison, however, showed that some aspects of farmers' characterisation methods correspond well to the actual genetic diversity of the enset clones (Figs. 1 and 2). It also enabled us to understand how farmers value, manages, use and conserve genetic diversity. Farmers are always interested in clones with contrasting traits that fit different needs and constraints, rather than a single plant with particular traits such as high yield (Table 1; Tsegaye and Struik, 2000a). A research agenda, which is geared only towards developing and/or selecting only yielding cultivars, would never be accepted, as farmers do not look only for one or two criteria when selecting clones. This finding would be a useful tool to design programmes for conservation and utilisation of genetic diversity.

There are no standardised phenotypic descriptors for the enset plant. We suggest to include leaf colour, pseudostem colour, midrib colour, fibre quality, maturity period, corm use and medicinal use when developing the list. Further studies on genetic diversity of enset for evaluation are needed, using agronomic and physiological quantitative characteristics.

CHAPTER 5

Growth, radiation use efficiency and yield potential of enset (*Ensete ventricosum* (Welw.) Cheesman) at different sites in southern Ethiopia

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CHAPTER 5

Growth, radiation use efficiency and yield potential of enset (*Ensete ventricosum* (Welw.) Cheesman) at different sites in southern Ethiopia

Abstract
Knowledge on the physiological parameters that determine the growth of enset (*Ensete ventricosum* (Welw.) Cheesman) and on how these parameters develop over time and affect yield under field conditions is scarce. Field experiments were carried out at three sites in southern Ethiopia, using suckers of several clones, to generate crop physiological parameters and to describe the time course of leaf number, leaf area and plant height. Yield potentials at different sites were estimated using these parameters and weather data, and compared with the actual yield.

Plant height and LAI increased faster at Awassa and Areka than at Hagereselam because of a higher leaf appearance rate associated with temperatures being closer to the optimum. The trend in plant height was best described by a logistic function, whereas the trend in LAI was best described by a logistic function only at Awassa and Areka. A high leaf appearance rate (0.18 leaves d^{-1}) during early growth at Awassa and Areka made it possible that leaves that were senesced during unfavourable climatic conditions could be rapidly replaced without strong fluctuation in leaf area index. At Hagereselam, however, the rate of leaf appearance (0.09 leaves d^{-1}) was too small to compensate for the decline in the number of green leaves per plant during adverse conditions and thus LAI fluctuated over the whole growing period.

The trend in fraction of intercepted PAR was best described by a generalised logistic function. At 300 days after transplanting, LAI reached a value of 4.5 and enset clones intercepted 92–97% of incoming PAR. The mean extinction coefficient was between 0.56–0.91 and radiation use efficiency (RUE) ranged from 1.43–2.67 g MJ^{-1}, respectively. Dry matter 'kocho' yield potentials of 17.1 to 33.8 t ha^{-1} y^{-1} were estimated for enset clones. Important yield potential differences existed between clones mainly due to differences in radiation use efficiency probably associated with viral infection. The average ratio actual yield : yield potential (0.24) was low mainly because of large losses associated with traditional fermentation techniques, yield-reducing cultivation methods such as repetitive transplanting and leaf pruning, presence of diseases, lack of adequate fertilisation and shortage and uneven distribution of rainfall.

Keywords: Enset, plant height, leaf appearance rate, leaf area index, light use efficiency, yield potential

Introduction

Ensete ventricosum (Welw.) Cheesman is a herbaceous monocarpic plant, which belongs to the family Musaceae. The crop is grown to produce a starchy food from its vigorous pseudostem, corm and stalk of inflorescence. The mixture of scraped pseudostem pulp, the pulverised corm and stalk of the inflorescence is put in a pit for fermentation and the resulting product is locally called 'kocho'. It is the most important staple food for 7–10 million people in the south and southwestern parts of Ethiopia. The crop is grown at altitudes from 1500–3100 m asl, but scattered plants can also be found at lower altitudes. For optimum growth the crop requires an average rainfall of 1100–1500 mm per year and average monthly temperature of 16–20 °C.

Several environmental (biotic and abiotic) and management factors potentially affect the productivity of a crop. In order to find out which factors limit and reduce yield and to understand how they operate in a given environment, it is vital to know the yield potential situation of the crop. The yield potential of a crop has been defined as the yield of a crop when grown in environments to which it is adapted, with water, plant nutrients or crop management not limiting, and when no growth-reducing factors such as diseases, pests and weeds are present (Evans and Fischer, 1999). The yield potential of enset, however, has not yet been assessed.

In the absence of adverse environmental conditions, which could limit or reduce crop growth, a potential production is reached as determined entirely by the amount of available light, prevailing temperature and crop characteristics (Goudriaan, 1982; Lövenstein *et al.*, 1992). The efficiency of conversion of radiation to dry matter (g MJ^{-1} PAR) can be estimated from the linear relationship between accumulated total dry weight and accumulated intercepted radiation (Monteith, 1977a; Spitters, 1987). Monteith also pointed out that the relationship between intercepted radiation and accumulated dry matter was similar for a number of crops as different as cereals and apples. Dry matter distribution is strongly related to crop development as different crop organs are formed during the subsequent development stages in a crop's life cycle. The rate of development increases more or less linearly with a rise in temperature above a base temperature until an optimum temperature. As temperature rises further above the optimum, rate declines, again more or less linearly, until a maximum (or ceiling) temperature is reached (Monteith, 1977b; Hay and Walker, 1989; Squire, 1990).

Thermal duration has been a useful concept in linking plant performance to changes in temperature and is as appropriate to tropical crops as it is to temperate ones (Squire, 1990). It has the advantage that once a relationship between thermal duration and development is established it can often be used in new environments with good success.

Yield data on enset are very scarce. There is also a lack of knowledge on the physiological parameters of enset that determine the growth of the crop and how these parameters develop and affect growth under field conditions in which environmental factors are very variable. As a result, it has been impossible to assess the yield potential and thus the effect of diseases, weeds, insects, agro-ecological zones and various cultural practices on performance and yield of the enset crop. Van der Zaag (1984) pointed out that yield potential estimates can be used: (1) to provide information on factors limiting yield, (2) to assess local technical level of production, and (3) as a starting point in preparing a programme of crop improvement. Therefore, in this chapter, the time course of leaf appearance, leaf area index and plant height of enset clones at different sites were assessed together with the development of yield parameters over time. The yield potential of enset clones at different sites were estimated using plant characteristics and weather data, and compared with the actual yields based on processing of literature data.

Material and methods

Experimental sites and design

Field experiments were carried out in 1997–2000 at three sites with different elevations (see Table 1 and Fig. 1 for details on experimental sites). At each site two well-known clones were planted separately in a 90 m^2 area at a spacing of 2.0 m × 1.5 m in two replications. At Awassa and Hagereselam, 'Halla' and 'Addo' clones were used, whereas at Areka, 'Halla' and 'Nekakia' were planted. Eight plants from each cultivar at each site were tagged in order to take measurements at monthly intervals.

Crop management

Suckers for planting were produced from immature enset corms of about 2-years-old. For this, the plants were cut 10 cm above the junction between the pseudostem and the corm; the upper central part of the corms were removed. The corms were planted 1 m apart under 10–20 cm of soil mixed with cow manure on 15 January 1996. In May 1997, suckers were separated from the mother corm and transplanted. Nitrogen and phosphorous were applied at a total rate of 100 kg ha^{-1} y^{-1} in two split applications at a six month interval. Potassium was applied at a rate of 200 kg ha^{-1} y^{-1} in one application only. Crop husbandry measures such as cultivation and weeding were carried out continuously to keep the field free from weeds.

Table 1. Site and soil characteristics (0 to 30 cm soil depth) of the experimental sites.

Sites/locations	Texture (%)			pH	Organic	Total	CEC
	Sand	Silt	Clay	H_2O	Carbon (%)	Nitrogen (%)	meq/100 g
Awassa (1650 m asl) Sidama (7°04′ N, 38°31′ E)	54	27	19	6.31	1.58	0.16	10.99
Areka (1750 m asl) Wolaita (7°09′ N, 37°47′ E)	30	46	24	5.22	3.39	0.24	29.65
Hagereselam (2600 m asl) Sidama (6°03′ N, 38°31′ E)	35	40	25	5.36	3.07	0.36	12.13

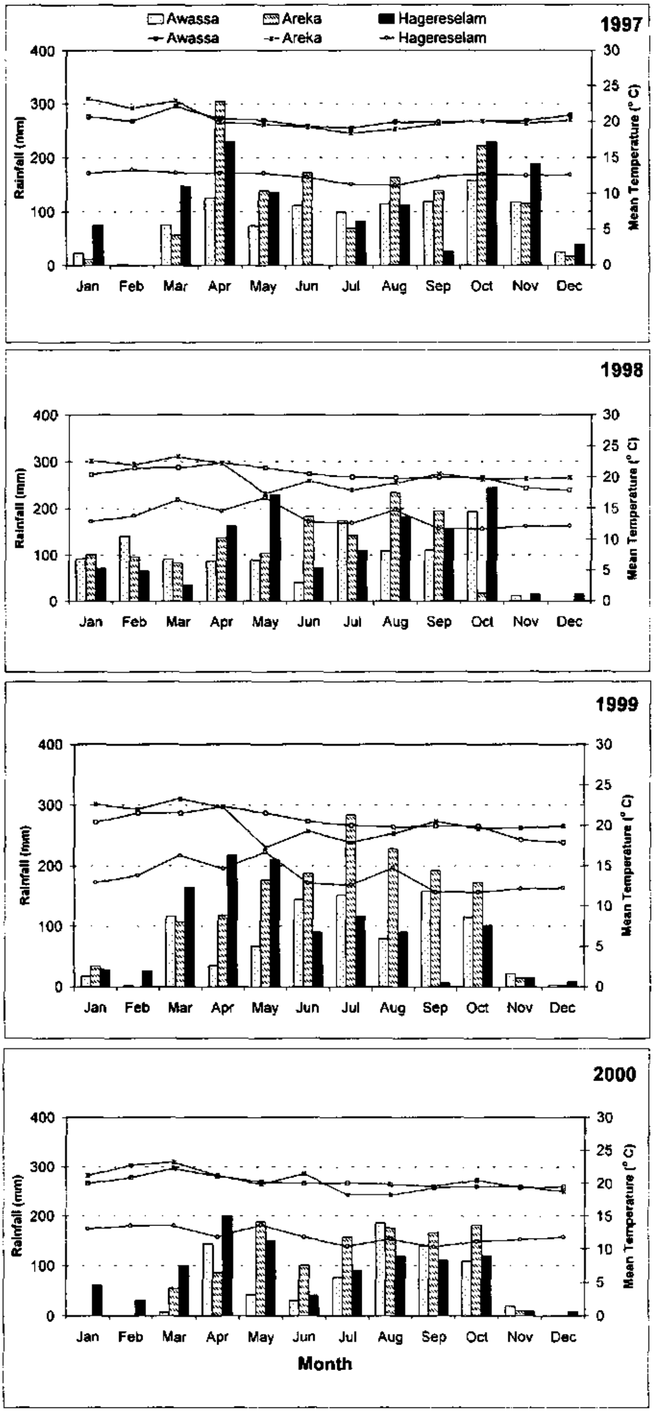

Fig. 1. Mean temperature and precipitation in Awassa, Areka and Hagereselam sites during the time of the experiment.

Measurements

Leaf Appearance Rate (LAR). Leaf numbers were assessed on eight plants per cultivar at monthly intervals. A leaf was considered appeared when the lamina disclosed its full length.

Mean leaf area. Leaf areas (L_A in m^2) were assessed at monthly intervals from June 1997 until full canopy coverage was attained. They were assessed by measuring the length and the width of the individual leaves and calculating the area using the formula for banana developed by Turner (1972a):

$$L_A = \sum(0.83 \times l \times b) / P_n \tag{1}$$

where, l is the length of lamina (m), b the maximum width of lamina (m), and P_n the number of leaves per plant.

Leaf Area Index. LAI ($m^2\ m^{-2}$) was estimated monthly as a product of number of plants per unit ground area (P_g), number leaves per plant (P_n) and the mean area of a single leaf (L_A):

$$\mathrm{LAI} = P_g \times P_n \times L_A \tag{2}$$

Plant height. Plant height (in m) was measured on eight plants at monthly intervals from the ground to the petiole of the last leaf to emerge. The time course of plant height and leaf area index was described using the following equation:

$$Y = A + C / (1 + \exp(-B\,(X - M))) \tag{3}$$

where, B, X, M, C and A are fitted initial relative rate of increase (d^{-1}), time (d), fitted time of maximum growth (d), fitted maximum increment in height (m), and fitted minimum height (m), respectively.

Thermal time. Thermal time (°C month) was calculated by monthly integration of mean temperature minus a base temperature of 5 °C. Enset is ecologically adapted to high altitudes where the temperature is low. Thus, it is assumed that the base temperature would be considerably lower than 10 °C, the base temperature for banana.

Radiation. The Photosynthetically Active Radiation (PAR) is approximately 50% of the total incoming global radiation (Doorenbos and Pruitt, 1984). The total incoming global radiation (Rs; MJ m^{-2}) of the Awassa site was obtained from a nearby weather station. Since the radiation measuring instruments of Areka weather station were not functional, solar radiation was calculated from measured sunshine duration records based on the relationship of Ångström (1924):

$$Rs = [(a + b \times n/N) \times Ra] \times W \quad (4)$$

where, Rs is global radiation (MJ m^{-2}), Ra is extraterrestrial radiation expressed in equivalent evaporation in mm d^{-1}, n is bright sunshine hours (h), N is the maximum possible sunshine hours (h), a and b are the Ångström coefficients (0.24 and 0.59, respectively), W is weighing factor reflecting the effect of temperature and altitude on the relationship between Rs and total evapotranspiration. Maximum possible sunshine hours (N), a, b and W were obtained from Doorenbos and Pruitt (1984). Neither radiation nor sunshine duration records were available for Hagereselam. The calculated evaporation (mm d^{-1}) was converted to radiation using the following conversion factor (Doorenbos and Pruitt, 1984):

$$1 \text{ Joule cm}^{-2} \text{min}^{-1} \text{ (24 hr)} = 5.73 \text{ mm d}^{-1} \quad (5)$$

Fraction of incoming PAR absorbed by the canopy. The incident radiation flux (f_{ab}) decreases about exponentially with increasing leaf area within the canopy (Goudriaan and Van Laar 1994):

$$f_{ab} = (1 - e^{-k\,\mathrm{LAI}}) \quad (6)$$

where, k is the canopy extinction coefficient (m^2 ground m^{-2} leaf). To calculate k, starting from date of leaf emergence until maximum canopy closure, ground cover was recorded at monthly intervals using a grid of 2.0 m × 1.5 m divided into 100 equal rectangles. The grid was put between rows. Per date, eight measurements were made for each cultivar by counting the number of rectangles more than half filled with green leaf. The fraction of intercepted PAR was calculated assuming a 1:1 relationship between percentage ground cover and percentage intercepted radiation (Burstall and Harris, 1983; Spitters, 1990). A negative exponential (Goudriaan, 1982) was used to analyse the relationship between leaf area index (LAI) and intercepted PAR.

$$-k = \ln(1 - f_{ab})/\mathrm{LAI} \quad (7)$$

Radiation Use Efficiency (RUE). At the time of transplanting, from two sample plants the initial dry matter production of the suckers was determined. Afterwards, at three months interval, two sample plants from each cultivar were uprooted and the above-ground dry weight was determined by drying the sample at 105 °C for 24 hours in a forced-ventilated oven. The RUE (g DM MJ^{-1}) was then calculated as the slope of the linear relationships, forced through the origin, between cumulative intercepted PAR and cumulative above-ground DM of each clone.

PAR absorption over time. The monthly values of fraction of intercepted PAR from first transplanting until maximum light interception were calculated based on the measured LAI and calculated canopy extinction coefficient values using equation (5). The enset plant is harvested immediately after flowering and thus the fraction of intercepted PAR will be assumed to remain constant from its higher intercepted PAR until harvest. Since the generalised logistic function fitted well for all clones and data sets, the monthly fraction of intercepted PAR throughout the growing season was estimated using the following equation:

$$f_t = A + C / (1 + T \times \exp(-B \times (X - M)))^{1/T} \qquad (8)$$

where, f_t is the fraction PAR intercepted by the canopy, A and $(A + C)$ are the lower and upper asymptote, the latter being the maximum fraction intercepted PAR by a canopy, M is the time of maximum increase of intercepted PAR by the canopy, B is the initial relative rate of increase, T is proportional to the slope at maximum fraction intercepted PAR and X is the date after first transplanting. Cumulative PAR interception was calculated by integrating the product of the monthly values of f_t and PAR.

The total biomass and yield potential. Total biomass (Bio; kg ha^{-1} y^{-1}) was obtained by multiplying cumulative intercepted PAR by RUE.

$$\text{Bio} = \sum (f_t \times \text{PAR}) \times \text{RUE} \qquad (9)$$

The 'kocho' yield potential (Y; kg ha^{-1} y^{-1}) was calculated by multiplying the total biomass by the harvest index (HI).

$$Y = \sum(f_t \times \text{PAR}) \times \text{RUE} \times \text{HI} \qquad (10)$$

Harvest index (HI). A combined pseudostem and corm dry matter yield as a fraction of total plant dry weight can be estimated for different harvesting procedures. In Chapter 7, harvest indices of 0.74 and 0.26 before scraping pseudostem and after 88 days of fermentation, respectively, were estimated. A substantial dry matter loss occurs because of the different traditional harvesting and fermenting procedures that can be partly avoided by improved techniques. In this study, the average of the two harvest indices (0.50) was assumed as a potential harvest index to calculate the 'kocho' yield potentials from total biomass.

Results

Weather and soil

In 1997, 1999 and 2000, the total annual precipitation of Areka was higher than that of Awassa or Hagereselam, whereas in 1998 the total annual precipitation of Hagereselam was higher (Fig. 1). In 1998, the distribution and amount of precipitation were more favourable at all sites than in the other years, whereas the 2000-growing season had less precipitation. In 2000 at Areka and Awassa, the periods November to February had received almost no rain. The average annual temperatures of Awassa and Areka were similar and higher than in Hagereselam. The soils were classified as sandy loam, light clay and loam at Awassa, Areka and Hagereselam, respectively (Table 1). The Areka soil had higher CEC and organic carbon percentage than the soils of Awassa or Hagereselam.

Plant height

The increase in plant height of enset clones at Awassa, Areka and Hagereselam sites from first transplanting until 570 days was best described by a logistic function (Fig. 2 and Table 2). The fitted initial relative increase of plant height (d^{-1}) was similar for all clones at all sites (Table 2). Increase in plant height was earlier in 'Nekakia' at Areka, as shown by the earlier mid point (*M*) of the fitted curve which was achieved 120 days earlier compared to 'Halla' at the same site. At Awassa, 'Halla' achieved the maximum

Table 2. Estimated parameters and goodness of fit for fitted model by the logistic function eqn. (3) describing the height of enset clones at Awassa, Areka and Hagereselam from first transplanting until 570 days (n=19).

Site	Clone	*B*	*M*	*C*	*A*	*MI*	R^2
Awassa	Halla	0.0086 (0.0007)	272 (8.0)	8.9 (0.5)	−0.7 (0.3)	0.022	0.98
	Addo	0.0076 (0.0012)	279 (14.2)	9.3 (1.1)	−0.9 (0.7)	0.023	0.99
Areka	Halla	0.0127 (0.0014)	359 (8.9)	7.1 (0.4)	0.5 (0.2)	0.018	0.99
	Nekakia	0.0091 (0.0017)	239 (19.0)	7.3 (0.9)	−0.6 (0.7)	0.018	0.99
Hagereselam	Halla	0.0135 (0.0012)	368 (6.7)	1.8 (0.1)	0.3 (0.0)	0.0045	0.99
	Addo	0.0173 (0.0023)	367 (8.6)	1.3 (0.1)	0.3 (0.0)	0.0065	0.98

B, *M*, *C*, *A* and *MI* are fitted initial relative rate of increase (d^{-1}), fitted time of maximum growth (d), fitted maximum increment in height (m), fitted minimum height (m) and fitted maximum rate of increase (m d^{-1}), respectively. *MI* is calculated as $B \times C/4$. Numbers in brackets are standard errors of the mean.

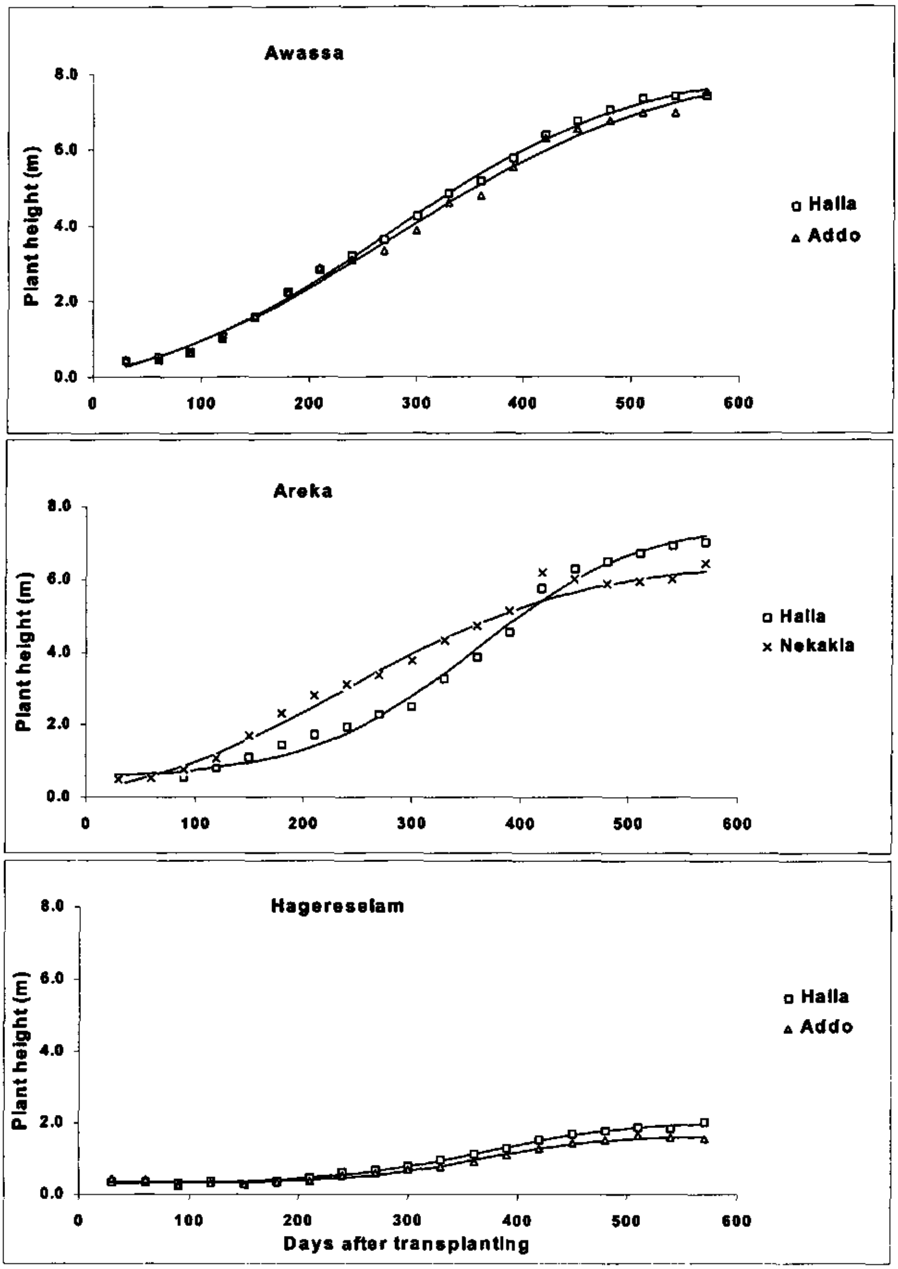

Fig. 2. Time course of plant height of enset clones at Awassa, Areka and Hagereselam from first transplanting until 570 days. Symbols: observed data; lines: fitted curves.

plant height 87 and 96 days earlier than at Areka and Hagereselam. The fitted maximum increment in height (*C*) of 'Halla' at Awassa was higher by 25 and 394% than at Areka and Hagereselam, respectively. The fitted maximum rates of plant height increase at *M* (m d^{-1}) were lower at Hagereselam compared to Awassa or Areka probably due to lower temperature.

Number of green leaves and leaf appearance rate

At Awassa and Areka, the average number of green leaves present on the enset plant increased up to 210 days after transplanting, then decreased to a stable value with increasing age (Fig. 3). At 210 days after transplanting, the average number of green leaves present on 'Halla' at Awassa was higher by 23 and 279% compared to the average leaf number at Areka and Hagereselam, respectively. 'Addo' at Awassa maintained the highest average number of green leaves at 210 days after transplanting. There was no difference in number of green leaves present between 'Halla' and 'Addo' at Awassa and Hagereselam but at Areka at all dates Nekakia maintained the highest number of green leaves.

There was no difference in leaf appearance rates (LAR) between clones or between Awassa and Areka sites, but at Hagereselam the LAR of both clones was low (Table 3). Given the drop in number of green leaves after 210 days after transplanting at Awassa and Areka, two leaf appearance rates were estimated, one until and the other after day 210 (Fig. 4). The average leaf appearance rates of the clones at Awassa and Areka until day 210 were higher by 100% compared to the leaf emergence rate from 240 days of transplanting onwards.

Table 3. Slope (±SE), intercept, correlation coefficient (R^2), and number of observations of the linear regression between total leaf number appeared and days after transplanting from first transplanting until 570 days.

Site	Clone	Slope	Intercept	R^2	n
Awassa	Halla	0.11 (±0.005)	6.28 (±1.74)	0.96	19
	Addo	0.11 (±0.005)	5.21 (±1.78)	0.96	19
Areka	Halla	0.12 (±0.005)	5.59 (±1.72)	0.97	19
	Nekakia	0.11 (±0.005)	5.38 (±1.59)	0.97	19
Hagereselam	Halla	0.09 (±0.002)	−3.28 (±0.76)	0.99	19
	Addo	0.08 (±0.001)	−1.64 (±0.53)	0.99	19

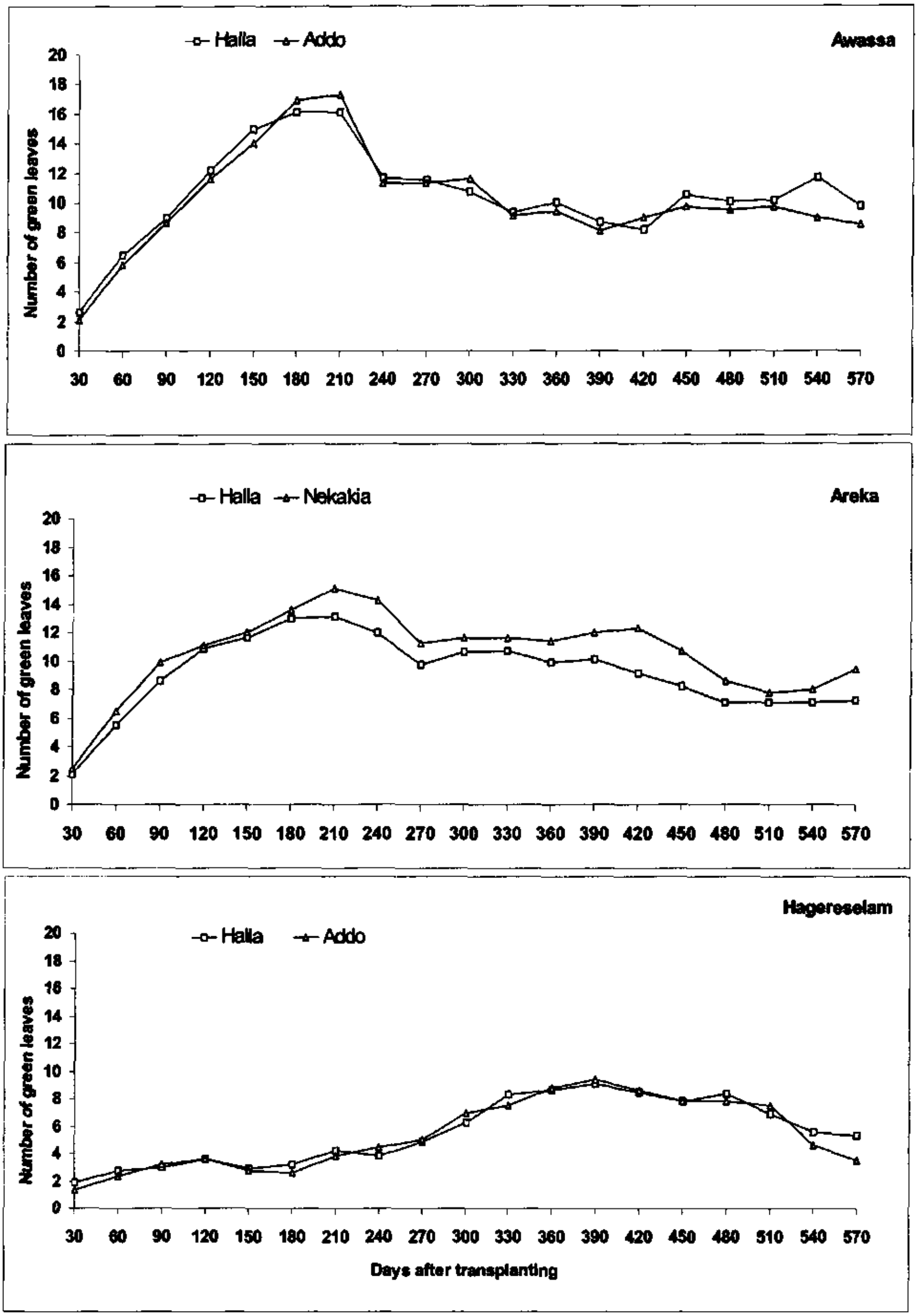

Fig. 3. Number of green leaves of enset clones at Awassa, Areka and Hagereselam at different dates after first transplanting until 570 days.

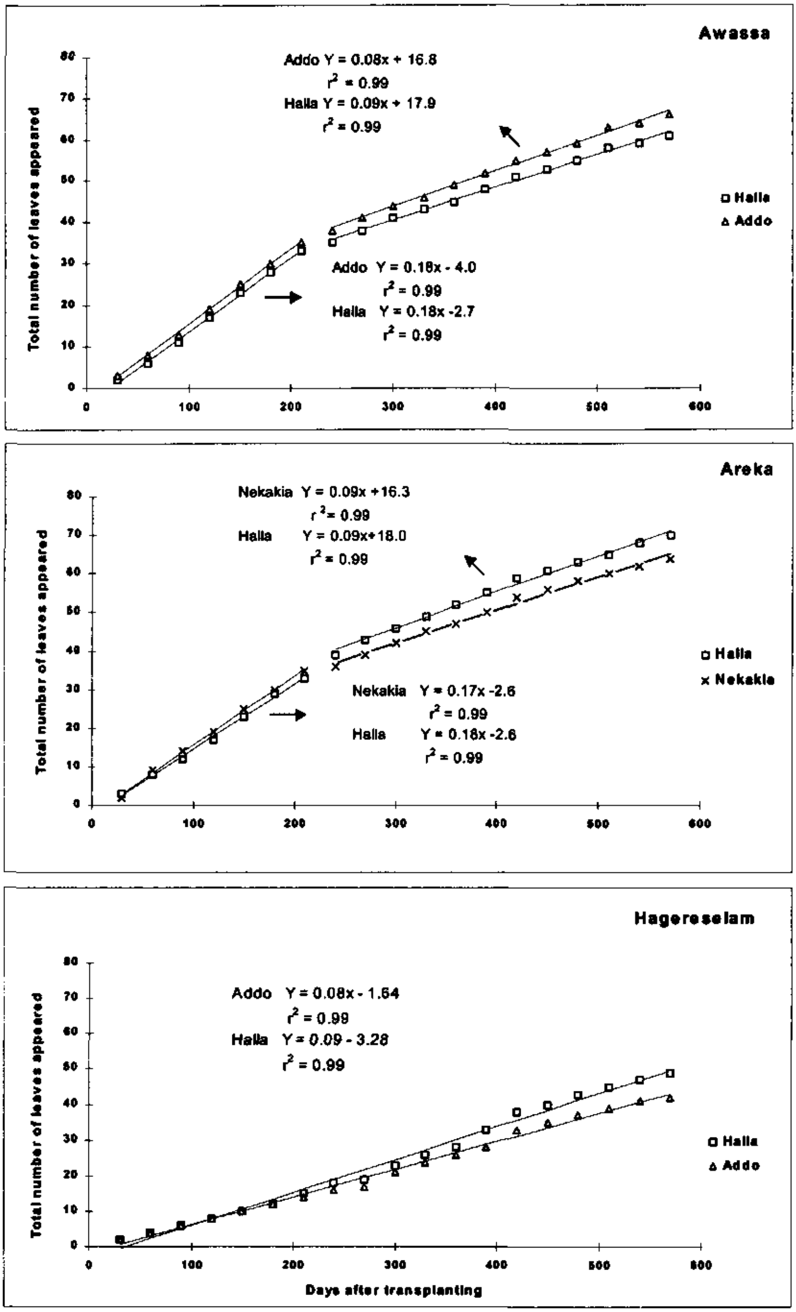

Fig. 4. Linear regression of total number of leaves appeared of enset clones on days after transplanting at Awassa, Areka and Hagereselam. At Awassa and Areka two rates were calculated. Symbols: observed data; lines: fitted curves.

Since sites differed considerably in environmental conditions, leaf appearance rates were also calculated based on temperature sum. An exponential function or asymptotic regression best described the relationship between total number of leaves appeared and thermal time at Awassa and Areka (Fig. 5). The total thermal time accumulated at Awassa and Areka was similar and the leaf appearance rate showed the same development over thermal time. The accumulated thermal time was lower by 47% at Hagereselam than at Awassa or Areka and thus the growing period at Hagereselam was not sufficiently long to define curves other than simple linear regressions.

Leaf Area Index

LAI was estimated until 300 days after transplanting at Awassa and Areka and until 570 days after transplanting at Hagereselam. At Awassa and Areka, after 300 days of transplanting, it was no longer possible to measure the areas of enset leaves because the leaves were beyond reach as a result of increased plant height. At that time radiation interception was already maximum.

The trend in LAI increase from first transplanting until canopy closure was best described by a logistic function at Awassa and Areka, whereas at Hagereselam the observed trend did not fit well (Table 4). Increase in leaf area index was faster for 'Halla' at Awassa as shown by the earlier midpoint (*M*) of the fitted curve, which was achieved 27 and 132 days earlier than at Areka and Hagereselam, respectively. Leaf area index development at Hagereselam was very slow. 'Nekakia' at Areka achieved maximum rate

Table 4. Estimated parameters and goodness of fit for fitted model by the logistic function eqn. (3) describing the LAI of enset clones from first transplanting until 300 days at Awassa and Areka and until 570 days at Hagereselam.

Site	Clone	*B*	*M*	*C*	*A*	*MI*	R^2
Awassa	Halla	0.05(0.01)	160.8(4.0)	4.2(0.2)	0.1(0.1)	0.05	0.99
(n=10)	Addo	0.06(0.02)	160.1(5.9)	4.2(0.3)	0.1(0.2)	0.06	0.97
Areka	Halla	0.04(0.01)	188.1(8.1)	3.2(0.3)	0.1(0.2)	0.03	0.96
(n=10)	Nekakia	0.03(0.00)	168.2(3.9)	4.3(0.2)	−0.1(0.1)	0.03	0.99
Hagereselam	Halla	0.04(0.03)	293.1(18.4)	1.2(0.2)	0.0(0.1)	0.01	0.79
(n=19)	Addo	0.02(0.01)	302.4(26.1)	0.9(0.2)	0.0(0.1)	0.01	0.79

B, *M*, *C*, *A* and *MI* are fitted initial relative rate of increase (d^{-1}), fitted time of maximum LAI increase rate (days), fitted maximum increment in LAI, fitted minimum LAI and fitted maximum rate of increase (d^{-1}), respectively. *MI* is calculated as $B \times C/4$. Numbers in brackets are standard errors of the mean.

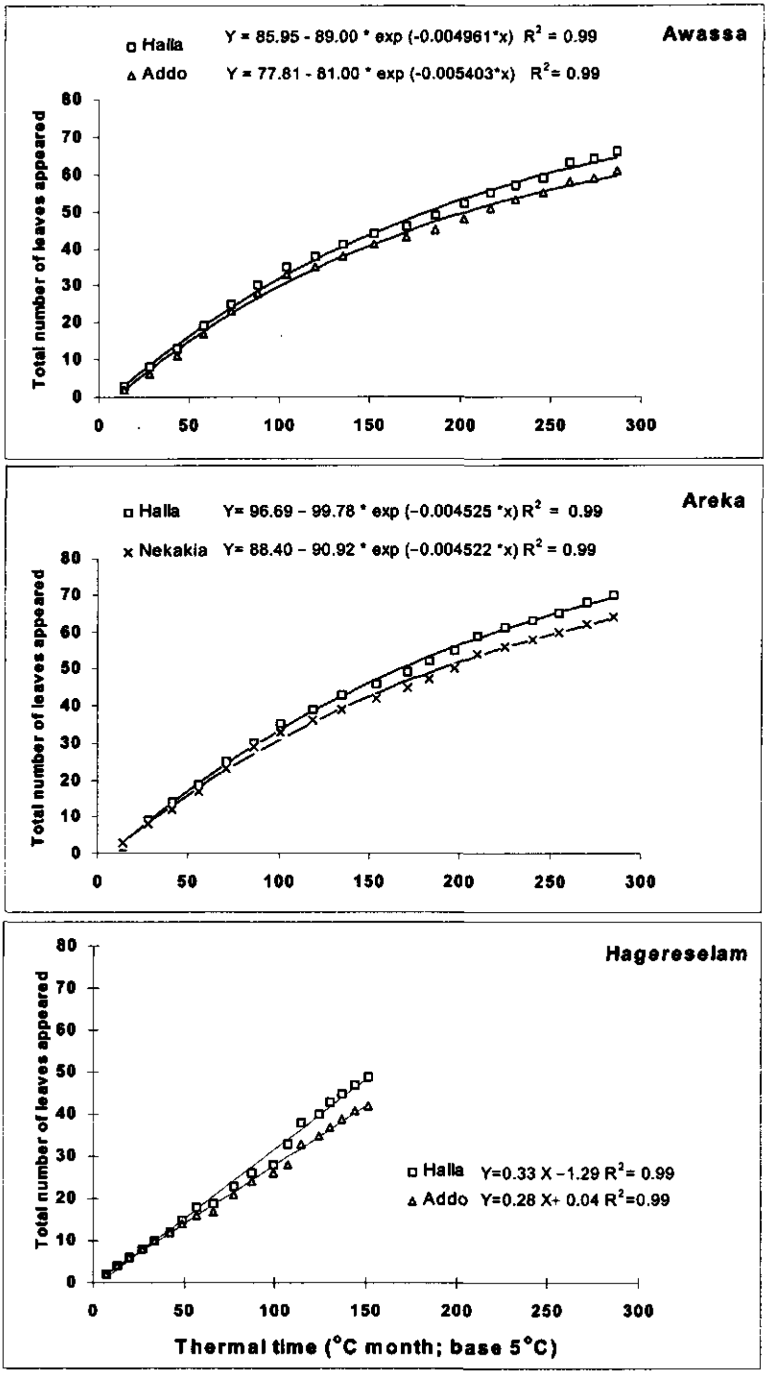

Fig. 5. Relationship between thermal time and total number of leaves appeared at Awassa, Areka and Hagereselam. Symbols: observed data; lines: fitted curves.

of increase of LAI 20 days earlier than 'Halla', whereas at Hagereselam 'Halla' achieved maximum rate of increase in LAI 9 days earlier than 'Addo'. The fitted maximum increment of LAI of 'Halla' and 'Addo' at Awassa and Nekakaia at Areka were the same, whereas the fitted maximum increment in LAI of 'Halla' at Areka was lower by 23% compared to the clones at Awassa or Areka. The fitted maximum rates of LAI increase (d^{-1}) of clones were lower at Hagereselam.

Radiation interception and radiation use efficiency

The fraction of intercepted PAR by enset clones at Awassa and Areka was best described by a generalised logistic function (Fig. 6). The fitted initial relative rate of increase in fraction of PAR was similar for all clones at Awassa and Areka (Table 5). Increase in fraction of intercepted PAR was earlier in 'Nekakia' at Areka, as shown by earlier *M* of the fitted curve which was achieved 40 days earlier compared to 'Halla' at the same site. The fitted maximum increment in the fraction of intercepted PAR was higher at Areka than at Awassa.

Since the enset plant is harvested immediately after flowering before reduction of canopy closure, the fraction of intercepted PAR was assumed to remain at its maximum from canopy closure until harvesting. The linear regression lines between cumulative absorbed PAR and accumulated dry matter yield of each clone from planting until canopy closure were plotted. The slopes are the radiation use efficiencies of the different clones and these are presented in Fig. 7. The average radiation use efficiency ranged from 1.43 to 2.67 g MJ^{-1}.

Table 5. Estimated parameters and goodness of fit for fitted model by the generalised logistic function eqn. (8) describing the fraction of PAR intercepted by enset clones from first transplanting until 300 days at Awassa and Areka.

Site	Clone	*B*	*M*	*C*	*A*	*T*	R^2
Awassa	Halla	0.06	143.48	0.93	−0.01	2.23	0.99
(n=10)		(0.01)	(4.19)	(0.03)	(0.03)	(0.80)	
	Addo	0.06	139.77	0.94	−0.02	2.13	0.99
		(0.01)	(4.68)	(0.03)	(0.03)	(0.88)	
Areka	Halla	0.06	167.30	1.16	−0.22	6.11	0.99
(n=10)		(0.02)	(11.00)	(0.14)	(0.15)	(4.05)	
	Nekakia	0.05	127.47	1.02	−0.05	1.96	0.99
		(0.01)	(5.36)	(0.05)	(0.05)	(0.95)	

B, *M*, *C*, *A* and *T* are fitted initial relative rate of increase (d^{-1}), time of maximum increase of intercepted PAR (d), fitted maximum increment (fraction PAR), fitted minimum fraction intercepted PAR and relative rate of increase at maximum fraction intercepted PAR (d^{-1}). If *T* is close to zero the general logistic function becomes a Gompertz function.

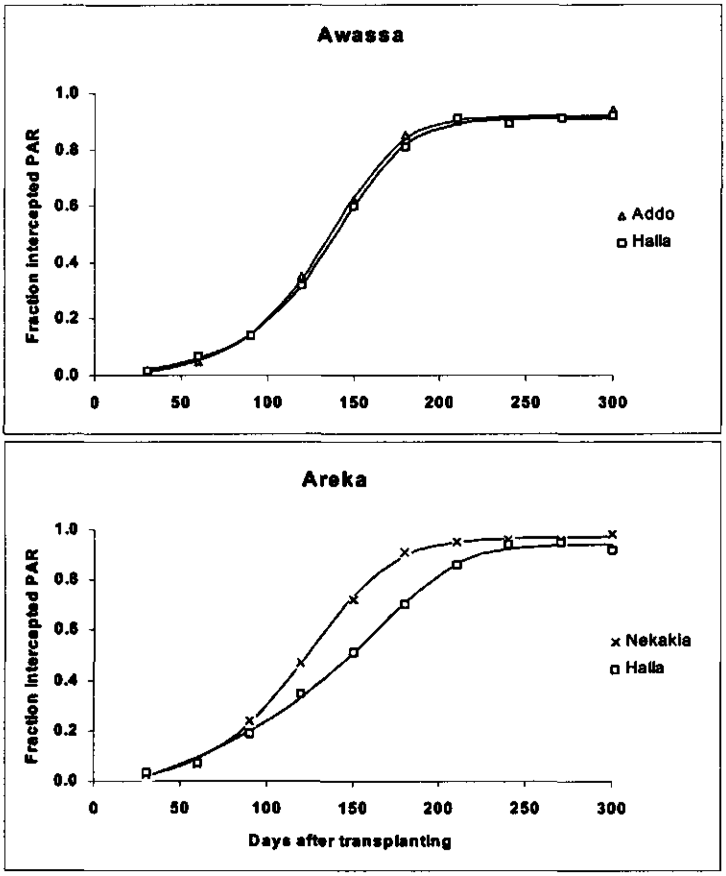

Fig. 6. The time courses of the fraction of intercepted PAR by enset clones fitted by generalised logistic function eqn. (8). Symbols are observed data; lines are fitted curves. Estimates of parameters with SE in brackets are presented in Table 6.

Extinction coefficient

At plant establishment, the LAI of enset is low; during this period a high extinction coefficient was obtained because of clustering of leaves. Based on eqn. (6) fitted *k*-values of 0.56 and 0.62 were calculated at Awassa for 'Addo' and 'Halla', respectively, whereas at Areka, *k*-values were 0.88 and 0.91 for 'Halla' and 'Nekakia', respectively (Fig. 8).

Yield potential

The calculated 'kocho' yield potential of 'Halla' and 'Addo' was the same at Awassa (Table 6). The yield potential of 'Nekakia' at Areka was higher by 29 and 96% than that of 'Addo' or 'Halla' at Awassa and 'Halla' at Areka, respectively.

Table 6. Estimated parameters, yield potential and actual yields of clones at Awassa and Areka research sites.

Site	Clone	Radiation extinction coefficient (k)	$\Sigma(f_i \times PAR)$† (MJ ha^{-1})	RUE (g MJ^{-1})	Total biomass (kg ha^{-1})	Growth period (years)	Potential growth rate (kg ha^{-1} y^{-1})	HI*	Calculated yield potential (kg ha^{-1} y^{-1})	Actual yield (kg ha^{-1} y^{-1})	Ratio of actual/ potential yield
Awassa	Halla	0.56	7.8807×10^7	2.25	177316	3.4	52152	0.50	26076	7650	0.29
	Addo	0.62	7.9515×10^7	2.23	177318	3.4	52152	0.50	26076	7650	0.29
Average			7.9161×10^7	2.24	177317	3.4	52152	0.50	26076	7650	0.29
Areka	Halla	0.88	8.1300×10^7	1.43	116259	3.4	34194	0.50	17097	4688	0.27
	Nekakia	0.91	8.5400×10^7	2.67	228018	3.4	67064	0.50	33853	4688	0.14
Average			8.3350×10^7	2.05	172139	3.4	50629	0.50	25475	4688	0.21
Grand mean			8.1256×10^7	2.14	174728	3.4	51391	0.50	25776	6169	0.25

Note: Actual fresh 'kocho' yield of enset reported by CSA (1997a) was 34.68 and 21.25 kg per plant in Sidama and Wolaita, respectively. The actual yield (kg ha^{-1} y^{-1}) in this study was calculated from these values assuming a growth period of 3.4 years, 2500 enset plants per hectare (Makiso, 1996), and 30% dry matter content (Chapter 8).

† f_i (fraction intercepted) was estimated by eqn. (8), see Table 5 for the parameters.

* HI is a combined pseudostem and corm dry matter yield as a fraction of total plant dry weight (see material and methods for detail information).

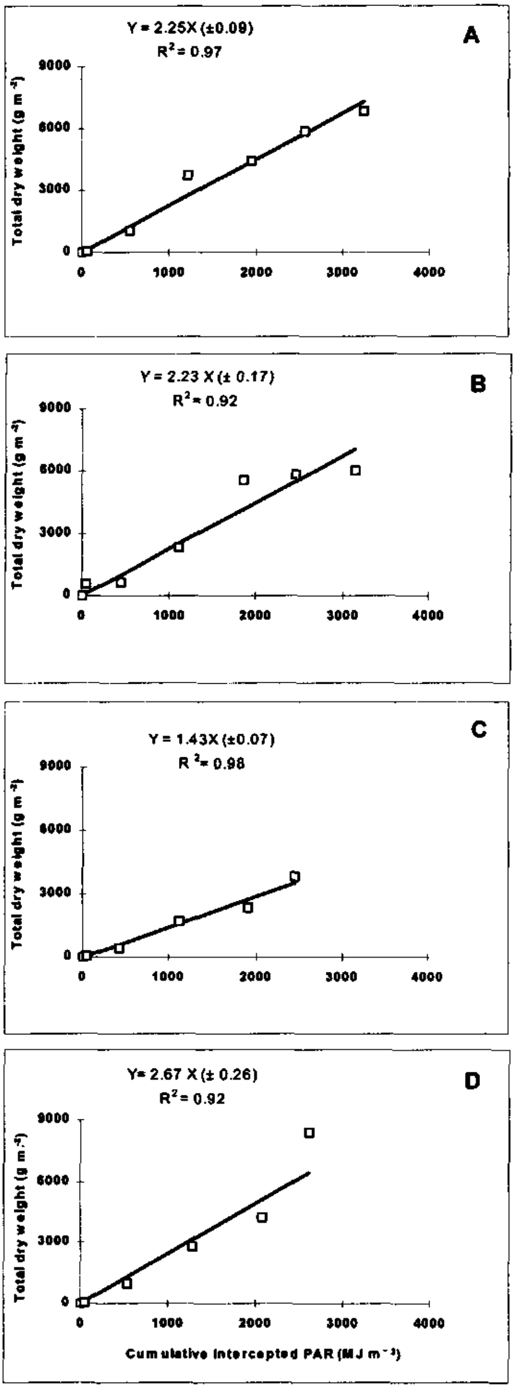

Fig. 7. Relationship between above-ground total dry matter production and cumulative intercepted PAR. (A) 'Halla' in Awassa; (B) 'Addo' in Awassa; (C) 'Halla' in Areka and (D) 'Nekakia' in Areka. Linear regression is applied to determine the radiation use efficiency (RUE) which is given by the slope of the regression lines with SE between brackets. Symbols: observed data; lines: fitted lines. The regression line is forced through the origion.

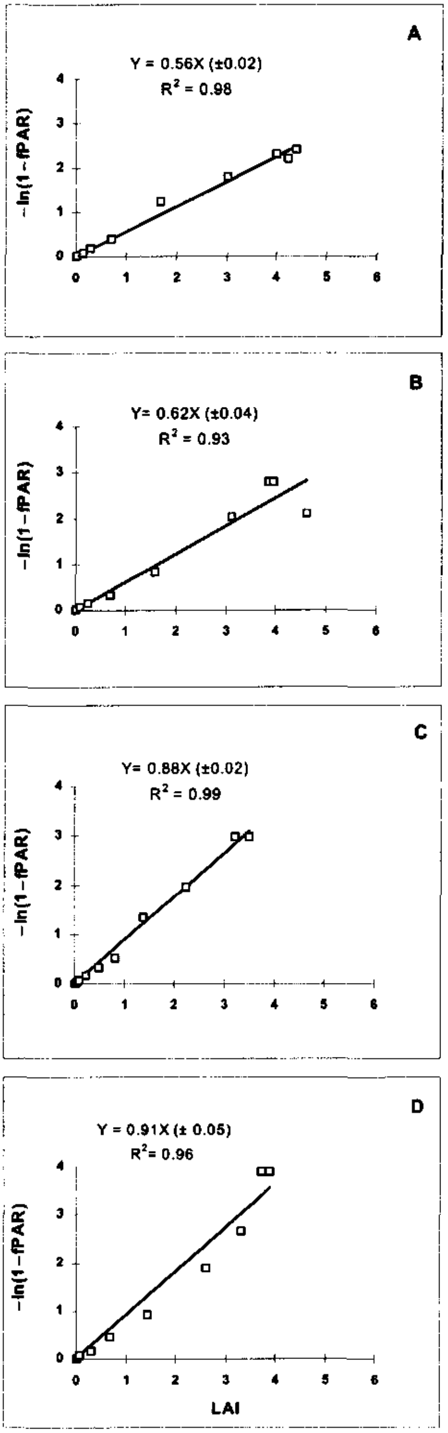

Fig. 8. Linear regression of log transformed fPAR on LAI. (A) 'Addo' in Awassa; (B) 'Halla' in Awassa; (C) 'Halla' in Areka and (D) 'Nekakia' in Areka The regression line was forced through the origion. Linear regression is applied to determine the radiation extinction coefficient (k) which is given by the slope of the regression line with SE between brackets. Symbols: observed data; lines: fitted data.

The actual 'kocho' yields of enset reported by CSA (1997a) were 34.68 and 21.25 kg plant^{-1} for Sidama and Wolaita, respectively. From these figures, actual 'kocho' dry matter yield in kg ha^{-1} y^{-1} was estimated assuming a growth period of 3.4 years, 2500 enset plants per hectare (Makiso, 1996) and 30% dry matter content (Chapter 8). The mean actual 'kocho' dry matter yield of Sidama where the Awassa site is located was higher by 63% than for Wolaita where the Areka site is located (Table 6). The gap between actual yield and yield potential was wider at Areka than at Awassa.

Discussion

The maximum plant height and LAI were reached earlier in Awassa and Areka than in Hagereselam associated with a higher leaf appearance rate due to more optimal temperatures (Tables 2, 4). The monthly mean temperatures of Awassa and Areka sites during the growing period were within 20–23 °C, whereas at Hagereselam the mean monthly temperatures were within 10–13 °C (Fig. 1). The more favourable temperature at Awassa and Areka increased the number of green leaves present on the plant. The greater number of leaves per plant increased early interception of photosynthetically active radiation and thus the LAI developed faster (Table 4). The negative effect of low temperature on leaf appearance rate and area development of Musaceae leaves was confirmed by results on banana obtained by Allen *et al.* (1988), Eckstein and Robinson (1995) and Eckstein *et al.* (1997).

At Awassa and Areka, the leaf appearance rate increased in the first 210 days and then, switched to a lower value. This result seems to agree with the findings of Allen *et al.* (1988) on banana who reported that leaf appearance rate increased during the establishment phase of the plants and then, after 64 days, decreased with increasing time. Leaf appearance rate of enset has not been reported before. The values of the leaf appearance rates found in this study are, however, with some exceptions, within the range of 0.05–0.18 leaves d^{-1} of banana in the report of Eckstein and Robinson (1995) and Eckstein *et al.* (1997).

The growth period and thermal time until the switch in leaf appearance rate were 210 days or 101–104 °C month, respectively; 33–35 leaves appeared within this period (Fig. 4). The switch from the higher to the lower leaf appearance rate might be associated with the transition from the vegetative to reproductive phase of the apical meristem. Since using chronological age seems inadequate because the duration of the vegetative stage depends on the environmental conditions, the number of initiated leaves probably is the best to estimate the maturity period (Bernier *et al.*, 1981). At Awassa, 'Halla' produced 88 leaves from planting to flowering, whereas at Areka 'Halla' and 'Nekakia' produced 92 and 94 leaves, respectively (data not shown). According to our previous assumption of the transition phase, an enset plant might produce about 1/3 of its total number of leaves during its vegetative phase. Leaf appearance could also be described by an exponential relationship with thermal time (Fig. 5). This is in agreement with Van Esbroeck *et al.* (1997) who reported an exponential relationship between thermal time and visible leaves in switchgrass.

The values of plant height found by the fitted procedure at Areka were in the range of measured values ranging from 3.0 to 7.7 in the report of Endale (1997). The fitted maximum plant heights of the clones at Awassa were greater probably because of better cultural practice; those of Hagereselam were lower as plants of this site were not advanced because of the effect of low temperature.

No studies on enset have been conducted to test the growth functions to study the progress of growth or light interception in enset plants. The trend in plant height was best described by a logistic function at all sites, whereas the trend in LAI was well-described by a logistic function only at Awassa and Areka. The high leaf appearance rate at Awassa and Areka made it possible to compensate for leaf senescence and thus leaf area index did not fluctuate. At Hagereselam, however, the rate of leaf appearance became too small to compensate for the seasonal rapid change in number of green leaves per plant and, thus, LAI fluctuated over the whole growing period. The parameters of the functions fitted to the leaf area index and plant height of 'Halla' differed significantly from site to site indicating the influence of climatic conditions on plant growth. The wide spacing between plants (1.5 m × 2.0 m) and transplanting shocks resulted in a low LAI during the first 120 days after first transplanting at Awassa and Areka, whereas at Hagereselam because of the additional effect of low temperature LAI development was slow during the first 300 days (data not shown). The observations on maximum LAI (3.2–4.6) compared well with LAI of 4.8 reported by Turner (1972b) and 3.2–4.3 reported by Stover (1982) for banana.

Dry matter production of enset clones from first transplanting until canopy closure was linearly related to the amount of intercepted PAR (Fig. 7). The radiation use efficiency (1.43 MJ^{-1} PAR) of 'Halla' at Areka was much lower due to prolonged clustering of leaves associated with slower LAI development (Table 4); a relatively low dry matter production probably caused by a virus infection might also have caused this. Van der Werf (1988) reported reduction in RUE because of viruses in sugar beet. The potential threat of the wide spread mosaic streak, which is suspected to be of viral nature in enset farming, was reported by Quimio and Tessera (1996). The more rapid development of LAI of the virus free clone 'Nekakia' at Areka increased early PAR interception and total dry matter production and was associated with higher RUE. The radiation use efficiencies of enset clones compared well with RUEs of 2.10 to 2.46 g MJ^{-1} reported for other C_3 species such as potato and tomato (Van der Zaag, 1991;

Scholberg *et al.*, 2000). The RUE of enset clones were lower than the RUE of about 3.0 g MJ^{-1} of PAR estimated by Turner (1990) for high yielding banana plantations probably because of ample irrigation and supply of fertilisers in the banana plantations. The RUE of enset clones were much higher than those of woody species; for example, Squire and Corley (1987) reported 1.69 MJ^{-1} of PAR for oil palm and Mariscal *et al.* (2000) reported 1.35 g MJ^{-1} of PAR for a young olive orchard. Although enset is perennial, the main chemical component is non-structural carbohydrate, which is produced at lower cost than oil and lignin, and also fat and protein (Penning de Vries, 1975).

The average radiation extinction coefficient (k) (0.56–0.62) of the enset clones at Awassa was within the range of 0.46–0.75 reported by Turner (1990) for banana. The k-value of 'Nekakia' at Areka was higher due to clustering of leaves caused by greater leaf number throughout the growing period (Fig. 3).

The calculated average dry matter 'kocho' yield potential value of 26.20 t ha^{-1} y^{-1} obtained in this study was low compared to the high experimental yields of potato in tropical regions (31 t ha^{-1} y^{-1} reported by Kooman *et al.* (1995)), cassava (48 t ha^{-1} y^{-1} reported by CIAT (1969)), sweet potato (39 t ha^{-1} y^{-1} reported by IITA (1976)) and taro (39 t ha^{-1} y^{-1} reported by Plucknett and De La Pena (1971)). These reported high experimental yields were before processing and/or storage. The low average dry matter 'kocho' yield potential of enset was mainly attributed to the lower harvest index of enset compared to the root and tuber crops. Important 'kocho' yield potential differences exist between clones mainly because of differences in radiation use efficiency caused by presence of viruses.

The average ratio actual yield : yield potential was 0.24 illustrating the wide gap between the actual and yield potential. This wide gap was mainly due to the traditional fermentation processes, cultivation methods such as repetitive transplanting and leaf pruning, presence of diseases and lack of adequate fertilisation. The ratio was almost the same for all clones and regions except for 'Nekakia' at Wolaita indicating similarities in the technical level of production between regions.

Conclusions

- The leaf appearance rate of enset is high during the crop establishment phase of the plant and then switches to a lower value. The transition might be related to the transition from the vegetative to the reproductive phase of the apical meristem.
- The high leaf emergence rate in most areas results in a stable leaf area even when unfavourable climatic conditions induce leaf senescence. Thus, leaf area index did not fluctuate.
- The radiation use efficiencies of enset compared well with the RUEs of other C_3

species; there were differences among enset clones in radiation use efficiency.

- With the current knowledge on radiation use efficiencies of enset clones and *k*-values dry matter production of enset can be calculated. Further research using recorded values of photosynthetically active radiation is needed to verify *k*-values and RUE of enset clones.
- The gap between the actual and yield potential is wide; among others the traditional fermentation process contributed much to the gap. Improvement in fermentation and agronomic practices could reduce the gap between the actual and yield potential.

CHAPTER 6

Influence of repetitive transplanting and leaf pruning on dry matter and food production of enset (*Ensete ventricosum* (Welw.) Cheesman)

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CHAPTER 6

Influence of repetitive transplanting and leaf pruning on dry matter and food production of enset (*Ensete ventricosum* (Welw.) Cheesman)

Abstract

Crop establishment methods affected the growth, dry matter production and distribution in enset (*Ensete ventricosum*) plants studied at the Areka Research Centre, North Omo, southern Ethiopia. Enset suckers transplanted only once (i.e., directly into permanent fields) flowered at about 104 weeks; flowering triggered plant senescence and shifted assimilate partitioning towards the developing inflorescence. Enset plants transplanted twice flowered at about 234 weeks, and those transplanted thrice flowered within 260 weeks. At the end of the experiment, dry matter yields per plant (excluding roots) were higher for plants transplanted twice than for plants transplanted once or thrice.

At 104 weeks after separating the suckers from the corm, the production per ha and per year for transplanting once was 148 and 25% of 'kocho' dry matter more than for transplanting twice or thrice, respectively. However, at 130 weeks after separating suckers from the corm, production of dry matter of fermented 'kocho' per ha and year was not significantly different for plants transplanted once or twice. The dry matter loss during the fermentation process ranged from 41–57%.

Repetitive partial defoliation by removing 4–5 lower leaves at 6-month intervals did not affect the rate of progress from planting to flowering or the fresh and dry matter production rates of 'kocho' after 104 weeks (before fermentation) after first transplanting. Later during the growth period, however, continued leaf pruning significantly reduced dry matter production rate of 'kocho' (before fermentation). At both dates, leaf pruning effects were significant for values after fermentation.

Transplanting suckers directly into permanent fields may be practised to obtain early yields and overcome disease problems. More frequent transplanting often delays flowering and results in higher yields per plant. To practise this method, however, suitable cropping systems and techniques need to be established that allow farmers to have enset plants at different developmental stages in order to have enough mature enset plants that can be harvested for food every year.

Keywords: Enset, fermentation, 'kocho', leaf pruning, staple, transplanting

Introduction

The genus *Ensete* (order Zingiberales, family Musaceae) contains species equally divided between Africa and Asia (Simmonds, 1962). Among them, enset (*Ensete ventricosum* (Welw.) Cheesman) has been used as a food plant since early Egyptian civilisation (Moore, 1957). Currently, it is used as a staple food for about 7–10 million people, in the southern parts of Ethiopia, and its use is expanding in other parts of the country as well.

Starch produced in the pseudostem, corm and the stalk of the inflorescence of enset is usually fermented giving rise to a food product locally known as 'kocho'. Part of the starchy liquid obtained by squeezing the mixture of scraped pseudostem, pulverised corm and stalk of the inflorescence may also be consumed as porridge after the liquid is allowed to settle for some days. The corm can also be cooked fresh and consumed in a way similar to Irish potato, sweet potato and cassava.

All parts of enset are used. Enset fibre has an excellent structure, and its strength is equivalent to that of abaca, a world-class fibre crop (Brandt *et al.*, 1997). The entire enset plant may be used to feed livestock. The dried leaf sheaths are also used as packing and wrapping material, in fences, mattresses, mats and in house construction. Locally, enset is thought to have various medicinal properties.

In contrast to banana, enset is usually not suckering. Removing the apical bud, however, will induce many lateral buds on the corm to grow into suckers. Enset is therefore usually propagated from new shoots (suckers) on an immature corm taken from the plant, which need to be transplanted to avoid crowding. Although not common, seeds are also used to produce seedlings and create diversity in some parts of the region.

The main enset-growing areas (with about 167,900 ha cropped; CSA, 1997a) are inhabited by more than 10 related ethnic groups, having different cultures, traditions, agricultural systems, and agronomic practices in growing enset. Differences in agricultural practice may also be related to agro-ecological conditions. Most obvious variations in agronomic practice relate to methods of propagation, transplantings prior to harvest, plant arrangement, and leaf pruning. In addition, processing methods vary from place to place (or from ethnic group to ethnic group).

In many traditional production systems, enset shoots undergo yearly transplanting before well-developed propagules are moved to the site where they will grow and mature. This practice of repetitive transplanting varies with region, Zippel and Kefale (1995) noting shoots transplanted 4–5 times in Gurage but only twice in Derashe. In Sidama and Gedio, suckers are usually only transplanted once, though plants which remain small, may be transplanted into another field. The advantages of repetitive transplanting are controversial among researchers and farmers, yet, many farmers stress the importance of repetitive transplanting, claiming that it results in more vigorous growth of pseudostems and corms, the main harvestable parts of the plant.

Another traditional practice in enset production is leaf pruning. As the possibilities for forage production become limited, farmers increasingly turn to crop residues for livestock feed with pruned enset leaves, thinned plants and harvested plant tops widely utilised as animal feed. In densely populated and dry areas where forage supply is most limited, leaf pruning to the point of complete defoliation of the plant may be practised, as in the Gurage region (Spring *et al.*, 1996).

The practices of repetitive transplanting and leaf pruning are not consistent over all enset-growing areas. Advantages and disadvantages of the different practices may depend on the prevailing agro-ecological conditions and need to be evaluated to optimise the cultivation system. Also, transplanting suckers directly into the permanent field needs to be evaluated, since this method of crop establishment is becoming increasingly popular in most enset-growing areas. Therefore, the effects of single and repetitive transplanting and of leaf pruning on production of dry matter and of 'kocho' per unit of time and area were investigated to define production systems. A second paper in this series will consider the effects of repetitive transplanting and leaf pruning on harvest indices, harvest and post-harvest losses of enset in more detail (see Chapter 7).

Materials and methods

Experimental site

The study was carried out at Areka Research Centre, North Omo Zone, southern Ethiopia. Areka is located 7° 09′ N and 37° 47′ E at an elevation of 1750–1820 m asl. Average annual rainfall (1993–1998) was 1580 mm with a minimum/maximum mean air temperature of 14.8 °C/25.7 °C. The soil was well-drained, stone free, with texture class of silt loam at 0–15 and 30–45 cm depth and loam at 15–30 cm depth. The pH was 4.9, 4.5 and 4.6 at 0–15, 15–30 and 30–45 cm depth, respectively. The total N % (Kjeldahl) and CEC at 0–15 cm were 0.196 and 22.1 meq per 100 g, respectively. Fertilisers (100 kg urea ha^{-1} y^{-1} and 100 kg DAP ha^{-1} y^{-1}) were applied for the first two years both in nursery beds and permanent fields.

Treatments and experimental design

The treatments consisted of three transplanting methods combined with two leaf pruning methods. The transplanting methods were (i) transplanting 1-year-old suckers produced in the nursery from the corm directly into the permanent field (T1), (ii) transplanting 2-years-old transplants into permanent field after they had been raised from the corm nursery by transplanting into nursery beds (T2), (iii) transplanting 3-years-old transplants into the permanent field after they had been raised by transplanting twice into nursery beds (T3). See also Fig. 1. Nursery spacings were 1.0 m × 1.0 m for sucker production (to give adequate space to the 50–150 new shoots per corm), 1.0 m × 0.5 m for raising 1-year-old transplants into 2-years-old transplants, and 1.0 m × 1.0 m for raising 2-years-old transplants into 3-years-old transplants. The spacings during transplant raising are in accordance with common practice, aiming to optimise land use. The nursery sites were located adjacent to the permanent field. The leaf pruning methods were (i) without leaf pruning (P0) and (ii) with leaf pruning (P1).

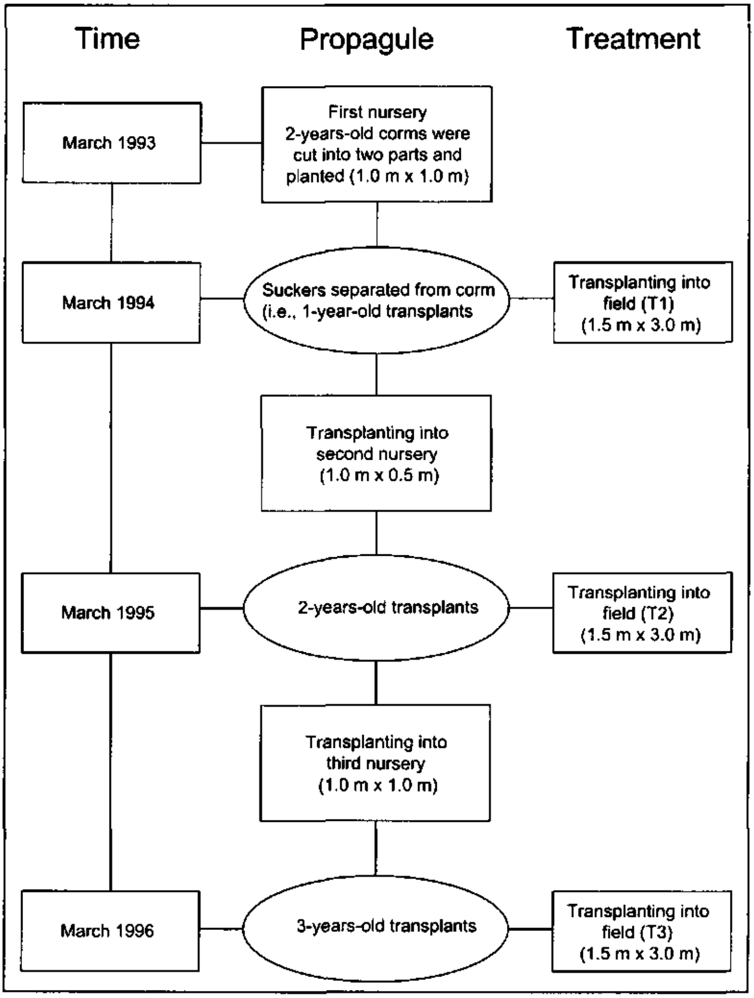

Fig. 1. Schedule of the transplanting treatments. Figures between brackets indicate the spatial arrangement in the different phases.

The six treatment combinations were arranged in a randomised complete block design with four replications. The plants were grown in the permanent field in a 1 .5 m × 3.0 m plant arrangement. There were 24 plants per plot of 12 m × 9 m.

Crop management

Two-years-old plants of the cultivar 'Halla' were cut 10–15 cm above the junction of the peudostem and corm. The corms were split into two parts and the apical buds were removed to induce several buds from the mother corm piece to grow into shoots (suckers). The split corms were then planted 1 m apart under 10–20 cm of soil mixed with cow manure on 2 March 1993. In March 1994, suckers were separated from the mother corm, and either transplanted directly into the permanent field (T1) or transplanted into a second nursery bed. In March 1995, some 2-years-old transplants were transferred into the permanent field (T2), while the remaining shoots were transplanted into a third nursery bed at a spacing of 1.0 m × 1.0 m. These 3-years-old transplants were transplanted into the permanent field in March 1996 (T3). See also Fig. 1.

Leaf prunings (P1) were carried out as practised in certain regions: the dead leaf sheaths and the old green leaf blades on the lower part of the plant were removed twice a year (in March and September). At least eight functional leaves were left on the plant. Plants without leaf pruning (P0) were allowed to grow freely.

Data collection and analysis

At the time of transplanting suckers into the permanent field, and afterwards at 26-week intervals, yield data of plant components were recorded. Weight increases during the nursery phases were not recorded. At each sampling two plants per plot were measured, uprooted and separated into corm, pseudostem, leaf blades and sheaths, and inflorescence. Leaf blades and sheaths include parts of enset shoots other than the scraped part of pseudostem, stalk of inflorescence and inflorescence. The above-ground fresh weight of all fractions was determined. The material of all fractions was chopped and then subsampled. Per fraction from each plot, 500 g of fresh material was dried at 105 °C for 24 hours in a forced-air ventilated oven to assess the dry matter concentration. It proved impossible to recover roots quantitatively. In this chapter, we report on the development over time of the dry weights per plant for each fraction, whereas a detailed analysis on yield is provided for the harvests on 104 and 130 weeks after separation of the suckers from the corm. On these dates the yield of T1 was at its maximum; therefore these sampling dates provide the best information to compare productivity per unit of time and unit of area (see below).

The pseudostem of the sample plants was cut into several pieces. The scraped pseudostem pulp (parenchymatous tissue) and the pulverised corm were mixed. After the fresh weights of samples were determined and subsamples for drying were taken, the remaining mixture was put into a pit for fermentation. Every two weeks the fermentation pits were opened and the contents were pressed and re-arranged to improve the fermentation process. After 88 days of fermentation the fresh weights were assessed again and the material was subsampled for assessing dry matter concentration as described before.

Dry matter production of plant components and fresh and dry matter production of 'kocho' were expressed per plant (in kg plant^{-1}) or per unit space and time (in kg m^{-2} y^{-1} or kg ha^{-1} y^{-1}). For the latter parameters it is relevant that the spacing of transplants in the nurseries and of the plants in the permanent field was different in the various phases. Yields per unit space and time accounting for treatment differences in spacing after removal of the suckers from the corm were calculated on the basis of the following formula:

$$Y = W / \Sigma(TP \times AP)$$

in which, Y is yield per unit space and time in kg m^{-2} per year, W the yield per plant in kg, TP the time per phase in years and AP the area per plant per phase in m^2.

For example on 130 weeks (2.5 years) after removing suckers from the corm, the total area × time available per plant was 11.25 m^2.year for T1 (2.5 years × 4.5 m^2), 7.25 m^2·year for T2 (1 year × 0.5 m^2 + 1.5 years × 4.5 m^2) and 3.75 m^2·year for T3 (1 year × 0.5 m^2 + 1 year × 1 m^2 + 0.5 year × 4.5 m^2).

The yield data of plant components and 'kocho' were processed by analysis of variance procedures. Mean comparison was performed using Duncan's 'multiple range test' to assess the effect of different cultural practices on the total yield of the crop.

Results

Flowering and growth of various plant parts

Flowering. The rate of progress from planting to flowering was influenced by the different transplanting treatments. The enset plants from T1 flowered within 104 weeks, and vegetative growth slowed down and finally ceased (Fig. 2). Those transplanted twice flowered within 234 weeks. Thrice transplanted plants flowered just before the end of the experiment at 260 weeks. Leaf pruning alone or the interaction between leaf pruning and transplanting treatments did not affect the rate of progress from planting to flowering.

Growth per plant. The total above-ground dry matter yield of directly transplanted (T1) enset suckers (including the corm) reached 27.1 kg per plant 104 weeks after transplanting and thereafter started to decrease mainly by leaf senescence not compensated by continuing leaf initiation. It was only 18.0 kg per plant 156 weeks after transplanting (Fig. 2). In addition to this loss, assimilates were partitioned from the pseudostem and corm to the developing inflorescence (Fig. 2). At 104 weeks after first transplanting T1 outyielded the other two treatments by 355% (T2) or 794% (T3) based on yield per plant. Enset plants that were transplanted directly into the permanent field (T1) were dead at 182 weeks after transplanting, whereas those transplanted twice or thrice were still growing rapidly after 208 weeks of vegetative growth and had accumulated at that time already 34.8 and 24.3 kg per plant above-ground dry matter, respectively. At 234 weeks after first transplanting T2 plants which flowered at that time and T3 plants which were

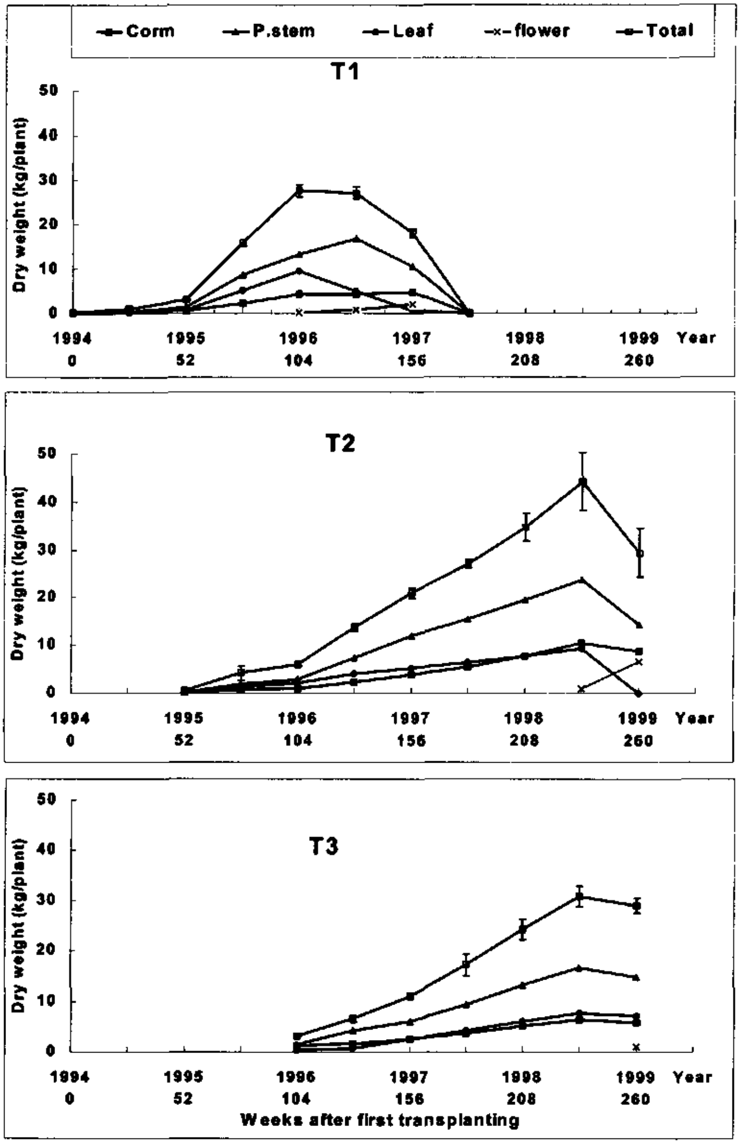

Fig. 2. Average dry matter yield per plant of corm, pseudostem, leaf and flower, and total dry matter yield of enset during the growing period for the different transplanting treatments. Note: At the time of transplanting into permanent field, and afterwards at 26-week intervals, yield data of plant components were recorded. T2 (transplanted twice) and T3 (transplanted thrice) plants were transplanted into permanent field 52 and 104 weeks later than T1 (transplanted once) plants, respectively. Vertical bars indicate standard errors. The T1 plants were dead at 182 weeks after removing the suckers from the corm, which is indicated by a dry weight of 0 kg per plant, even though some fibrous dry matter may have been recovered.

still vegetative and rapidly growing accumulated 44.3 and 30.9 kg per plant above-ground dry matter, respectively. During the final 26 weeks of the experiment all treatments showed a decrease in yield. In the case of T3 this decrease was partly caused by corm rot, a fungal disease that is common when plants are in the field for too long.

Height and circumference of the pseudostem at 104 and 130 weeks after first transplanting. Transplanting treatments significantly affected pseudostem height and circumference at 104 weeks after first transplanting (Table 1). Transplanting once increased pseudostem height by 166 and 114% compared to transplanting twice and thrice, respectively. Transplanting once also increased the circumference of the pseudostem by 22 and 70% compared to transplanting twice and thrice, respectively. Leaf pruning treatments significantly affected circumference of pseudostem: plants grown without leaf pruning had a 13% higher circumference of pseudostem than pruned plants. There were no significant interactions between transplanting and leaf pruning treatments (Table 1).

The height of pseudostem was also significantly affected by transplanting treatments at 130 weeks after first transplanting (Table 2). Transplanting once increased height of pseudostem by 38 and 107% compared to transplanting twice or thrice, respectively. Frequent transplanting also reduced the circumference of pseudostem. Leaf pruning treatments did not affect height and circumference of pseudostem. There were no statistically significant interactions between transplanting and leaf pruning treatments (Table 2).

Dry matter production rate of plant components

At 104 weeks after first transplanting, dry matter production rate of the various parts of enset plants was significantly affected by transplanting treatments. Transplanting once gave higher dry matter production rate of corm and of pseudostem than transplanting twice or thrice at both leaf pruning treatments (Table 1). For pseudostems and leaves, production rates were higher at transplanting thrice than transplanting twice. This was associated with the differences in plant density (Fig. 1; see also Discussion). There was no significant difference in leaf dry matter production rate between transplanting once or thrice, but these treatments gave higher leaf yields than transplanting twice at both leaf pruning levels. There was no statistically significant difference in dry matter production rates of plant components as a result of leaf pruning treatments. There were no significant interactions between treatments in dry matter production rate of various parts of the enset plant.

There were also substantial differences between transplanting treatments in dry matter production rate of corm at 130 weeks after first transplanting. Transplanting once without

Table 1. Effects of repetitive transplanting and leaf pruning on growth characteristics and dry matter production of plant components and total dry matter production of enset 104 weeks after the first transplanting. Dry weight production rates are based on the yield increase per plant per year and plant densities during phases of production after transplanting.

Treatments	Average height of pseudostem (m)	Average circumference of pseudostem (m)	Dry weight ($kg\ m^{-2}$ per year) Corm	Pseudostem	Leaf	Total dry matter	Harvest index ($kg\ kg^{-1}$)
Transplanting							
Once	1.65 a	1.34 a	0.49 a	1.48 a	1.07 a	3.04 a	0.65 ab
Twice	0.62 c	1.10 b	0.21 b	0.59 c	0.41 b	1.21 c	0.66 a
Thrice	0.77 b	0.79 c	0.26 b	1.03 b	0.83 a	2.08 b	0.61 b
Significance	****	****	****	****	****	****	*
Leaf pruning							
Without	1.06 a	1.14 a	0.33	1.06	0.80	2.17	0.64
With	0.97 b	1.01 b	0.32	1.00	0.74	2.05	0.64
Significance	*	***	ns	ns	ns	ns	ns
Transplanting × leaf pruning							
Once/without	1.74	1.44	0.47	1.50	1.06	3.03	0.66
Twice/without	0.61	1.15	0.21	0.52	0.41	1.13	0.65
Thrice/without	0.82	0.84	0.31	1.15	0.92	2.38	0.62
Once/with	1.56	1.24	0.52	1.44	1.08	3.04	0.65
Twice/with	0.64	1.06	0.21	0.67	0.42	1.30	0.68
Thrice/with	0.72	0.75	0.22	0.92	0.75	1.82	0.59
Significance of interaction	ns	ns	ns	ns	ns	ns	ns
Grand mean	1.01	1.08	0.32	1.03	0.77	2.13	0.64
CV (%)	10.6	10.2	25.8	20.4	30.2	23.1	8.2

Note: *, *** and **** indicate significant levels at $P < 0.10$, 0.01 and 0.001 (F-test), respectively; ns = not significant. Different letters in a column indicate significant difference at $P < 0.05$, according to Duncan's 'multiple range test'.
Harvest index refers to the proportion of the total dry weight in the harvested organ (corm + pseudostem) prior to 'kocho' making processes such as scraping the pseudostem pulp, pulverising the corm and fermenting the mixture.

leaf pruning produced more whereas transplanting thrice produced less at both leaf pruning levels (Table 2). Differences between transplanting treatments were not statistically significant in the pruned treatments. For the pseudostem, there was only a significant reduction by transplanting thrice, when averaged over leaf pruning treatments. This difference was not significant for the unpruned treatments. Transplanting or leaf pruning treatments did not affect leaf dry matter production.

Total dry matter production rate

Transplanting once had a much higher dry matter production rate than transplanting twice or thrice at 104 weeks after first transplanting (Table 1). Transplanting thrice produced more per plant than transplanting twice. These findings were true for both leaf pruning treatments. There was no significant effect of pruning treatments and no treatment interactions were observed.

Averaged over leaf pruning treatments, transplanting thrice produced significantly less than transplanting once or twice at 130 weeks after first transplanting (Table 2). There

Table 2. Effects of repetitive transplanting and leaf pruning on growth characteristics and dry matter production of plant components and total dry matter production of enset 130 weeks after the first transplanting. Dry weight production rates are based on the yield increase per plant per year and plant densities during phases of production after transplanting.

Treatments	Average height of pseudostem per plant (m)	Average circumference of pseudostem (m)	Dry weight (kg m^{-2} per year) Corm	Pseudostem	Leaf	Total dry matter	Harvest index (kg kg^{-1})
Transplanting							
Once	2.32 a	1.34 a	0.39 a	1.48 a	0.45 ab	2.32 a	0.81
Twice	1.68 b	1.24 b	0.30 b	1.56 a	0.58 a	2.44 a	0.77
Thrice	1.12 c	0.86 c	0.21 c	1.10 b	0.43 b	1.73 b	0.75
Significance	****	****	****	***	*	***	ns
Leaf pruning							
Without	1.76	1.19	0.32	1.42	0.48	2.21	0.79
With	1.63	1.09	0.28	1.34	0.49	2.11	0.77
Significance	ns	ns	ns	ns	ns	ns	ns
Transplanting × leaf pruning							
Once/without	2.53 a	1.44	0.46 a	1.57 ab	0.40	2.43	0.84
Twice/without	1.74 b	1.25	0.30 bc	1.48 ab	0.58	2.36	0.76
Thrice/without	1.03 d	0.91	0.20 c	1.20 bc	0.45	1.85	0.76
Once/with	2.11 ab	1.23	0.32 b	1.38 ab	0.50	2.20	0.77
Twice/with	1.63 bc	1.24	0.31 b	1.65 a	0.58	2.53	0.78
Thrice/with	1.16 cd	0.80	0.21 bc	1.00 c	0.40	1.60	0.75
Significance of interaction	*	ns	***	***	ns	ns	ns
Grand mean	1.70	1.15	0.30	1.38	0.48	2.16	0.78
CV (%)	15.2	14.2	21.1	18.6	25.7	16.0	6.8

Note: *, *** and **** indicate significant levels at $P < 0.10$, 0.01 and 0.001 (*F*-test), respectively; ns = not significant. Different letters in a column indicate significant difference at $P < 0.05$, according to Duncan's 'multiple range test'.

Harvest index refers to the proportion of the total dry weight in the harvested organs (corm + pseudostem) prior to 'kocho' making processes such as scraping the pseudostem pulp, pulverising the corm and fermenting the mixture.

were no significant differences between transplanting once or twice. Leaf pruning treatments did not affect total dry matter production and treatment interactions were not significant.

Harvest index

The harvest index in this context refers to the proportion of the total dry weight in the harvested plant parts prior to 'kocho' preparation.

Harvest indices 104 or 130 weeks after first transplanting ranged from 0.60 to 0.68 and 0.75 to 0.84, respectively. Harvest indices were affected by treatments in the first harvesting time. Successive transplanting significantly reduced harvest index. Transplanting thrice also showed reduced harvest index in the second harvesting, but the effect was not significant. Leaf pruning effects or interactions were not significant either.

As 'kocho' making includes several processes, there is a tremendous loss of dry matter. Thus, the harvest index of enset will be very small if the final fermented yield of 'kocho' is the only product of interest.

Dry matter production rate of 'kocho' soon after scrapping

At 104 weeks after removing the suckers from the corm, transplanting of enset directly into the permanent field (T1) gave highest fresh and dry matter production rates of 'kocho' soon after scraping at both leaf pruning treatments. Production rate of transplanting thrice and especially of transplanting twice were considerably lower (Table 3). Differences in 'kocho' production rates were consistent with differences in total dry matter production rate and those in pseudostem production rate. Leaf pruning had no effect on 'kocho' production rates. Significant interactions were not observed among treatments.

Averaged over leaf pruning treatments, there was a significant difference in 'kocho' (before fermentation) dry matter yield between transplanting once or twice 130 weeks after first transplanting. Both treatments were significantly higher than transplanting thrice (Table 4). Leaf pruning significantly reduced 'kocho' production rate, especially for the once transplanted crop. The interaction between treatments was statistically significant at $P < 0.10$.

Dry matter production rate of 'kocho' after fermentation

At 104 weeks after first transplanting, fresh and dry matter production rates of 'kocho' after 88 days of fermentation were higher for transplanting once than for transplanting twice or thrice (Table 3). There was a significant difference between leaf pruning methods on fermented fresh or dry matter production rate of 'kocho'. Leaf pruning reduced dry matter yield of fermented 'kocho' by 17%.

Table 3. Effects of repetitive transplanting and leaf pruning on final yield of 'kocho' 104 weeks after the first transplanting.

Treatments	Soon after scraping			After 88 days of fermentation			Recovery (%)	
	Fresh weight (kg ha^{-1} per year)	Dry weight (kg ha^{-1} per year)	Moisture (%)	Fresh weight (kg ha^{-1} per year)	Dry weight (kg ha^{-1} per year)	Moisture (%)	Fresh	Dry
Transplanting								
Once (T1)	59310 a	11790 a	80	18430 a	5968 a	68	31	51
Twice (T2)	25650 c	4908 c	81	7508 c	2403 c	68	29	49
Thrice (T3)	36750 b	8558 b	77	10430 b	4792 b	54	28	56
Significance	****	****		****	****			
Leaf pruning								
Without (P0)	41267	8559	79	12809	4798	63	31	56
With (P1)	39870	8276	79	11433	3976	65	29	48
Significance	ns	ns		*	**			
Transplanting × leaf pruning								
Once/without	62500	11822	81	20669 a	6942 a	66	33	59
Twice/without	22800	4355	81	6625 d	2120 c	68	29	49
Thrice/without	38500	9500	75	11133 c	5333 b	52	29	56
Once/with	56111	11750	79	16190 b	4994 b	69	29	43
Twice/with	28500	5460	81	8390 cd	2685 c	68	29	49
Thrice/with	35000	7617	78	9717 c	4250 b	66	28	56
Significance of interaction	ns	ns		**	**			
Grand mean	40569	8418	79	12121	4387.4	63	30	52
CV (%)	19.9	19.8		15.2	20.0			

Note: *, ** and **** indicate significant levels at probability < 0.10, 0.05 and 0.001 (F-test), respectively); ns = not significant. Different letters in a column indicate significant difference at $P < 0.05$, according to Duncan's 'multiple range test'.

For fresh and dry matter yields of fermented 'kocho' there was a significant interaction between leaf pruning and transplanting treatments. For transplanting once leaf pruning reduced the production rates of fermented 'kocho' considerably, for transplanting twice leaf pruning did not significantly or consistently affect production rates and for transplanting thrice leaf pruning had a small negative non-significant effect (Table 3).

At 130 days after first transplanting, transplanting once resulted in higher fresh and dry matter production rates soon after scraping than for the other two transplanting treatments; leaf pruning reduced these production rates at transplanting once or thrice (Table 4). After fermentation, transplanting thrice resulted in significantly lower production rates, both without and with leaf pruning, than the other transplanting treatments. Leaf pruning also reduced fermented fresh yields, but the effect was not significant for dry yields at $P < 0.05$, because of the large variation.

Table 4. Effects of repetitive transplanting and leaf pruning on final yield of 'kocho' 130 weeks after the first transplanting.

Treatments	Soon after scrapping			After 88 days of fermentation			Recovery (%)	
	Fresh weight (kg ha^{-1} per year)	Dry weight (kg ha^{-1} per year)	Moisture (%)	Fresh weight (kg ha^{-1} per year)	Dry weight (kg ha^{-1} per year)	Moisture (%)	Fresh	Dry
Transplanting								
Once (T1)	62560 a	11550 a	82	19000 a	5704 a	69	30	49
Twice (T2)	46720 b	8878 b	81	16898 a	5090 a	70	36	57
Thrice (T3)	36670 c	5637 c	85	7833 b	2673 b	73	21	38
Significance	****	****		****	****			
Leaf pruning								
Without (P0)	54332 a	9552 a	82	16303 a	4820 a	70	30	50
With (P1)	42966 b	7826 b	82	12850 b	3791 b	71	30	48
Significance	***	**		**	*			
Transplanting × leaf pruning								
Once/without	75110 a	13600 a	82	23000	7267 a	68	31	53
Twice/without	46550 b	8845 bc	81	17240	4769 abc	72	37	54
Thrice/without	41330 bc	6207 cd	85	8667	2427 cd	72	21	39
Once/with	50000 b	9500 b	81	15000	4142 bcd	72	30	44
Twice/with	46900 b	8910 bc	81	16550	5410 ab	67	35	61
Thrice/with	32000 c	5067 d	84	7000	1820 d	74	22	36
Significance of interaction	**	*		ns	*			
Grand mean	48649	8688	82	14576	4356	71	29	48
CV (%)	16.5	20.6		26.4	37.5			

Note: *, **, *** and **** indicate significant levels at $P < 0.10$, 0.05, 0.01 and 0.001 (F-test), respectively; ns = not significant. Different letters in a column indicate significant difference at $P < 0.05$, according to Duncan's 'multiple range test'.

Moisture content of 'kocho'

The moisture content of 'kocho' (the mixture of scraped pseudostem and pulverised corm) soon after scraping in the two harvesting times ranged from 75 to 85%, whereas the moisture content of the fermented dough before squeezing ranged from 52 to 74% (Tables 3 and 4). Soon after scraping, 'kocho' has a high content of moisture. Since the pit where the mixture was put for fermentation was reopened and rearranged to press the product again, after the fermentation process the fermented dough contained less moisture compared to the mixture soon after scrapping. Moisture contents were fairly similar for all treatments or treatment combinations before fermentation, but considerably lower for transplanting thrice after fermentation at 104 weeks after first transplanting.

Recovery of 'kocho' dry matter

Weights of the fermented 'kocho' were taken 88 days after the time of scraping. The fresh matter recovery of 'kocho' after fermentation in the two harvesting times ranged from 21 to 37%, whereas dry weight recovery of 'kocho' after fermentation ranged from 36 to 61%. Recoveries were affected by transplanting treatments: transplanting thrice showed lower recovery, whereas transplanting twice showed higher recovery than transplanting once at 130 weeks after first transplanting.

Discussion

Flowering and maturity

In enset, the latest moment for harvesting is when the inflorescence appears. At that time the dry matter yield is about maximum and the distribution of the dry matter most advantageous for 'kocho' production. A 3 to 10-years maturity period has been reported frequently for enset (Simmonds, 1958; Stanley, 1966; Bezuneh and Feleke, 1966; Bezuneh *et al.*, 1967; Westphal, 1975; Kefale and Sandford, 1991; Pijls *et al.*, 1995). This long maturity period is presumably the result of the traditional cultivation practices whereby every shoot is transplanted 2–4 times using narrow spacing before it is planted into permanent field. Under the conditions of our experiment (1750 m asl), the least disturbed plants (T1, without pruning) took two years to reach harvest maturity, whereas more frequent transplanting postponed flowering by 2–3 years. Our results are consistent with earlier observations of HSIU (1985) and Bezuayehu *et al.* (1996) on time of maturity. Although yield data were not available from the earlier studies, in both cases they observed that suckers directly transplanted into permanent field after separating from the mother corm reached maturity earlier and gave greater measurements of yield components. Therefore, the reduction in rate of growth as a result of repetitive transplanting may be compensated by the prolonged growth period. The precise mechanisms for the delay in flowering and prolongation of the growing period need to be investigated further.

Cumulative dry matter yield per plants

The cumulative above-ground dry matter yield of individual enset plants from different transplant treatments peaked at different dates and at different levels, before yields started to decline due to the senescence triggered by flowering. Plants transplanted once reached a maximum of 27 kg per plant two years after separating suckers from the corm, plants transplanted twice accumulated 44 kg per plant after 4.5 years, and plants transplanted thrice reached a maximum yield of 31 kg per plant 4.5 years after sucker planting (Fig. 2). The decline in yield in all treatments was due to the monocarpic nature of the enset plant. After the terminal bud is induced to flowering, the vegetative growth of the whole plant ceases, present leaves die, whereas no new ones are initiated. In this respect enset behaves similarly to banana. The inflorescence then starts to use up the starch produced by the plant and temporarily stored in the pseudostem and corm. Decline in leaf and pseudostem growth at the onset of fruiting was also reported by Bezuneh *et al.* (1967).

Dry matter production rate of plant components and total dry matter production rate
As reliable data on dry matter yield of plant components of enset after long-term growth are not present in literature, it was not possible to compare our results of this trial to those of other authors. We will, therefore, restrict ourselves to a discussion on the treatment effects over time.

Whereas the duration of rapid growth was much longer in plants transplanted twice, the maximum rate of growth of the entire plant achieved by T1 plants was never attained by the other treatments. This is also true for the production rates of the harvestable plant fractions.

The higher dry matter production rate of enset plants transplanted only once over the first 104 weeks after removing suckers from the corm – for plant fractions, total dry matter and 'kocho' – was because of a faster growth as reflected in leaf area development (not shown) and the pseudostem, and to less competition. The directly transplanted enset plants were not disturbed by repetitive transplanting shocks and remained in the permanent field for longer. Consequently, the corm and pseudostem accumulated more dry matter in the first years, compared to twice or thrice transplanted shoots (Table 1). Associated with the uninterrupted growth, the 1-year-old transplants flowered after only 104 weeks. Those transplanted twice or thrice experienced more transplant shocks and more competition but had a prolonged time from planting to flowering (Fig. 2). As a result, the 1-year-old transplants gave higher dry matter production rate of 'kocho' soon after scraping and after fermentation when the growing period was short. A higher yield of 'kocho' soon after flowering was also mentioned from observations and survey works of Bezuneh (1984), Kefale and Sandford (1991) and Zippel and Kefale (1995).

The initial differences in dry matter yield and dry matter production rate between transplanting treatments in favour of direct planting soon disappeared, at least when transplanting once was compared to transplanting twice. This is partly due to the positive consequences of the change in dry matter partitioning caused by repetitive transplanting and partly due to the more effective utilisation of space in the frequently transplanted treatments. Although the yield per plant of 1-year-old transplants was higher on 130 weeks after removing suckers from the corm, when yield is expressed per unit space and time, there was no significant difference in the production of dry matter. The same effect was also observed at 104 weeks after first transplanting between twice and thrice transplanted enset suckers. Thrice transplanted enset suckers gave higher dry matter production rates of pseudostem, leaf and total dry matter compared to twice transplanted enset suckers when yield is expressed as per unit space and time (Table 1). This could be one of the justifications why farmers in densely populated areas practise repetitive transplanting in the first years of growth.

The general lack of significant early effects of leaf pruning on dry matter production rates of plant components and total dry matter of 'kocho' could be due to the high leaf emergence rate of enset plants at early stages of growth. Leaf emergence rate of enset has not yet been described accurately. Allen *et al.* (1988) indicated that in bananas, a plant in the same family with enset, leaf emergence rate increases during the establishment phase of the plants and then, after 64 days, decreases over time. During the experiment leaf pruning was repeated every 6 months and the effect of leaf pruning gradually increased over time (data not shown). First significant reducing effects of leaf pruning on 'kocho' yield in treatment T1 already appeared when the inflorescence reached considerable weight (i.e., at 130 weeks after first transplanting (Table 4). It is likely that leaf pruning would have become more deleterious for the other transplanting treatments after 5 years as well, since also in these treatments leaf initiation stopped after the appearance of the inflorescence. This indicates that in enset plants at the later stage of growth, when leaf emergence slows down, leaf pruning might have an effect on the yield of plant components and 'kocho', and this needs to be investigated further. For banana, Robinson *et al.* (1992) showed that maintaining eight functional leaves after flowering was enough to obtain full bunch growth, the same number as was maintained in our enset experiment.

Bezuneh (1984) determined the food potential of three major enset clones. The yield of fermented product was 18.5, 22.2 and 29.8 kg per plant for 'Ferezae', 'Tuzuma' and 'Adew', respectively. Although the investigator did not mention whether the enset plants had already flowered at the time of harvesting, it was indicated that the enset plants were harvested after 40 months of field cultivation. In this experiment, after 24 months of field cultivation directly transplanted enset plants of clone 'Halla' gave 16.6 kg per plant of fermented product. Leaving other factors aside and considering the dry matter production per month, the yield of 'Halla' was with 0.69 kg per plant per month higher than the yield of 'Fereze' (0.46 kg per plant per month) and 'Tuzuma' (0.56 kg per plant per month).

Loss of dry matter during the fermentation process

We observed dry matter losses of 39–64% at 104 or 130 weeks after first transplanting due to 88 days of fermentation. Bezuneh (1984) did not mention the length of the fermentation period but he found 66–70% dry matter loss for three clones of enset during the fermentation period. This dry matter loss is greater than the dry matter loss recorded in our experiment. The greater loss might be due to the longer duration of the fermentation period, the condition of the pit, type of the clone, etc. Anyway, a dry matter loss of about 50% seems normal. This high loss of dry matter might be because of the long fermentation period, loss of soluble materials because of leaching, type of wrapping materials used in the fermentation process, types of herbaceous plants and enset plant parts used as a yeast source to hasten the fermentation, storage temperature, etc. To find ways of minimising the loss of dry matter during the fermentation process, more research in this field is needed, especially because in all enset growing areas farmers traditionally use various methods of fermentation, and different herbaceous plant species and parts of specific enset clones as a yeast source to hasten the fermentation process.

Practical implications

Farmers have different options. Transplanting enset suckers directly into permanent field shortens the period until maturity, provides a reasonable yield soon after removing the suckers from the corm and reduces the chance of attack by diseases or pests. Therefore, farmers may practise transplanting suckers directly into permanent field to obtain an early yield. Generating enough suckers is usually not a problem. For direct planting, however, a suitable cropping system is needed that enables farmers to secure enough mature enset plants that can be harvested for food at any time of the year.

Traditionally, however, farmers practise repetitive transplanting at early stages of growth, to save space and get high dry matter yield per unit area of land. This practice makes sense for longer growing periods, since flowering and plant senescence are delayed and thus the growing period is prolonged to such an extent that it more than compensates for the extra transplant shock, the reduction in early growth rate and the extra competition in the nursery.

Since leaf emergence rate of enset is high at early stage of growth, especially in areas where there is shortage of animal feed, partial leaf pruning can be practised to feed animals or for other purposes. At later stages of growth, however, prolonged leaf pruning may become more deleterious and should be avoided.

CHAPTER 7

Influence of repetitive transplanting and leaf pruning on harvest indices, harvest and post harvest losses of enset (*Ensete ventricosum* (Welw.) Cheesman)

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CHAPTER 7

Influence of repetitive transplanting and leaf pruning on harvest indices, harvest and post harvest losses of enset (*Ensete ventricosum* (Welw.) Cheesman)

Abstract

Harvesting and processing procedures in enset *(Ensete ventricosum)* production systems are diverse and their efficiency may depend on the agronomy of the crop. Understanding the patterns of growth and dry matter partitioning may be useful in optimising harvesting and processing. Influences of repetitive transplanting and leaf pruning methods on harvest indices and recovery of the main food product 'kocho' after fermentation were studied at the Areka Research Centre, North Omo, southern Ethiopia. Repetitive transplanting prolonged the partitioning to harvestable parts and restricted losses because of scraping or fermentation. Until flowering, partitioning was rather constant. At flowering, harvest indices based on fermented enset products of once, twice and three times transplanted enset suckers were 0.20, 0.35 and 0.25 kg kg^{-1}, respectively. Leaf pruning alone or the interaction between leaf pruning and transplanting did not significantly affect dry matter partitioning, harvest index or processing losses.

Although repetitively transplanted enset plants combined high yield and low losses at the time of flowering, most farmers cannot afford to wait until flowering because of shortage of food. We suggest to harvest repetitively transplanted enset suckers at approximately 182 weeks after first transplanting.

Keywords: Enset, transplanting, leaf pruning, harvest index, 'kocho', harvest losses

Introduction

Enset (*Ensete ventricosum* (Welw.) Cheesman) is a large herbaceous banana-like plant. It is a major food source of people in the highlands of south and southwestern Ethiopia. By-products include good quality fibre for making rope and livestock feed. Local people also believe that specific landraces have various medicinal properties.

Enset is primarily grown to obtain a starchy product from the pseudostem and corm, which is fermented into 'kocho'. The optimal harvesting time of enset for the preparation of 'kocho' is soon after the appearance of the inflorescence (Tsegaye and Struik, 2000a). At which age enset plants are harvested is decided in different ways depending on region. Gurage farmers harvest the crop nearly mature, while Hadiya and Sidama farmers tend to harvest many mature plants with few young immature ones. In general, poor farmers never wait until flowering because of shortage of food.

The harvesting of enset has various stages. The main are: (a) removing leaf blades and upper top of the shoot of the plant that are not used for food preparation; (b) cutting the pseudostem longitudinally into pieces; and (c) scraping the fleshy parts of the pseudostem and pulverising corm into small pieces. In general, the various stages of harvesting are accomplished by hand using traditional tools; considerable harvest losses occur. The harvested products of enset are not immediately consumed but are mixed, compressed and allowed to ferment in a pit for a period of several weeks or even months. Fermentation is a conservation method, but Urga *et al.* (1997) reported that 'kocho' fermentation also improved flavour and texture of the food product. Fermentation is also associated with (partly unavoidable) losses.

Agronomic practices of enset related to repetitive transplanting and leaf pruning methods are diverse. Farmers usually transplant enset suckers once or up to four times, at ever wider spacing before transferring into permanent field (Brandt *et al.*, 1997). Tsegaye and Struik (2000b, Chapter 6) concluded that transplanting enset suckers once shortens the period until maturity, provides a reasonable yield soon after removing suckers from the corm and reduces the chance of attack by diseases and pests, but transplanting twice increases yield potential over a longer growing period. However, the effect of transplanting several times on partitioning of assimilates to the harvestable parts and their subsequent recovery has not been reported in detail.

Farmers usually remove part of the leaves from enset plants. The number of leaves removed depends on available alternative sources for livestock feed and utensils construction. This practice may reduce yield. Lövenstein *et al.* (1992) and Hay and Walker (1989), however, noted that at greater leaf area index older, shaded leaves in the lower parts of the crop canopy tended to reach light levels below the compensation point, and thus became sinks rather than sources of assimilates. Mild leaf pruning may therefore be harmless. Severe leaf pruning, however, as is common in some enset growing regions, may result in shortage of assimilate and irregular growth and development. Pillai and Shanmugagelu (1977) reported a delay in flowering and reduction of bunch mass of banana when leaf number was continually maintained at 6 instead of 18. Robinson *et al.* (1992) reported that with four leaves retained, annual yield decreased in a ratoon crop of banana. Tsegaye and Struik (2000b, Chapter 6) observed no consistent effect of mild leaf pruning on enset yield. The interaction between transplanting and leaf pruning practices were also not significant.

The effects of cultural practices such as repetitive transplanting and leaf pruning on yield losses at the various harvest stages and the associated post harvest losses have not been reported in detail. A better insight in these effects may help to understand the rationale behind current procedures and may be useful in optimising cultural and processing practices. It can also help the farmers to predict the most suitable harvesting time.

Materials and methods

Experimental site

The study was carried out at Areka Research Centre, North Omo Zone, southern Ethiopia. Areka, located 7° 09′ N and 37° 47′ E at an elevation of 1750–1820 m asl, is a representative national research centre for enset and root and tuber crops. Average annual rainfall (1993–1999) was 1546 mm with a minimum/maximum mean air temperature of 14.5 °C/25.8 °C. The soil was well-drained, stone free, with texture class of silt loam at 0–15 and 30–45 cm depth and loam at 15–30 cm depth. The pH was 4.9, 4.5 and 4.6 at 0–15, 15–30 and 30–45 cm depth, respectively. The total N % (Kjeldahl) and CEC at 0–15 cm were 0.196 and 22.1 meq per100 g, respectively. Fertilisers (100 kg urea ha^{-1} y^{-1} and 100 kg DAP ha^{-1} y^{-1}) were applied for the first two years both in nursery beds and permanent fields.

Treatments and experimental design

The treatments consisted of three transplanting methods combined with two leaf pruning methods. The transplanting methods were (i) transplanting 1-year-old suckers produced in the nursery from the corm directly into the permanent field (T1), (ii) transplanting 2-years-old transplants into permanent field after they had been raised from the corm nursery by transplanting into nursery beds (T2), (iii) transplanting 3-years-old transplants into the permanent field after they had been raised by transplanting twice into nursery beds (T3). The leaf pruning treatments were (i) without leaf pruning (P0) and (ii) with leaf pruning (P1). The six treatment combinations were arranged in a randomised complete block design with four replications. For details, see Fig. 1 in Chapter 6.

Crop management

Split corms of cultivar 'Halla' were planted 1 m apart under 10 to 20 cm of soil mixed with cow manure on the 2nd of March 1993. In March 1994, suckers were separated from the mother corm, and either transplanted directly into the permanent field (T1) or transplanted into a second nursery bed of 1.0 m × 0.5 m. In March 1995, some 2-years-old transplants were transferred into the permanent field (T2), while the remaining shoots were transplanted into a third nursery bed at a spacing of 1.0 m × 1.0 m. These 3-years-old transplants were transplanted into the permanent field in March 1996 at 1.5 m × 3.0 m (T3). For details, see Fig. 1 in Chapter 6.

Leaf prunings (P1) were carried out by removing the dead leaf sheaths and the old green leaf blades on the lower part of the plant in March and September of each year. At least eight functional leaves were left on the plant. Plants without leaf pruning (P0) were allowed to grow freely.

Data collection and analysis

Details on data collection and yield data have been reported previously by Tsegaye and Struik (2000b, Chapter 6). In short procedures were as follows. From 104 weeks after first transplanting into the permanent field onwards, yield data of plant components were recorded at 26 weeks intervals. Per sampling two plants per plot were uprooted and separated into harvestable (corm, pseudostem and stalk) and not harvestable (leaf blades and sheaths, and inflorescence) plant components by experienced local housewives. The above-ground fresh weight of all fractions and their dry matter concentration were determined. Pseudostem and corm processing was also carried out by experienced local women (housewives). The pseudostem of the sample plants was cut into several pieces and scraped, whereas the corm was pulverised. The scraped pseudostem and the pulverised corm were mixed. After determining fresh weight and sampling for assessing dry matter concentration, the remaining material was put into a pit for fermentation. Every two weeks the pits were opened and the contents were pressed and re-arranged to improve the fermentation process. After 88 days of fermentation, the fresh weights and dry matter concentrations were assessed again.

Dry matter production of pseudostem and corm before and after scraping and dry matter production of 'kocho' were expressed per plant (in kg plant^{-1}). Harvest indices were calculated as the ratio of the combined pseudostem and corm dry matter weight before scraping, after scraping and after 88 days of fermentation divided by whole plant dry weight at harvest.

Losses because of scraping were defined as the combined dry matter yield of the pseudostem and corm minus the consumable dry matter recovered after scraping. These losses were expressed as percentage of the combined pseudostem and corm dry matter weight. Losses because of fermentation were defined as the dry matter yield after scraping minus the dry matter after fermentation and expressed as percentage of the dry matter after scraping.

The data were processed by analysis of variance procedures (Genstat 5.4.1). When significant treatment effects occurred, means were separated by LSD (0.05).

Results

Total dry matter production per plant

Transplanting effects on total dry weight (kg plant^{-1}) were significant for all harvest dates except at 260 weeks after first transplanting (Table 1). Maximum total dry weights were 29.40 and 48.20 kg plant^{-1} for T1 and T2, respectively, and were obtained at flowering. Thrice transplanted enset plants showed its maximum dry weight already before flowering. The T2 treatment usually had the highest yields. The mild leaf pruning treatment hardly affected total plant yield (data not shown).

Combined corm and pseudostem dry matter yield

Transplanting effects on combined dry matter yield of corm and pseudostem before scraping were significant at all harvest dates except at 260 weeks (Table 1). Maximum dry matter yields were 20.95 and 37.20 kg per plant for T1 and T2, respectively, and were obtained at (T2) or shortly after (T1) flowering. At 104 and 130 weeks, T1 treatment gave the highest harvestable dry matter yield, but thereafter T2 yielded best. At 260 weeks, T2 and T3 treatments gave similar harvestable yields. Leaf pruning did not affect the harvestable yield (data not shown).

Table 1. Total and harvestable dry matter yields of enset (in kg per plant) and the percent dry matter losses associated with the process of harvesting or conservation, when harvested at different weeks after first transplanting into permanent field for three transplanting treatments. Plants of T1 senesced after 156 weeks after first transplanting.

Trans-planting	Stages of harvesting	Weeks after removal from the mother corm						
		104	130	156	182	208	234	260
Once	Total yield (kg plant^{-1})	29.40	27.13	27.61				
	Corm and pseudostem (kg plant^{-1})	17.68	20.95	17.22				
	% loss because of scraping	40	38	52				
	% loss because of fermentation	49	51	34				
Twice	Total yield (kg plant^{-1})	6.80	17.67	23.39	26.98	35.00	48.20	32.70
	Corm and pseudostem (kg plant^{-1})	4.01	13.54	18.76	22.11	27.60	37.15	22.80
	% loss because of scraping	39	52	50	47	45	46	24
	% loss because of fermentation	51	44	40	21	22	17	57
Thrice	Total yield (kg plant^{-1})	3.20	6.45	11.61	16.91	24.40	31.00	29.10
	Corm and pseudostem (kg plant^{-1})	2.19	5.20	9.03	14.90	20.60	26.90	23.46
	% loss because of scraping	33	57	57	52	56	43	23
	% loss because of fermentation	44	64	29	27	30	30	56
	Total yield CV (%)	45.1	14.2	15.2	15.9	18.6	20.0	15.6
	LSD (0.05)	6.3***	2.6***	3.4**	3.9***	6.0**	8.9**	ns
	Corm and pseudostem CV (%)	28.1	18.0	21.1	21.2	22.4	21.0	14.6
	LSD (0.05)	2.4***	2.5***	3.4***	4.3**	5.9*	7.3**	ns
	Loss because of scraping CV (%)	15.6	13.9	22.6	27.0	23.3	14.9	54.0
	LSD (0.05)	$P<0.08$	7.3***	ns	ns	$P<0.09$	ns	ns
	Loss because of fermentation CV (%)	22.6	28.1	27.6	28.4	37.9	56.0	15.1
	LSD (0.05)	ns	15.8	$P<0.09$	$P<0.09$	ns	$P<0.08$	ns

Note: ns, *, **, and *** stands for non-significant, significant at $P < 0.05$, 0.01, and 0.001, respectively (F-test). Different letters in a column indicate significant difference at $P < 0.05$. T1, T2 and T3 plants flowered at 104, 234 and 260 weeks after first transplanting, respectively.

Harvest indices (HI), harvest and post harvest loss

The combined pseudostem and corm dry matter yield as a fraction of total plant dry weight before scraping and pulverising (HI(1)), after scraping and pulverising (HI(2)) and after 88 days of fermentation (HI(3)) were not affected by the leaf pruning treatments.

For T1, the HI(1), HI(2) and HI(3) at 130 weeks of first transplanting were considerably higher than at 104 weeks but subsequently decreased again (Fig. 1). Dry matter loss because of scraping ranged between 38–52% for T1 and was highest at 156 weeks when plants already started to senesce (Table 1). The losses because of fermentation started to decrease at senescence. On average, scraping caused ca 43% and fermentation ca 45% loss in T1.

For T2, HI(1) initially increased after 104 weeks of first transplanting, then levelled off and finally decreased again (Fig. 1). HI(2) initially was rather stable, but reached a higher level at 182 weeks, and increased rapidly over the last phase. The HI(3) increased slowly at first, but rapidly between 156 and 182 weeks and then declined again. The maximum dry matter losses because of scraping of T2 treatment were recorded at 130 or 156 weeks and thereafter started to decrease reaching the lowest value at 260 weeks (Table 1). The fermentation losses were initially higher and started to decrease after 182 weeks, reaching the lowest value at flowering. On average, scraping caused about 43% and fermenting about 36% loss in T2.

HI(1) of the T3 treatment initially increased but remained more or less constant after 182 weeks (Fig. 1). HI(2) initially decreased and only started to increase considerably after 208 weeks. HI(3) initially declined and then increased reaching a peak at 234 weeks. For T3, yield loss because of scraping ranged from 23–57% being the lowest at flowering (Table 1). Initially, yield loss because of fermentation was high for T3 but later decreased until 234 weeks. Averaged over all harvest dates scraping losses were 46% and fermentation losses were 40%.

Discussion

Use of harvest index as an indicator of quality of processing

The harvest index is frequently used as an indicator of partitioning to crop organs that are used for human food. Although starch is extracted only from the corm and pseudostem, the whole plant except the roots is economically important. In this paper we use harvest indices to refer to the combined corm and pseudostem dry matter yield before scraping, after scraping and after fermentation as a fraction of total plant dry matter yield.

The harvesting process of enset has several complicated stages. The leaf sheaths of the pseudostem are peeled off one after the other until the peduncle is reached. These sheaths

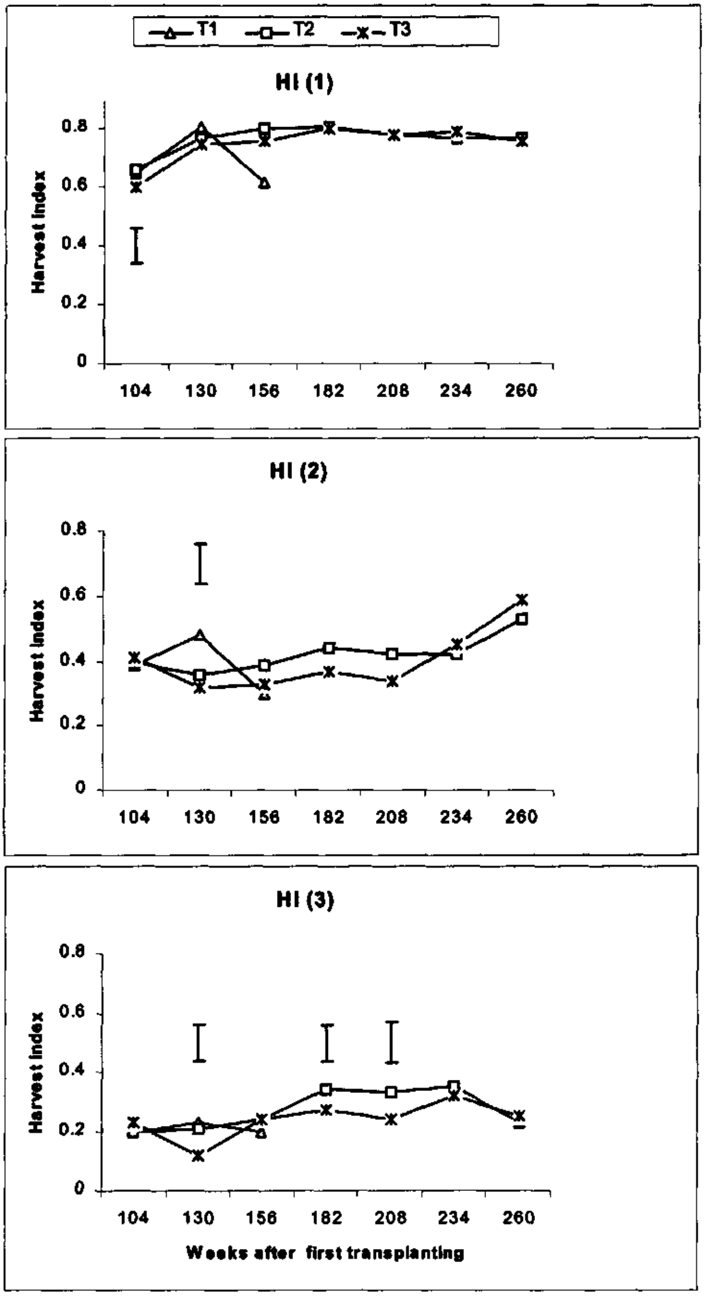

Fig. 1. Harvest index (kg kg^{-1}) of enset transplanted once (T1), twice (T2) and three times (T3) at different weeks after first transplanting. HI(1), HI(2) and HI(3) are harvest indices before scraping, immediately after scraping and after 88 days of fermentation, respectively. Vertical bars indicate LSD (P=0.05) where differences were significant.

are cut into several longitudinal pieces and made ready for scraping. A single cut of the leaf sheaths is attached to the wooden pole with a string, and using a bamboo split, a woman from a strenuous sitting position scrapes the fleshy part down towards a collecting place lined with enset leaves. This process leaves the fibre in the stem, while letting the fleshy part and juice to accumulate. The corm is also dug out and transported to the place where the leaf sheaths of the pseudostem are processed. A serrated animal bone (scapula) or a sharp wood is used to pulverise the corm into smaller granted pieces. The scraped fleshy part of the pseudostem and the pulverised corm are mixed and transported to a pit to ferment. All these processes are accomplished by hand using traditional tools and thus a substantial loss occurs. Moreover, during scraping the pseudostem and pulverising the corm, the upper most parts of the pseudostem sheaths, long fibres of pseudostem and the outer core of the corm which are believed to spoil the quality of 'kocho' are removed. In our trials this resulted in a HI(2) of about 44%.

Pre-harvest growing conditions affect HI(2). Excessive rainfall causes pseudostem rotting, and prolonged dry periods reduce the fleshy parts of the sheaths resulting in an increase in yield loss because of scraping. Decay of corm by potential pests such as mole rat and nematodes also increases the yield loss during pulverising the corm.

The mixture of the scraped pseudostem pulp and pulverised corm is not immediately consumed but allowed to ferment in a water-permeable earthen pit for a period of weeks or months. This again is associated with considerable losses of dry matter. The fermentation process itself is associated with the production of volatile compounds and water resulting in unavoidable dry matter losses. On top of that inefficiencies in the system cause additional losses. Our method of drying may also have resulted in extra loss of dry matter that is not relevant for practical considerations. As a result the average HI(3) of all the three transplanting treatments was much lower than the average HI(2). Urga *et al.* (1997) also reported a 15, 16 and 34% reduction in protein, ash and the most abundant carbohydrates, respectively, following a short period of fermentation. Tsegaye and Struik (2000b) indicated that more dry matter was lost by longer duration of fermentation associated with prolonged activity of micro-organisms and loss of soluble materials because of leaching. Also, dry matter loss could occur when pits were opened and contents were pressed and re-arranged every two weeks to improve the fermentation process. Although some of the harvest and processing losses of enset are associated with extracting edible parts, conservation or improving the digestibility, the overall estimated losses are higher than for fruits, tuber crops and vegetables. For example, Srinivas *et al.* (1997) reported losses to the extent of 17.9% for mango; Madan (1988) reported about 9–15% loss of banana and Bancroft *et al.* (1998) reported about 10% losses for yam (*Dioscorea* spp.). Similarly, Harvey (1978) estimated post harvest loss of 11.7% for lettuce, 14.2% for tomato and 12.6% for peach.

Allen and Scott (1980), Yao *et al.* (1988), Bouwkamp and Hassam (1988) and Chowdhury (1998) reported harvest index ranges of 0.61–0.90 for potato, 0.45–0.54 for cassava, 0.46–0.81 for sweet potato and 0.50–0.69 for yam, respectively. Our average HI(1) of T1 (0.73), T2 (0.75) and T3 (0.74) plants fall within the harvest index range of potato and sweet potato. The average HI(2) (0.4) averaged over all harvest dates is comparable to the harvest index of improved varieties of wheat and barley. Irvine (1983) estimated the harvest index of sugar cane to be 0.23 assuming sucrose the only economically useful product, which is within our range of HI(3) (0.20–0.35).

Trends over time

In general, the dry matter partitioning in enset is rather conservative until flowering. As transplanting had a large effect on the time of flowering it also affected the harvest indices and the losses. Most dramatic changes in harvest indices were observed after flowering, suggesting that farmers cleverly use that physiological stage to identify best harvest time. After flowering losses because of scraping and fermentation show opposite trends. This may indicate that at plant senescence the housewives tend to add extra material to the pit that would otherwise be discarded. At the same time plant senescence results in loss of material that is essential to the fermentation or forces housewives to include material in the pit that cannot be stored properly.

Effects of transplanting and leaf pruning treatments

The total dry matter yield (kg plant^{-1}), the dry matter yield of the harvestable parts and the harvest indices at the different stage of processing were improved as a result of repetitive transplanting (Fig. 1; Table 1), especially for T2 compared to T1. An increase in dry matter yield of the harvestable parts of T2 and T3 treatments as the growing period progresses may be due to the prolonged vegetative phase of the crop. Repetitive transplanting initially retarded the growth of the pseudostem and corm but later it increased the sink size and capacity and delayed senescence. As the leaf emergence rate of enset was high and leaf area was adequate leaf pruning treatments did not affect the yield, harvest losses or harvest indices. Interaction between transplanting and leaf pruning treatments were also not significant.

Practical implications

Most farmers cannot afford to wait until the enset plant flowers because of shortage of food. This study suggests that harvesting repetitively transplanted enset suckers may start approximately after 182 weeks after first transplanting. Harvest indices and the recovery of 'kocho' of repetitively transplanted enset suckers improved after 182 weeks after first transplanting. In the traditional harvesting procedures, harvest indices are rather low and losses of dry matter considerable. There is ample room for improving traditional procedures for harvesting, processing and conservation.

Repetitive transplanting prolonged the immaturity period of enset, improved the partitioning of dry matter to the harvestable parts, increased 'kocho' yield per unit space and time and sometimes improved the recovery of 'kocho' after fermentation.

Enset plants maintain more green leaf area than is essential to obtain a high yield of 'kocho' or total plant dry matter. Further research work should investigate the minimum leaf number that needs to be retained on the plant to use excess leaves for other purposes.

CHAPTER 8

Enset (*Ensete ventricosum* (Welw.) Cheesman) 'kocho' yield under different crop establishment methods as compared to yields of other carbohydrate-rich food crops

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CHAPTER 8

Enset (*Ensete ventricosum* (Welw.) Cheesman) 'kocho' yield under different crop establishment methods as compared to yields of other carbohydrate-rich food crops

Abstract

The 'kocho' yield of enset, in terms of weight and energy, under different crop establishment methods, was investigated at Areka Research Centre, southern Ethiopia, and compared with the yields of other main starch crops grown in the country. The maximum fresh weights of 'kocho' after fermentation from enset plants transplanted once (T1), twice (T2) or thrice (T3) were 25.9, 54.1 and 37.1 kg plant^{-1}, respectively. When yield was expressed per unit of space and time, the maximum fresh yields of fermented 'kocho' (70% moisture) from T1, T2 and T3 were 19, 33 and 26 t ha^{-1} y^{-1}, respectively.

The 'kocho' yield of enset per unit space and time, in terms of edible dry weight and energy, was much higher than the yields of any other crop cultivated in Ethiopia. Second to enset, the root and tuber crops also produced high yields of dry matter and energy. The cultivation of enset and root and tuber crops in densely populated areas under low input conditions can sustain the population better than that of other crops. Moreover, enset produces various by-products and the prolonged presence of a closed canopy has an ecological advantage similar to that of forest.

Keywords: *Ensete ventricosum*, 'kocho', fresh yield, dry matter yield, food security, fermentation

Introduction

Enset (*Ensete ventricosum* (Welw.) Cheesman) is a herbaceous monocot, large, banana-like plant that grows 4–8 m (sometimes even up to 11 m) in height. Enset traditionally ranked first in importance as cultivated staple food crop in the highlands of central, south and southwestern Ethiopia. The main food product from it is obtained by fermenting the mixture of the scraped pulp of the pseudostem, pulverised corm and stalk of inflorescence and is locally known as *'kocho'*.

The area where enset is used as staple food is characterised by a high density of human population, which cannot be supported with any other type of land use. Stanley (1966), Bezuneh (1984) and Pijls *et al.* (1995) concluded that enset yield is relatively high compared with yields of other food crops. Brandt *et al.* (1997) suggested that the huge volume of harvested yield from one enset plant and from an area, particularly compared to cereals, contribute to the unsubstantiated perception among both farmers and scientists that the yield of enset is tremendous.

Assessment of the usable yield of enset, however, is difficult due to complicated production methods and processing procedures. Enset is a perennial and the vegetatively propagated planting material is yearly transplanted into several nurseries until finally it is planted in a part of the field where it matures until harvest. The spacing varies from phase to phase: the distance between plants is increased at each successive transplantation until it reaches its final spacing in the permanent location. The number of repetitive transplantings, and the spacing of propagules in each nursery phase and in the final field differ among enset-growing regions. Most agronomic research on enset only accounts for the wider spacing of the plant in the final field when determining the 'kocho' yield of enset (Pijls *et al.*, 1995; Endale, 1997).

Leaf pruning is common in enset production, but again the frequency and severity also vary among different enset-growing regions and over time. In some areas the enset plant is left to grow undisturbed, while in others frequent leaf pruning is practised in order to use the leaves for other purposes. Leaf pruning frequency may depend on transplanting practices. Leaf pruning may not only affect yield but also the fermentation processes by influencing the chemical composition of the raw material.

During harvesting the scrapings from the pseudostem together with pulverised corm are put in a pit for storage, usually together with some natural products (e.g., from older corm or some herbaceous plants) that contain the yeast required to rapidly initiate the fermentation process. The starchy product ferments but does not stabilise, so that the pit has to be restored frequently. Unavoidable losses of dry matter may occur through these processes and can be considerable.

To determine yield of usable food from enset for comparison with yields of other crops, it is important to consider the various methods of production, space used at various stages of transplantation and the duration of the growth period. Moreover, it is vital to measure yield in units of edible dry matter and energy to avoid variation in quality of products of different sources. If production of crops can be measured in units of edible dry matter per unit of time and space, it is possible to compare yields of perennial crops with those of annual crops (Cannell, 1989).

In this study, therefore, the edible dry matter yield and energy (kJ) production per unit of space and per day of growth of enset, as affected by different crop establishment methods (repetitive transplanting and leaf pruning), was investigated and compared with the edible dry matter and energy from cereals and root and tuber crops.

Materials and methods

Experimental site

The study was carried out at Areka Research Centre, North Omo Zone, southern Ethiopia, located at 7° 09′ N and 37° 47′ E at an elevation range of 1750–1820 m asl. Areka is a representative national research centre for enset and root and tuber crops.

Averaged over 1993–1999, the annual rainfall was 1546 mm with a minimum/maximum mean air temperature of 14.5 °C/25.8 °C. Rainfall is a bimodal pattern giving rise to two distinct seasons: the short rains between March and May and the heavy rains between June and October. The soil was a well-drained, stone free, silt loam with a pH of 4.5–4.9, depending on depth. The pH of the soils of the southern highlands of Ethiopia are inherently low. The total N % (Kjeldahl) and CEC at 0–15 cm were 0.196% and 22.1 meq per100 g, respectively. Fertilisers (100 kg urea ha^{-1} y^{-1} and 100 kg DAP ha^{-1} y^{-1}) were applied for the first two years both in nursery beds and permanent fields.

Treatments and experimental design

The treatments consisted of three transplanting methods combined with two leaf pruning methods. The transplanting methods were (i) transplanting 1-year-old suckers produced in the nursery from the corm directly into the permanent field (T1), (ii) transplanting 2-years-old transplants into permanent field after they had been raised from the corm nursery by transplanting into nursery beds (T2), (iii) transplanting 3-years-old transplants into the permanent field after they had been raised by transplanting twice into nursery beds (T3). The leaf pruning methods were (i) without leaf pruning (P0) and (ii) with leaf pruning (P1).

The six treatment combinations were arranged in a randomised complete block design with four replications. The spacing between plants in the permanent field was 1.5 m × 3.0 m and there were 24 plants in each plot.

Crop management

Corms of 2-years-old plants of cv. 'Halla' were split into two parts and the apical buds were removed to induce suckers production. The split corms were then planted in a 1.0 m × 1.0 m arrangement under 10 to 20 cm of soil mixed with cow manure in March 1993. In March 1994, suckers were separated from the mother corm, and thereafter some of the suckers were transplanted directly into the permanent field (T1, transplanting 1-year-old suckers). The other suckers were transplanted into the second nursery bed at a spacing of 1.0 m × 0.5 m. In March 1995, 2-years-old transplants were transferred into the permanent field (transplanted twice; T2) while the remaining shoots were transplanted into a third nursery bed at a spacing of 1.0 m × 1.0 m. In March 1996, the 3-years-old transplants were transplanted into the permanent field (transplanted thrice; T3).

Leaf pruning (P1) was carried out by removing the dead leaf sheaths and the old green leaf blades on the lower part of the plant twice a year (in March and September). At least eight functional leaves were left on the plant. In the treatment without leaf pruning (P0), plants were allowed to grow without any leaf removal.

Data collection

The enset plants from T1, T2 and T3 flowered within 104, 234 and 260 weeks, respectively (for details see Tsegaye and Struik, 2000b; Chapter 6). At 104 weeks after first transplanting, and afterwards at 130, 156, 182, 208, 234 and 260 weeks, two sample plants per plot were used to produce 'kocho'. The pseudostem was cut into several pieces and the pulp (parenchymatous tissue) was scraped using a sharp-edged bamboo tool. The corm was pulverised using a wooden tool with a flat sharp edge. The resulting pulps were thoroughly mixed. After the fresh weight of the mixture was determined, a representative subsample of 500 g was taken and the dry weight was assessed by drying the samples at 105 °C for 24 hours in a forced-ventilated oven. The remaining mixture was then put into a pit for fermentation. Every two weeks the fermentation pits were opened and the contents were pressed and re-arranged to enhance the fermentation process. After 88 days of fermentation the fresh and dry matter weights were assessed again.

Fresh and edible dry matter yield of fermented 'kocho' were expressed per plant (kg plant^{-1}) or per unit space and time (g m^{-2} y^{-1}). For the latter parameter it is relevant that the spacing of transplants in the nurseries and of the plants in the final field were different in various phases. Thus, the yield per m^2 and year at different harvest dates was calculated using the following equation:

$$\text{Yield} = \frac{\text{plant weight at harvest or after fermentation (g)}}{\sum(\text{area per plant in each phase in m}^2 \times \text{duration of each phase in years})} \qquad (1)$$

The yield data from the various treatments were subjected to an analysis of variance with the GENSTAT statistical package to determine the effects on dry matter yield of fermented 'kocho' at different harvest dates.

To compare the productivity of enset with other crops, the average yields of the major cereal and root and tuber crops grown in Ethiopia were taken from the reports of the Central Statistical Authority (CSA, 1990–1997) and Southern Nations Nationalities and Peoples Regional State, Bureau of Agriculture (SNNPRS, 1998–1999). To facilitate comparison, these yields were expressed in edible dry matter, and the growth period of each crop was estimated using information from literature. Then, the energy production (kJ) per harvest or per day was calculated using tables compiled by the Ethiopian Health and Nutrition Research Institute (EHNRI, 1995–1997) and Platt (1977).

Results

Fresh weight of fermented 'kocho' per plant

Starting from 104 weeks after the first transplanting until flowering or shortly after flowering, the enset plant could be harvested for 'kocho' production at any stage of development. Fresh weight of fermented 'kocho' per plant initially increased with time from first transplanting to flowering for T1 and T2 plants, and thereafter, in both cases the yield decreased (Table 1). Thrice transplanted enset plants showed a 15% decrease in yield at the time of flowering compared to the yields of T3 plants six months before flowering.

Transplanting effects on fresh weight of fermented 'kocho' per plant were significant at all harvest dates except at 260 weeks after the first transplanting. Until 156 weeks after first transplanting, T1 plants gave the highest fresh weight of fermented 'kocho', after which the plants of this treatment rapidly died. From 182 weeks onwards, the 'kocho' yields of T2 plants were the highest.

Table 1. Fresh weight (kg plant^{-1}) of fermented 'kocho' when harvested and processed at different weeks after removal from the mother corm for different transplanting and leaf pruning treatments. Plants of T1 senesced rapidly after flowering.

Transplanting (A)	*Leaf pruning* (B)	Weeks after removal from the mother corm 104	130	156	182	208	234	260
Once	Without	18.6	25.9	20.3				
	With	14.6	16.9	18.0				
	Mean	16.6a	21.4a	19.1a				
Twice	Without	3.3	12.5	13.5	22.5	27.5	54.1	28.5
	With	4.2	12.0	16.5	16.6	24.8	53.9	30.5
	Mean	3.8b	12.3b	15.0b	19.6a	26.1a	54.0a	29.5
Thrice	Without	1.7	3.3	3.9	9.5	15.5	37.1	31.0
	With	1.5	2.6	4.3	10.0	12.5	29.9	26.0
	Mean	1.6c	2.9c	4.1c	9.8b	14.0b	33.5b	28.5
Average (B)	Without	7.9	13.9a	12.5	16.0	21.4	45.6	29.8
	With	6.7	10.5b	12.9	13.3	18.6	41.9	28.3
Grand mean		7.3	12.2	12.7	14.7	20.1	43.8	29.0
CV (%)		21	29	14	23	17	23	22
P or LSD (0.05) A		1.6***	3.8***	1.9***	3.8***	3.9**	11.4**	ns
P or LSD (0.05) B		ns	3.1*	ns	ns	ns	ns	ns
P or LSD (0.05) A × B		2.3*	5.3*	2.7*	P<0.09	ns	ns	ns

Note: ns, *, **, and *** stands for non-significant, significant at $P < 0.05$, 0.01, and 0.001, respectively (F-test). Different letters in a column indicate significant difference at $P < 0.05$, according to Duncan's 'multiple range test'.

Except at 130 weeks after first transplanting, leaf pruning did not significantly reduce fresh weight of fermented 'kocho'. Although the effects were not statistically significant, the fresh weight of fermented 'kocho' from pruned enset plants was slightly lower at all other harvesting dates, except at 156 weeks after first transplanting. Interactions between frequency of transplanting and leaf pruning were significant at the first three harvests (at 104, 130 and 156 weeks after first transplanting): 'kocho' yields were reduced by leaf pruning for plants transplanted once but not affected or even slightly increased by leaf pruning in the other transplanting treatments.

Dry weight of fermented 'kocho' per plant

Maximum dry weights of 'kocho' were 7.44 and 16.23 kg plant^{-1} for T1 and T2, respectively, and were obtained at flowering or shortly after flowering (Fig. 1). Enset plants transplanted once or twice thus showed an increase in dry weight of fermented 'kocho' until 130 and 234 weeks after the first transplanting, respectively, and thereafter in both cases the yield decreased. Thrice transplanted enset plants showed a 28% decrease in dry weight of fermented 'kocho' per plant already at the time of flowering compared to the yields of plants six months before flowering. At the first three harvest dates T1 plants gave the highest dry weight of 'kocho' per plant and thereafter the plants of this treatment died because of senescence. At 182, 208, 234 and 260 weeks after first transplanting the T2 treatment increased dry weight of 'kocho' per plant by 102, 93, 65 and 0.4%, respectively, compared to the T3 treatment. Transplanting effects on dry weight of fermented 'kocho' were significant ($P < 0.001$) at all harvest dates except at 260 weeks after the first transplanting (Fig. 1).

Leaf pruning significantly reduced dry weight of fermented 'kocho' per plant after 104 and 208 weeks. Although the effects were not statistically significant, leaf pruning reduced dry weight of fermented 'kocho' per plant at 130, 156, 182, 234 and 260 weeks after the first transplanting. Except at 104 weeks after the first transplanting, interaction effects were not significant (Fig. 1).

Dry matter yield of fermented 'kocho' per unit space and time

The dry matter yield of fermented 'kocho' (g m^{-2} y^{-1}) in Table 2 was calculated using eqn. (1). The area and time used by a sucker before removal from the mother corm was ignored as a large number of suckers (50–150) shared only 1 m^2 area of land. Dry matter yield of fermented 'kocho' was higher for transplanting once than for transplanting twice or thrice at 104 weeks after first transplanting. At 130 weeks after first transplanting, however, there was no significant difference between transplanting once or twice. Since enset plants transplanted once were dead, it was not possible to compare the fermented dry matter yield of the three treatments after 182 weeks of first transplanting.

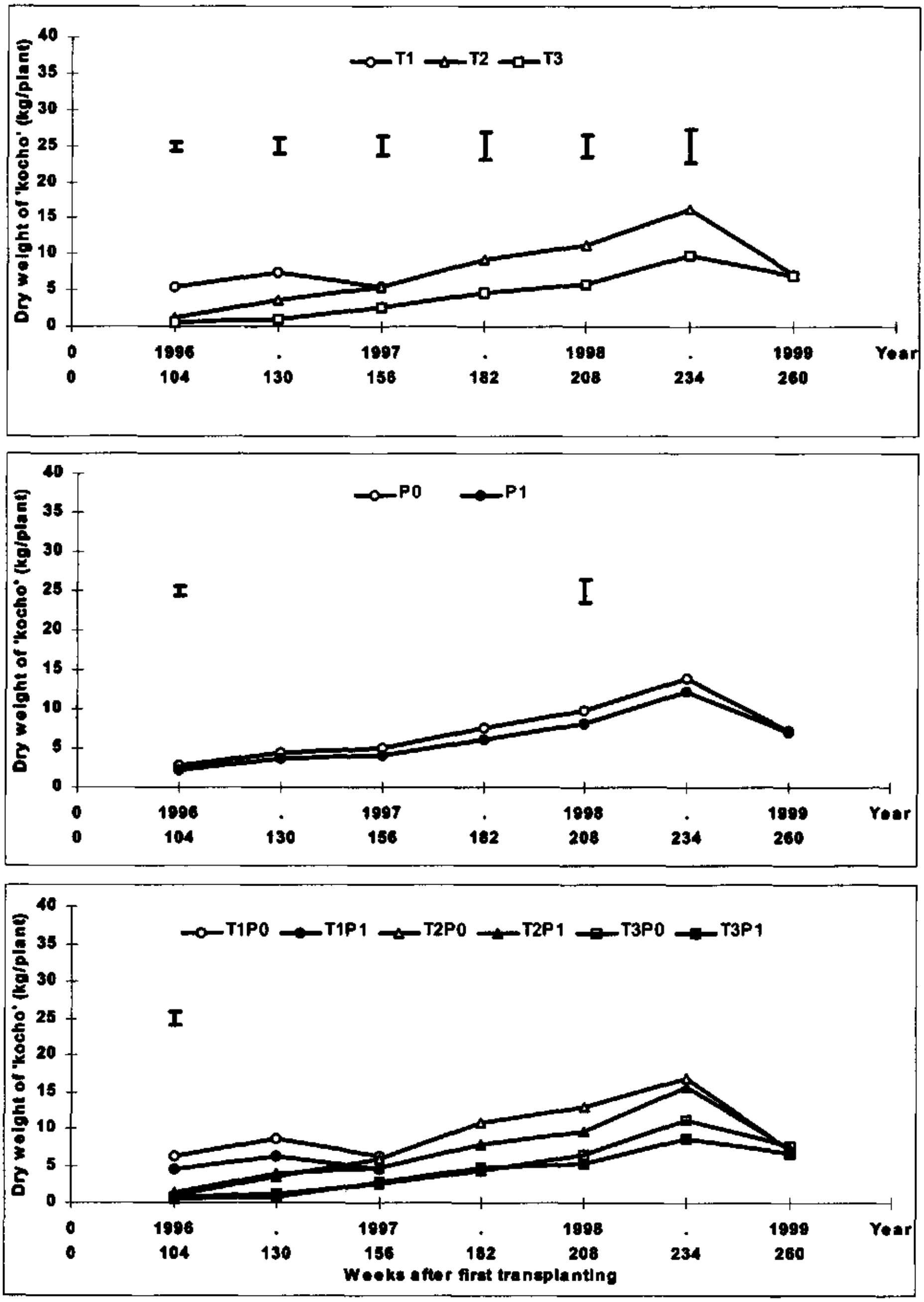

Fig. 1. Effects of repetitive transplanting (T1 = transplanting once; T2 = transplanting twice; T3 = transplanting thrice) and leaf pruning (P0 = without pruning; P1 = with pruning) on the development over time of the dry weight of 'kocho' per plant. Vertical bars indicate LSD.

Table 2. Dry weight (g m^{-2} y^{-1}) of fermented 'kocho' when harvested and processed at different weeks after removal from the mother corm for different transplanting and leaf pruning treatments. Plants from the T1 treatment senesced shortly after flowering.

Transplanting	*Leaf pruning*	Weeks after removal from the mother corm						
(A)	(B)	104	130	156	182	208	234	260
Once	Without	694	727	463				
	With	499	414	339				
	Mean	597a	570a	401b				
Twice	Without	212	477	620	917	928	1032	377
	With	269	541	505	660	687	968	397
	Mean	240c	509a	563a	789a	808a	1000a	387
Thrice	Without	533	243	438	532	618	868	510
	With	425	182	450	580	500	675	440
	Mean	479b	267b	444b	556b	559b	772b	475
Average (B)	Without	480a	482a	507	725	774a	950a	443
	With	398b	379b	432	620	594b	821b	418
Grand mean		439	431	492	672	684	886	431
CV (%)		20	37.5	24.6	24.2	18.4	17.1	23.3
P or LSD (0.05) A		94***	172***	100*	183*	142**	172*	ns
P or LSD (0.05) B		77*	P<0.13	ns	ns	142*	P<0.12	ns
P or LSD (0.05) A × B		133*	P<0.09	ns	P<0.09	ns	ns	ns

Note: ns, *, **, and *** stands for non-significant, significant at $P < 0.05$, 0.01, and 0.001 (*F*-test), respectively. Different letters in a column indicate significant difference at $P < 0.05$, according to Duncan's 'multiple range test'.

Compared to transplanting thrice, transplanting twice increased the dry matter yield of fermented 'kocho' by 42, 45 and 30% at 182, 208 and 234 weeks after first transplanting, respectively. Although it was not statistically significant at 260 weeks after first transplanting, transplanting thrice gave a higher dry matter yield per unit time and space compared to transplanting twice.

Transplanting once and twice gave higher dry matter yield of 'kocho' per unit space and time at the time of flowering (at 104 weeks for T1 and at 234 weeks for T2), whereas transplanting thrice reduced dry matter yield of 'kocho' by 38% at the time of flowering (at 260 weeks after first transplanting) compared to T3 plants at 234 weeks after first transplanting. The maximum yield of 'kocho' obtained from T2 plants is higher by 68 and 30% compared to the maximum 'kocho' yields obtained from T1 or T3 plants, respectively.

Leaf pruning significantly ($P < 0.05$) reduced dry matter yield of fermented 'kocho' per unit space and time after 104 and 208 weeks after first transplanting. Although effects were not statistically significant ($P > 0.05$) leaf pruning also reduced dry matter yield of fermented 'kocho' at 130, 156, 182, 234 and 260 weeks after first transplanting. Except at 104 weeks after first transplanting, interaction effects were not statistically significant.

Productivity of enset compared to other crops

Edible dry matter production. Enset plants transplanted once, twice and thrice produced much more edible dry matter per unit space and time compared to the other main crops (Table 3). The edible dry matter production rate of enset plants transplanted twice and thrice was much more compared to all crops, whereas the difference between enset plants transplanted once and sweet potato or taro in terms of edible dry matter production rate was very small. The average edible dry matter production rate of enset from the three crop establishment methods was about 133 and 69% higher than the average values for cereals and root and tuber crops, respectively. The dry matter percentage of fermented 'kocho' was almost comparable to that of taro, yam and sweet potato.

Energy production. The average energy production rates of enset under different crop establishment methods and main crops in Table 4 are calculated from the data in Table 3 using food composition tables compiled by (EHNRI, 1995–1997) and Platt (1977). Twice transplanted enset plants increased energy production rate by 80 and 27% compared to once and thrice transplanted, respectively. Enset plants transplanted once, twice and thrice produced much more energy per unit space and time compared to other high energy producing crops in Ethiopia (Table 4). The average energy production rate from the three enset crop establishment methods was about 286 and 172% higher than that of cereals and root and tuber crops, respectively.

Second to enset sweet potato and Irish potato produced high yields (in terms of weight and energy). The average edible dry matter production rate of root and tuber crops was about 26% higher than that of cereals (Table 3). Except for potato, root and tuber crops also require a relatively shorter period of time for land preparation than cereals; the agronomic practices are relatively simple and they require low inputs.

Discussion

Fresh and dry yield of fermented 'kocho' per plant

A prolonged time from first transplanting to flowering increased fresh and dry matter yield of fermented 'kocho' per plant or per unit space and time of T1 and T2 plants. This

Table 3. Average yields and edible dry matter production rates of main crops grown in Ethiopia as compared with enset under different crop establishment methods.

Crops	Yield ($g\ m^{-2}$) (based on average spacing)	Edible portion (%)	Dry matter (%)	Edible dry matter ($g\ m^{-2}$ per harvest)	Growth period (days)	Edible dry matter ($g\ m^{-2}\ d^{-1}$)
Enset (*Ensete ventricosum*)						
Transplanted once	3686 [a]	80 [a]	32 [a]	944	730 [a]	1.29
Transplanted twice	14958 [a]	80 [a]	30 [a]	3590	1643 [a]	2.19
Transplanted thrice	11817 [a]	80 [a]	29 [a]	2742	1643 [a]	1.67
Average of enset	10154 [a]	80 [a]	30 [a]	2425	1339 [a]	1.72
Teff (*Eragrostis tef*)	94 [b]	100	89	83	120	0.69
Barley (*Hordeum vulgare*)	104 [b]	100	87	90	150	0.60
Wheat (*Triticum durum*)	147 [b]	100	87	128	150	0.85
Maize (*Zea mays*)	159 [b]	100	80	127	150	0.85
Sorghum (*Sorghum bicolor*)	126 [b]	100	85	107	150	0.71
Finger millet (*Eleusine coracana*)	97 [b]	100	89	86	120	0.72
Average of cereals	121 [b]	100	86	104	140	0.74
Irish potato (*Solanum tuberosum*)	713 [c]	85	20	121	120	1.01
Sweet potato (*Ipomoea batatas*)	821 [c]	85	30	209	150	1.40
Cassava (*Manihot esculenta*)	688 [c]	83	40	228	270	0.85
Taro (*Colocasia esculenta*)	932 [c]	85	30	237	210	1.13
Yam (*Dioscorea sp.*)	750 [c]	85	27	172	270	0.64
Average of root and tuber crops	781 [c]	85	29	177	193	1.01

[a] Present study; the enset yield data are based on the values of 104 weeks after first transplanting for T1 and 234 weeks after first transplanting for T2 and T3 from Table 1, averaged over leaf pruning treatments and calculated per average spacing per plant being 4.5 m^2 for T1, 3.61 m^2 for T2 and 2.83 m^2 for T3.

[b] Central Statistical Authority, Average of eight years (CSA, 1990–1997).

[c] Southern Nations Nationalities and Peoples Regional State, Bureau of Agriculture, Planning Service (SNNPRS, 1998–1999).

was a result of a longer duration of growth which reflects not only the opportunity for prolonged interception of photosynthetically active radiation by the crop, but also the greater opportunity for uptake of N and other nutrients especially under low input conditions (Vergara *et al.*, 1964; Wada and Cruz, 1989). Unlike T1 and T2 plants, T3 plants showed decreased fresh and dry matter yield of fermented 'kocho' per plant or per unit space and time at flowering because of the occurrence of corm rot. Transplanting several times might decrease the natural resistance of the plant due to transplanting shocks or an interruption in assimilate production for some period of time. At the latest harvest, a large proportion of the corm of T3 plants was discarded or not mixed with the scraped pseudostem pulp for fermentation, as it was completely rotten by corm rot.

Table 4. Energy production rates of main crops as compared with the energy production rates of enset under different crop establishment methods.

Crops	Edible yield ($g\ m^{-2}$)	kJ/100 g of edible yield	Energy production ($kJ\ m^{-2}$)	Energy production rate ($kJ\ m^{-2}\ d^{-1}$)
Enset (*Ensete ventricosum*)				
Transplanted once	2949	883 [a]	26040	35.67
Transplanted twice	11966	883 [a]	105660	64.31
Transplanted thrice	9454	883 [a]	83479	50.81
Average of enset	8123	883	71726	50.26
Teff (*Eragrostis tef*)	94	1485 [a]	1396	11.63
Barley (*Hordeum vulgare*)	104	1552 [a]	1614	10.76
Wheat (*Triticum durum*)	147	1494 [a]	2196	14.64
Maize (*Zea mays*)	159	1569 [a]	2495	16.63
Sorghum (*Sorghum bicolor*)	126	1502 [a]	1192	7.95
Finger millet (*Eleusine coracana*)	97	1469 [a]	1425	11.88
Average of cereals	121	1512	1720	12.25
Irish potato (*Solanum tuberosum*)	606	431 [a]	2612	21.76
Sweet potato (*Ipomoea batatas*)	698	569 [a]	3972	26.48
Cassava (*Manihot esculenta*)	571	640 [b]	3654	13.53
Taro (*Colocasia esculenta*)	792	519 [a]	4110	19.57
Yam (*Dioscorea sp.*)	638	464 [a]	2960	10.96
Average of root and tuber crops	661	525	3462	18.46

Note: The edible yield and energy production rates are calculated from yield and growth period data in Table 3, using food composition tables compiled by [a]EHNRI (1995–1997) and [b]Platt (1977).

This is the first report with detailed information on dry matter yield of fermented 'kocho'. Most of the previous reports were on fresh yield of fermented 'kocho' and were based on survey works. In addition, they lacked information on the age of plants harvested, stage of transplantation and the duration of the fermentation period of the products. In this study maximum fresh yield of 'kocho' after 88 days of fermentation from T1 (at 130 weeks after first transplanting), T2 and T3 (at 234 weeks after first transplanting) were 25.87, 54.10 and 37.10 kg plant^{-1}, respectively. Bezuneh (1984), Makiso (1976) and CSA (1997a) reported values of 23.50, 30.60 and 30.15 kg plant^{-1}, respectively, which are substantially lower than the yields of T2 and T3, but close to the yield of T1. Shank and Ertiro (1996) reported a value of 44.20 kg plant^{-1} which is still well below the yield of T2 plants.

Determination of yield of enset is difficult due to complicated production and processing procedures. Thus, many aspects such as space used by suckers or transplants at each stage of transplantation, the age of the plants and type of clone need to be considered in yield determination.

Bezuneh (1984) reported the maximum value of 11950 kg ha^{-1} y^{-1} which is 2.8 fold less than our result of 33210 kg ha^{-1} y^{-1} yield obtained from T2 plants. Endale (1997), however, reported the maximum value of 24700 kg ha^{-1} y^{-1} which is relatively close to the 26260 kg ha^{-1} y^{-1} obtained from T3 plants, but much less than the yield obtained from T2 plants. In general, the yield results per unit space and time from T1, T2 and T3 plants were higher than the experimental and survey yields reported in literature. This could be the result of taking into account the limited space taken by suckers or transplants at earlier stages. In addition, the spaces used by suckers or transplants at early stages, the time it takes to ferment the products, type of clone, fertility of soil, method of processing and environmental factors can have affected 'kocho' yield depending on site and year.

Productivity of enset compared to other crops

Comparison of the edible dry matter and energy production rates of enset with the production rates of main crops grown in Ethiopia is difficult because of the following reasons: (1) The average edible dry matter and energy yields of main crops in Table 3 are calculated from figures from different sources as reported by the Ethiopian Central Statistics Authority and SNNPRS, Bureau of Agriculture; (2) The average edible dry matter and energy yields of 'kocho' are taken after a considerable loss of dry matter due to the complicated traditional harvesting and fermentation processes; (3) The growth period within a crop may show variation depending on the cultivar, altitude, cultural practices, etc. For example there are some sweet potato and maize cultivars that have shorter growth period but there are also cultivars with a much longer growth period. As Ethiopia is highly diversified in topography and climate, in hotter lower altitude crops usually have shorter growth cycles than crops grown in cooler higher altitude.

Even though the methodology of comparison followed most likely did not favour the enset crop, the edible yield of enset (in terms of weight and energy) is much higher compared to the cereals or root and tuber crops. This high yield of enset could be due to the longer growth period: the average growth period of enset under different crop establishment methods was about 7–10 times as long as that of other crops (Table 3). The canopies of enset have certain advantages compared to those of cereals and root and tuber crops. They are likely to be present for most of the year, so that more light is intercepted. The vertical orientation of upper leaves and deep canopies within enset crops favour effective light penetration and cause a high proportion of diffuse radiation, so that most leaves are neither light saturated nor severely light limited. Cannell (1989) also reported that canopies of perennial crops are aerodynamically rough and well-ventilated compared with short vegetations so that, at moderate wind speeds, there is little mid-day depletion of atmospheric CO_2 levels within the canopies.

Pijls *et al.* (1995) compared yield of enset with values of 950 g m^{-2} per year with yields of crops grown in Ethiopia in terms of weight, energy and protein. The reported low yield of enset seems to be based on field interviews and survey work. During field interviews farmers hardly inform researchers on the right age of the plant and survey work might include both high and low productive types out of proportion. In addition, the researchers accounted only the wider spacing of the plant in the final field to determine yield per unit space. As a result, in their report, the energy yield of enset is lower than cassava and slightly higher than cereals. Our results which were based on field experiments, however, indicated that the average energy production rate of enset was about 4-and 2-fold higher than that of cassava and sweet potato, respectively (Table 4). Flach and Rumawas (1996) reported the world's highest average energy production rate from sweet potato with a value of 43 kJ m^{-2} d^{-1}, but this is still much less than the average energy production rate of enset reported in this paper.

Based on field observations and survey works, Smeds (1955), Stanley (1966), Kefale and Sandford (1991), Pijls *et al.* (1995) and Shank and Ertiro (1996) concluded that enset gives higher yield per unit space and time than any other crop. But, Brandt *et al.* (1997) had a doubt on the yield of enset and suggested that the huge volume harvested from one plant and from an area, particularly in comparison with cereals, may contribute to the perception among both farmers and scientists that the yield of enset is tremendous. In this study, we have verified that the yield of enset is much higher than any other crop cultivated in Ethiopia. Therefore, cultivation of enset can sustain higher population densities than that of other crops.

Enset food products, however, are low in protein and vitamins (Pijls *et al.*, 1995; EHNRI, 1995–1997). Thus, the composition of diets based on enset products needs to be improved by supplementation with legumes, vegetables and fruits.

Besides source of food but also of forage, fibre, construction material, medicine and other by-products, the presence of the enset plant in the field throughout the year has several advantages over annuals. The perennial canopy of the crop intercepts heavy rain and reduces soil temperature and, thereby, protects the soil against erosion, decreases organic matter decomposition and reduces leaching of plant nutrients. As a result, problems of soil erosion and land degradation are rarely seen in enset-growing regions. This is in agreement with the conclusion of Asnakech (1997) that fields where enset had been continuously cultivated for several decades had higher organic contents and better nutritional status than fields used otherwise.

Conclusions and recommendations

- Transplanting enset suckers or transplants twice prolongs the maturity period of enset and consequently increases yield of 'kocho' per unit space and time compared to direct transplanting. Thus, if early yield is not important, farmers can practise this crop establishment method in order to get high edible dry matter and energy yield per unit space and time.

- In areas where there are serious disease and pest problems, transplanting enset suckers or transplants more than twice might increase the susceptibility of the enset plant to diseases and pests. Therefore, in such areas farmers should not transplant enset suckers or transplants more than twice.
- The 'kocho' yield of enset per unit space and time (in terms of weight and energy) is much higher than the yields of any other crop grown in Ethiopia. Therefore, the cultivation of enset in densely populated areas under low input conditions can sustain the population better than any other crop.

CHAPTER 9

General discussion

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General discussion

This thesis provides insight knowledge on the indigenous enset production methods, farm-based enset biodiversity and the plant and environmental characteristics that affect the potential of the crop to sustain food security and the environment. Some indigenous production methods and the plant and environmental factors influencing yield potential were analysed to identify yield potentials and constraints, and to design and implement better adopted research programmes. Farm-based enset biodiversity was identified and assessed using morphological and molecular markers (AFLPs) and farmers' knowledge of genetic diversity to develop a sound utilisation and conservation strategy. Furthermore, the effects of cultivation methods such as repetitive transplanting and leaf pruning on growth, dry matter production and partitioning, harvest and post harvest losses were investigated to reduce the gap between the actual and yield potential. In this general discussion, our major findings as reported in the previous chapters are highlighted and further discussed.

Indigenous production methods

The enset-based farming system is a unique ecological phenomenon of the south and southwestern highlands of Ethiopia. Abrams (2001) argues that the Ethiopian highlands became an important centre of domestication for small grains and for enset by 5,000 BC. Simmonds (1958), Shank (1963) and Pankhurst (1996) suggested that enset cultivation might be a successful and sustainable indigenous farming system, one of the few remaining in Africa.

The main enset-growing regions are inhabited by more than 10 related ethnic groups, having different cultures, traditions and agricultural systems. Population densities in these areas range from 200–500 persons per square kilometre, and are still growing at increasingly higher rate. Farmers in these areas have applied broad and complex indigenous knowledge of farming systems in which enset landraces, crop species, livestock and cultivation techniques interact to sustain the production. Since the last three decades, however, because of population pressure and recurrent drought, there has been degradation of the natural resource base, and thus the indigenous enset production system has failed to sustain the population. Increasing financial outlays for agricultural research and development have neither produced significant effects nor led to food security. One of the most important reasons for this failure is the lack of attention to the indigenous production knowledge in the process of improving the production system. Many technological solutions that have been proposed to address problems in rural communities have failed in the field because they do not take into account the local culture, particularly society's preferences, skills and knowledge (Warren and Cashman, 1988). On the other hand, research or scientific common knowledge does not always confirm farmers' knowledge.

Indigenous knowledge provides basis for decision making, much of which takes place at the community level through indigenous organisations and associations where problems are identified and solutions to them are determined (Warren, 1992). This made analysis of indigenous production methods and farm-based biodiversity necessary. The survey in Chapter 2 showed that there is a clear variation in cultivation methods between the three ethnic regions, such as for propagation techniques, transplanting, leaf pruning and planting pattern. Farmers in Sidama start with a relatively dense plantation and then use a thinning out process to eliminate the less promising plants (Fig. 1). In Hadiya and Wolaita a clear planting pattern was observed whereby every one or two years suckers change their location at wider space (Fig. 2). Leaf pruning is more severe in Wolaita than in Sidama or Hadiya (Fig. 3).

The different enset cultivation methods and its biodiversity at household farm level are summarised in Table 1. The Sidama area is located at higher elevation where the low temperature is less favourable for annual crop production. As a result, farmers in Sidama mainly depend on diverse enset landraces for food production, and on livestock to supplement the low protein and vitamin content of enset products. In Wolaita and Hadiya, however, the temperature is relatively favourable to cultivate diverse crop types and thus enset is cultivated as a co-staple with cereals, legumes and root and tuber crops.

Fig. 1. A dense enset plantation at Tula, Sidama region near Awassa. (Picture: Admasu Tsegaye)

Fig. 2. Enset planted in a fixed pattern with a wide spacing in Hadiya. (Picture: Paul Struik)

Fig. 3. Severe leaf pruning in Wolaita. (Picture: Paul Struik)

Table 1. Enset cultivation methods and its biodiversity in three major enset-growing regions.

Region	Elevation (m asl)	Frequency of transplanting	Leaf pruning	Farm size (ha)	Diversity/household (number)	
					Enset clones	Other crop species
Sidama	2600–2650	Once*	Not severe	1.7	14	3
Wolaita	1750–1820	2–3	Very severe	0.7	9	11
Hadiya	2220–2400	4	Moderately severe	1.0	12	6

* Followed by thinning.

The climatic conditions and the farming systems probably contribute to the variation in planting pattern and enset biodiversity. As farmers in the Sidama area do not need extra space for intercropping, they start with a relatively dense diverse enset plantation without a definite pattern and then thin the less promising plants to feed their livestock. The lower average farm size of Hadiya and Wolaita and the larger number of crop species grown for food to meet financial obligations might have forced the farmers to transfer enset plants from place to place with an increasingly wider spacing in order to have enough space to intercrop. Enset leaves are used for sale, animal feed and other purposes. The severe leaf pruning in Wolaita and Hadiya, however, might also create better conditions for light interception and aeration for the intercropped annual crops and to reduce stress during transplanting. There is a good relation between elevation and severity of leaf pruning: the higher the elevation (and thus the lower the average temperature) the less severe the pruning. The effects of transplanting and leaf pruning on growth and food production were further analysed and discussed in Chapters 6 and 7 (see also below).

In Sidama and Hadiya, there are more diverse enset landraces per household than in Wolaita. The larger diversity may be associated with the larger area of land available per household, but also with the larger dependence on the crop (see also Table 7 in Chapter 2). The disease pressure may also have an impact on the diversity. Bacterial wilt disease is less severe in Sidama or Hadiya than in Wolaita not only because of unfavourable environmental conditions for the spread of the disease but probably also because of the presence of diverse tolerant enset landraces. Severe disease pressure also may cause loss of genotypes.

Farm-based enset biodiversity

Biodiversity or biological diversity refers to the variety of life forms, the genetic diversity they contain, and the assemblages they form (De Boef, 2000). Farmers' varieties consist of mixtures of genetic lines all of which are reasonably well adapted to the region in which they evolved, but which differ in reaction to disease and insect pests, sometimes being resistant or tolerant to certain races of pathogens (Harlan, 1992). Genetic variation within and between crops often favours production stability through soil development and suppression of pests, diseases and weeds (Barrett *et al.*, 1990; Almekinders *et al.*, 1995).

Farmers in enset-growing areas have managed enset biodiversity for centuries with limited influence from outside. Thus, it is likely that a wealth of knowledge about landraces and capacity to manage this biodiversity exists. Collecting, formalising and testing the indigenous knowledge of enset biodiversity and the management and use of this diversity by the farmers are crucial for efficient utilisation and conservation of the genetic diversity. In Chapter 2, farm-based biodiversity of enset and its relationship with other household characteristics were analysed. Diverse enset landraces were identified in the Sidama (52), Wolaita (55) and Hadiya (59) regions. These landraces differ with respect to morphological characters (leaf, midrib, petiole and pseudostem colour), use value ('kocho', corm, 'bulla', fibre, medicine and ornamental), quality of products, maturity period, vigour and reaction to bacterial wilt (Chapter 4). Farmers use the enset plant for several purposes and thus select types of enset landraces that fit their different needs and constraints. Since one landrace can never fulfil all the selection criteria, farmers tend to keep 9–14 diverse enset types in their household farm (Chapter 2). Farmers' interest in maintaining multiple varieties with contrasting traits to fit different needs and constraints, rather than concentrating on a single variety with a particular trait, has also been reported for sorghum in Ethiopia (Teshome *et al.*, 1999; McGuire, 2000), for maize in Mexico (Bellón, 1996; Brush, 1995) and in many other crops.

A combination of factors including household resource, cultural background, population pressure and agro-ecology influenced the number of enset landraces (Chapter 2). There are more enset landraces in areas where people's culture has been highly associated with the crop. The advantage of numerous cultural beliefs and practices for conservation and survival of plant resources was also reported in India by Jain (2000). In all regions, rich farmers have more resources such as land, labour and livestock for source of manure and thus they maintain more different landraces with different specific characteristics than poor farmers. These results are in line with the finding of Cromwell and Van Oosterhout (1999), who reported that within any given community, crop diversity is often handled more by richer farmers.

In most developing countries women manage components of the farming system that contain a high level of biodiversity that can be used for daily culinary use (Jain, 2000; Cromwell *et al.*, 2000). Similarly, the studies described in Chapters 2 and 4 demonstrate that in all ethnic regions women have control over the enset field because it is an important source of daily food. Women are also more knowledgeable in identification of genetic diversity than men. This is in agreement with the findings of Negash (2001) who reported that women have tremendous knowledge of enset diversity and are more concerned with the balance of the landraces to be harvested at different stages than men are.

Conservation of enset biodiversity

In the past, the Ethiopian government mainly focused its agricultural research and development efforts on high-yielding annual crops that can be marketed. The attention of the government towards encouraging the adoption of new technologies for such crops resulted in a shift from enset to cereal-based agriculture, which consequently caused loss of valuable enset genetic materials.

The conservation and use of plant genetic resources are essential to the continued maintenance and improvement of agricultural production and, thus, to sustainable development and poverty alleviation. Effective conservation of plant genetic resources requires a complementary approach, which makes use of both *ex situ*, and *in situ* conservation methods to maximise the genetic diversity available for use (Karp *et al.*, 1997). Determination of the relationship between basic units in traditional classification systems and the structure of genetic variability in the traditional farming system is essential to define genetic entities that will be used as targets for efforts of conservation of genetic resources (Elias *et al.*, 2001).

Several ethnic groups having different languages evaluate, value, utilise and conserve enset genetic diversity in different manners. The existence of many vernacular names for the same cultivars based upon their plant characteristics has created problems to identify and classify clones/varieties while avoiding duplicates. Results in Chapter 3 showed that AFLP analysis can successfully be applied to study clonal diversity in enset, despite the absence of primers previously tested for their suitability for enset characterisation. Among 146 enset clones, a total of 180 AFLP fragments was scored of which 104 (58%) appeared polymorphic. Twenty-one duplication groups consisting of a total number of 58 clones were identified. Similarly, several studies have already shown the reliabilities of AFLP markers for characterisation of cultivated species including cassava (Elias *et al.*, 2001), Mangifera species (Eiadthong *et al.*, 2000), wheat (Manifesto *et al.*, 2001), cotton (Srivastava *et al.*, 2001), banana (Loh *et al.*, 2000) and many other crops.

The complementarity and significance of both molecular techniques (AFLPs) and farmers' characterisation methods for effective conservation and utilisation of genetic diversity of enset were investigated in Chapter 4. Despite the weak, positive correlation, the comparison showed that some aspects of farmers' characterisation such as absence of clear regional clusters and clustering of clones with various prefixes to a single group corresponds well to the results of AFLPs. Duplications in the clones by both farmers' classification and molecular analysis may be safely removed from a conservation programme. The comparison also revealed regional variation in farmers' skill in discriminating between clones that are genotypically different. The areas where people's culture is closely associated with the crop should receive high priority for collecting materials or serving as sites for *in situ* conservation. The complementarity of farmers' evaluation and genetic analysis for efficient sampling or conservation of genetic resources has also been reported for cassava (Elias *et al.*, 2001), pear millet (Busso *et al.*, 2001), taro (Jianchu *et al.*, 2001) and potato (Quiros *et al.*, 1990).

Yield potential

A rapid increase in population during the last few decades has reduced the availability of land for cultivation and grazing. Enset cultivation at the traditional technical level of production has failed to feed the population that has been growing at an increasingly higher rate. The traditional cultivation practices of enset are diverse, the crop has a long maturity period (Chapter 2), and the yield potential of the crop has not been utilised.

The yield potential of a crop is determined by the interaction of the climatic conditions of a region with its soil and crop characteristics. Crop growth simulation models are ideal tools to determine yield potential in different agro-climatic regions and also to quantify the magnitude of yield gaps and their principal causes. However, there has been a lack of basic crop physiological parameters to facilitate the use of crop simulation models for yield gap analysis in enset. In Chapter 5, important crop physiological parameters such as radiation use efficiency (RUE), canopy extinction coefficient, time course of radiation interception, and time course of leaf appearance and leaf area index were generated. These values were used to estimate the yield potentials of different clones at different agro-ecological locations.

Figure 4 describes a schematic representation of a simple model to calculate yield potential as described by Spitters (1990). This model uses the intercepted radiation (based on leaf area over time and radiation over time) and the average RUE. The former is estimated based on weather data and actual measurements of individual leaf area and leaf appearance records in combination with the extinction coefficient determined with direct radiation interception measurements. The latter is estimated in a simple manner from the regression of biomass on cumulative light interception. The RUE can often be considered constant over the growing season. The model is easy to use especially for crops like enset with insufficient crop physiological parameters and input data; it clearly

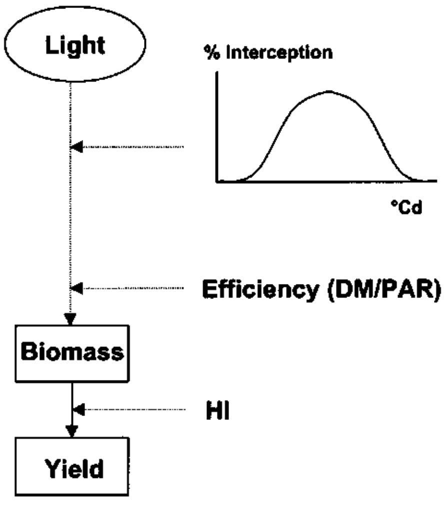

Fig. 4. Schematic representation of a simple model to calculate yield potential as described by Spitters (1990).

illustrates and quantifies the main aspects of crop production. Bouman *et al.* (1996) argued that models should be as simple as possible and require only small number of input data to be used in farmers' fields where several yield-limiting and yield-reducing factors occur simultaneously.

The result of this crop ecological analysis shows differences in yield potential of enset clones as a result of higher radiation use efficiency and an earlier expansion in leaf area and the consequent increase in absorbed PAR. This analysis together with the analysis of indigenous production methods (Chapter 2) allows further identification of different yield constraints.

Yield constraints

Yield-determining factors

One of the main yield-determining factors identified for enset-growing regions is temperature. Especially at higher altitude areas leaf appearance rate and leaf area index development were slower associated with temperatures being lower than the optimum. Unfavourable environmental conditions such as frost has also caused fluctuation in LAI in the growing season. These conditions affected early light interception and assimilation and thus clones were stunted in growth and have taken a longer period to fully develop their canopy. Temperature also affects the number of years that plants need to mature because cooler temperature slows plant growth and development. At Hagereselam, for example an enset plant needs about 10 years to mature whereas at Areka it matures within about 6 years under the traditional cultivation practices.

Yield-limiting factors

Yield-limiting factors such as repetitive transplanting, severe leaf-pruning practices, uneven distribution of rainfall and decline in soil fertility were identified in the three regions. Agronomic practices of enset related to methods of transplanting are diverse. Farmers usually transplant enset suckers once or up to four times, at wider spacing before transferring into permanent field. At the fourth transplanting stage, the enset plants are very big and a group of people is needed to carry the plant at transplantation site (Fig. 5). Farmers claim that repetitive transplanting results in more vigorous growth of pseudostem and corm, which are the main harvestable parts of the plant (Chapter 2). In addition, the general purpose of most transplant systems seems to be to maintain a leaf canopy that covers the soil for most of the year in order to utilise the space more efficiently. In Hadiya, for example, small suckers are transplanted in a hole in groups of 3–5 in alternate rows with large suckers (Chapter 2). Annual crops such as maize and beans are planted within the wider rows.

During the dry season, domestic livestock are substantially dependent on parts of enset, in particular the leaf. Leaf pruning practices, however, vary between the regions. Wolaita farmers severely prune enset leaves for animal feed or sale, whereas Sidama, usually use thinned enset plants for animal feed, except during the dry season. In Hadiya

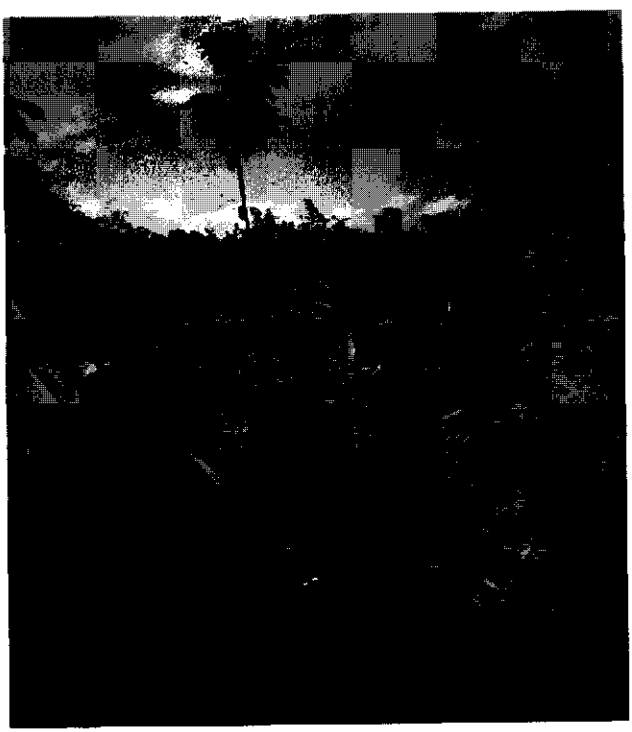

Fig. 5. Large enset transplants shortly after the fourth transplanting into the permanent field in Hadiya. (Picture: Paul Struik)

again except in dry seasons, severe leaf pruning is not practised. The leaves are used as a plate for serving cooked foods, for wrapping several kinds of materials such as fermented enset, butter, coffee and chat, but also to prevent the enset plants from too much drying during the dry season.

This study suggests that an enset plant maintains more green leaf area than is essential to obtain maximum yield of 'kocho' or total plant dry matter. Leaf pruning (removal of leaves, twice a year, leaving 8 functional leaves) did not affect the 'kocho' yield of enset (Chapters 6 and 7). This is because of the relatively high emergence rate of leaves at an early stage of growth (Chapter 5) and as a result of photosynthetic compensation at the later stage of growth. Robinson *et al.* (1992) indicated that in banana, a plant in the same family, disadvantages of moderate leaf pruning (eight leaves retained) are minimal as a result of photosynthetic compensation; when leaves are pruned the greater photosynthetic efficiency of healthy leaves compensates for the loss in area. As leaves have various uses, it would be important to identify the minimum leaf number that need to be retained on the plant to use the remaining leaves for other purposes.

Yield-reducing factors

Enset diseases such as those caused by viruses and bacteria were identified as a main yield-reducing factor. The RUE of 'Halla' at Areka was lower most likely associated with a virus infection. At the same site, the RUE of 'Nekakia' was much higher suggesting a lower level of virus infection and/or clonal variation in sensitivity to such an infection. Although bacterial wilt diseases caused by the bacteria *Xanthomonas campestris* pv *musacearum* were not observed in the yield potential trial, during the survey work it has been observed as the most serious disease of enset. Fungal leaf spot diseases are also common in enset-growing regions. Root lesion nematodes (*Pratylenchus goodeyi*) and root knot nematodes (*Meloidogyne* sp.) are commonly found and are apparently widely distributed (Quimio and Tessera, 1996). Mammals such as porcupines, mole rats, and wild pigs attack enset plants in the field.

Yield improvement

To increase actual yield of enset was one of the principal objectives of this study. In Chapter 2 it is described that the cultivation methods of enset vary within regions and that the crop has a long maturity period of 7–10 years. In Chapter 4, yield-reducing and yield-limiting factors were identified. Yield improvement is possible by optimising the effects of different cultivation methods on the yield and by tackling yield-reducing and yield-limiting factors. In Chapters 6 and 7, the effects of repetitive transplanting and leaf pruning on growth, food production, harvest indices, harvest losses and post harvest losses were studied in order to assess the possibilities of reducing the gap between the actual yield and yield potential.

Transplanting enset suckers directly into permanent field shortens the period until maturity and provides a reasonable yield soon after removing the suckers from the mother corm thus reducing the chance of attack by diseases and pests (Chapter 6). The partitioning of dry matter to the harvestable parts and the harvest indices at different states of processing, however, improved as a result of repetitive transplanting (Chapter 7). An increase in dry matter yield of the harvestable parts of repetitively transplanted plants as the growing period progresses may be due to the higher rate of translocation of photosynthates from the source (leaves) to the sink (corm and pseudostem). Repetitive transplanting retarded the growth rate of the pseudostem and corm at early stage of growth but at the later growth stage it increased the sink size and capacity (the competitive ability of corm and pseudostem to receive or attract assimilates). As the leaf emergence rate of enset is high at early stage of growth (Chapter 5), source limitation is unlikely. Thus, a well-developed sink both in size and capacity as a result of repetitive transplanting is beneficial provided the growing season is long enough to profit from this characteristic.

The investigations reported in Chapters 6 and 7 indicated that it is possible to reduce the gap between actual and yield potential by improving the cultural practices. Actual yield, experimental yield, yield potential and their corresponding ratios of the three transplanting treatments are presented in Table 2. Farmers transplant enset suckers 2–4 times before planting into permanent field (Chapter 2). The gap between the actual yield and yield potential can be reduced by transplanting enset suckers twice and improving the traditional fermentation (Table 2). The low value of the ratio actual yield : yield potential also suggests that much can be done to reduce the effects of yield-reducing and yield-limiting factors.

Current and improved harvesting and post-harvest techniques

One of the factors, which contributed to the wide gap between the actual yield and yield potential, is the yield loss associated with the traditional harvesting and fermentation practices. Although there are slight variations, the methods of harvesting, processing and fermentation are similar among the various enset-growing regions. The main processes of harvesting are scraping the pseudostem pulp (parenchymatous tissue) and pulverising the corm; the mix of the two products is then fermented in a pit.

The primary job of enset harvesting starts with the cutting of leaves and the upper part of the stalk of inflorescence. The leaf sheaths of the pseudostem of mature or big enset plants are peeled off one after the other until the peduncle is reached. The leaf sheath is then cut into several pieces and made ready for scraping (Fig. 6). A single cut of the leaf sheaths of the pseudostem is securely attached to the wooden pole with a string. Using a

Table 2. Actual yield, experimental yield and yield potential (kg plant^{-1}) of 'kocho' in dry matter for Awassa and Areka.

Trans-planting	Actual yield	Experimental yield		Yield potential	A:B	A:C	B:D	C:D	A:D
		Traditional fermentation	Improved fermentation						
	A	B	C	D					
Once		6.42	10.48		1.23	0.75	0.24	0.39	
Twice		16.26	18.56		0.49	0.43	0.61	0.69	
Thrice		9.84	13.45		0.80	0.58	0.37	0.50	
	7.9			26.81					0.29

Note: It is assumed that if the traditional fermentation process is improved the dry matter yield of fermented kocho will be 50 % of the dry weight of corm plus pseudostem. The actual yield and yield potential were calculated from Table 6 in Chapter 5.

bamboo split, the woman from a strenuous sitting position scrapes the fleshy part of the pseudostem down towards a collecting place lined with enset leaves (Fig. 7). She secures the pseudostem on the board by raising one leg and pressing it with her heel so that the stem will not slip down. In some areas the women bow to scrap the fleshy part of the pseudostem (Fig. 8). This processing separates the fleshy part of the pseudostem from the fibre while letting the juice flow down in a small pit lined with enset leaves. After a short period the juicy part sediments into a moist sticky substance known as 'bulla' (Fig. 9).

Using a local digging hoe, the corm is dug out and transported to where the leaf sheaths of the pseudostem are processed. A serrated animal bone (scapula) is used to pulverise the corm (Fig. 7). This process turns the corm into smaller grated pieces, which will be mixed with the fleshy scraped pseudostem.

A large pit is dug near a tree or inside a dense enset plantation to protect it from heavy rain or strong heat. Broad enset leaves are lined in the pit over the dried leaf sheaths to prevent the juicy part from leaking into the ground while keeping scraped pseudostem clean. Then, the mixture is buried in a pit for fermentation and after 2–3 months the product will be fermented and is ready for consumption (Fig. 10). Sometimes the pit is covered by a structure of enset leaves. A pit can be more than 1 m in diameter and up to 1.5 m deep.

The various stages of harvesting, processing and fermentation are done by hand using traditional tools and thus a substantial loss occurs (Chapter 7). Some of the losses due to scraping such as those caused by removing the outer epidermis of the leaf sheaths or separating the fibre from the fleshy parts are unavoidable. But, as these activities are accomplished by hand using traditional processing tools, substantial amount of food

Fig. 6. Cutting the sheaths of the pseudostem into pieces to make it ready for scraping; activities during the processing of the experimental harvests in the experiment at Areka described in Chapters 6, 7 and 8. (Picture: Admasu Tsegaye)

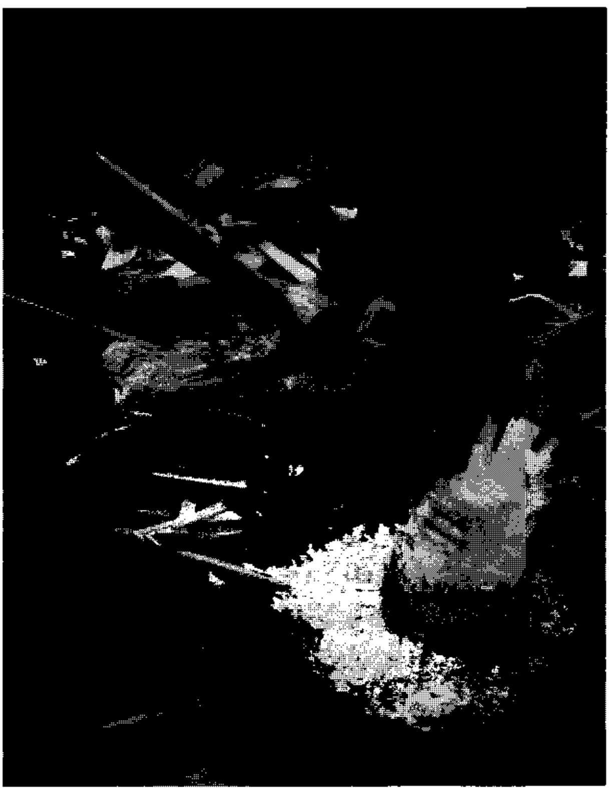

Fig. 7. Scraping pulp of pseudostem sheaths using bamboo split (back) and pulverising the corm using serrated animal bone (scapula) (front) at Tula, Sidama region. (Picture: Paul Struik)

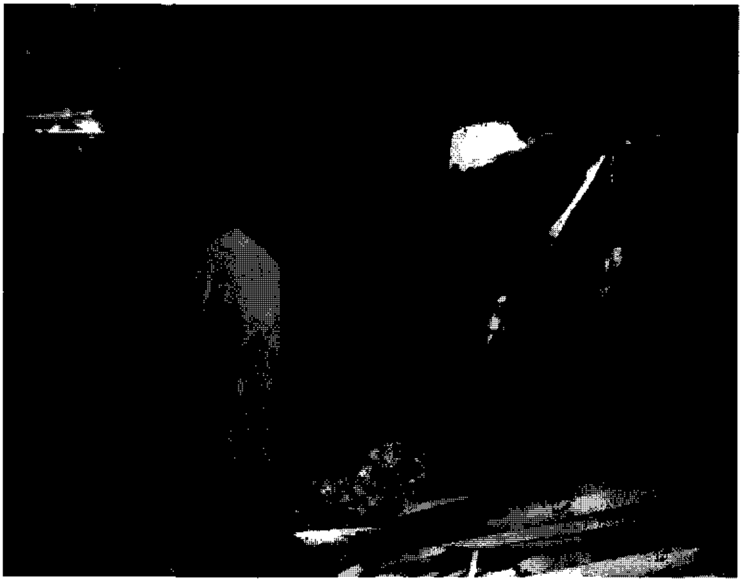

Fig. 8. Scraping pseudostem sheaths in Wolaita. (Picture: Admasu Tsegaye)

Fig. 9. A white sticky substance known as 'bulla' collected as the sediment from the small pit in which the juice is collected during scraping of the pseudostem. (Picture: Admasu Tsegaye)

Fig. 10. A fermented kocho ready for consumption. (Picture: Admasu Tsegaye)

could be left with the outer epidermis, the fibre and on the devices. In addition, the parts of the pseudostem and corm that are selected to be used for food depend on the climatic conditions and on the criteria of the harvester. If there is a prolonged wet or dry period before harvesting a large proportion of the pseudostem and corm could be discarded as the outer parts can be rotten or dried. This variation is also visible to some extent in the data set presented in Chapter 7.

In this study a substantial dry matter loss was also observed because of the traditional fermentation practices. Urga *et al.* (1997) reported that 'kocho' fermentation contributes to flavour and increases the range of raw materials available for food by detoxifying and digesting plant raw materials. On the other hand, Besrat *et al.* (1979) reported a substantial loss of protein as a result of fermentation. Recent studies on the effect of fermentation on protein content or yield losses are not available. But the traditional water permeable pit associated with a long period of fermentation might contribute significantly to yield loss due to leaching of more water-soluble proteins and amino acids.

The processing methods are inconvenient and unhealthy to women as it requires bowing or raising one leg and pressing the pseudostem leaf sheaths with the heel so that it will not slip down (Figs. 7 and 8). All these processes also make the processed products unhygienic. The Rural Technology Promotion Centre of the Ministry of Agriculture at Wolaita, the Nazareth Research Centre and the Awassa College of Agriculture have tried to develop improved enset processing devices, and they were tested on a large scale in different parts of enset-growing regions. As has been observed during the survey work, however, the impact of these improved processing devices on the traditional processing methods is quite limited.

The 'kocho' yield of enset, in terms of weight and energy under different crop establishment methods, was investigated and compared with the yield of other main starch crops in Chapter 8. In terms of weight and energy, enset is the most important in the country, sweet potato is second, taro is third and Irish potato is fourth. The high yield of enset is due to the longer growth period and thus the prolonged presence of a green canopy cover. The canopies of the enset have certain advantages compared to those of cereals and root and tuber crops. They are likely to be present for most of the year, so that more PAR is intercepted (Chapter 5).

Besides the higher yield both in terms of weight and energy, enset can survive in areas with prolonged dry season. The accumulation of water in its pseudostem and corm might help the plant to be physiologically more functional during drought periods than cereals or other root and tuber crops. Because of such hardness, farmers consider enset as a guarantee crop both for them and their livestock during dry spells (Chapter 2). The perennial canopy of the crop intercepts heavy rain and reduces soil temperature and, thereby protects the soil against erosion, decreases organic matter decomposition and reduces leaching of plant nutrients. As a result, problems of soil erosion and land degradation are rarely seen in enset-growing regions.

Big enset plants that surround the homesteads are also used as a shade to the family members and also protects the house against strong winds. A thick, almost impenetrable plantation serves, too, as an excellent protection for properties, livestock and people against vendettas and wild animals.

Future perspectives

In this thesis a number of important aspects, which have not been dealt with in the past, were described in detail. Moreover, knowledge on crop physiological parameters that determine the growth of enset and on how these parameters develop over time and affect yield under field conditions were generated. As research work on enset is at its infant stage, this thesis also identifies some topics for further improvement of the enset production system. These future research directives can be summarised as follows.

Social and cultural aspects

There is variation in cultivation methods among the three main ethnic groups and various agro-ecological conditions. In the three regions, women have responsibility to manage enset farms and have a well-developed knowledge of the crop and its biodiversity. As enset is cultivated by more than 11 ethnic groups at different agro-ecological conditions further research should investigate why there is variation in cultivation methods. Especially, the cultural, socio-economic and agro-ecological determinants responsible for the variation and their interactions need to be elucidated. A gender sensitive analysis is required to enable full comprehension of this variation.

Enset biodiversity

There is considerable genetic diversity in the crop, despite the reported loss of several important clones. Farmers who belong to regions where peoples' cultures are highly associated with the crop have acknowledged the advantages of genetic diversity for production stability, and have better skill in discriminating between clones than farmers who belong to regions where enset is cultivated as a co-staple food. In the future, these areas should receive high priority for collecting materials or serving as sites for *in situ* conservation.

Conservation activities alone will not be sufficient to preserve the remaining enset diversity and make it available to the farmers. As population increases and farmland decreases, farmers do not maintain enset for the sake of conservation, but rather because they are adapted to particular needs and conditions. Better documentation of the characteristics and specific uses of the multipurpose use of enset can serve to maintain interest among farmers and consumers. In addition, conservation through utilisation needs to be enhanced by involving the participation of governmental, non-governmental and farmers' organisations. One good example is the work of the agricultural club at Misha high school in Hadiya. This club asked the students who are coming from different corners of the region to bring different types of enset landraces being grown at their farm. At present more than 100 different landraces are being maintained at this school.

The molecular analysis of enset clones has shown that there might be some useful genes or materials for medicinal purposes or to alleviate some of the problems of enset diseases. The clones that are claimed by the farmers to be resistant to bacterial wilt and useful for medicinal purposes but not used for food have shown a unique band in the AFLP analysis. Thus, further research in the field of biotechnology is needed in order to use the useful genes for the betterment of the society.

A good set of (morphological) crop descriptors to assess the biodiversity in enset, can be a reliable and efficient way to store, retrieve and communicate information on genetic resources. Descriptor lists facilitate genetic resource workers to identify promising accessions. In this study some characters that need to be included in the descriptor lists have been suggested. Further research on genetic diversity using agronomic and physiological, quantitative characters are needed to develop a full set of standardised morphological descriptors.

Recently, there has been increased awareness of the importance of enset for food security and environmental sustainability even outside the traditional enset regions. There might be also a possibility of expanding this crop to other African countries. This put new challenges to maintaining, exploring, and enhancing biodiversity. Before enset is introduced to these areas, suitable clones for specific purposes such as 'kocho' production or corm use, and clones that can be adapted to different agro-ecological zones need to be selected. Furthermore, extension and development work should focus to teach farmers how to cultivate enset, process and utilise the different products.

Enset as an ornamental plant is gaining popularity with the growers and consumers in developed countries. Much effort needs to be done to establish nurseries and select specific enset clones suitable for ornamental purposes.

Crop husbandry

Enset is a singled-stemmed species and growth has precedence over flowering. The separation of growth and flowering in time makes the plant more flexible. As a result the crop responds very favourably to husbandry and reaches high and predictable yields. Thus, future research should concentrate on refinements in cultivation methods, based for instance on nutrient and water management, to maintain high growth rates and partitioning of assimilates to the harvestable parts of the crop.

In this study, yield potential of enset clones has been estimated in a monocropping (monoculture) system with only one clone. But, the enset production system involves intercropping with diverse crop species as well as clone mixtures. Future research, therefore, needs to investigate compatible crops for intercropping and the best mixtures of enset clones.

Diseases like bacterial, viral, fungal diseases and soil-borne pests, such as nematodes, have threatened the sustainability of enset agriculture. Insects that attack enset plant include hoppers, aphids and mealy bug. Wild animals such as porcupines, mole rats, and wild pigs also attack an enset plant. A highly co-ordinated multidisciplinary research that includes farmers' participation is needed to exploit the possibilities of using disease resistance clones, and cultural and management techniques that prevent or reduce the spread or eliminate pests in a field.

Harvesting and processing

The traditional harvesting and post harvesting procedures are tedious, labour intensive, unhygienic and associated with great yield losses. Future research therefore needs to be geared towards development of appropriate processing technologies and reducing the associated pre- and post-harvest losses. Although fermentation might be unavoidable, the traditional methods of fermentation that allow large losses of soluble materials to occur through leaching and prolonged (and repeated) fermentation need to be improved. In this regard the experience from sago palm processing might give a clue to improve the fermentation process. Similar to enset, sago palm accumulates starch in the trunk and processing consists of separation of the bark, pulverisation of the pith and separation of the starch grains from other pith constitutes by leaching out the starch grain with water over a sieve.

Nutrition

Enset produces remarkable quantities of energy per hectare per day, more than cereals do (Chapter 8). Enset products, however, are low in protein and vitamins. Further research, therefore, should investigate how to incorporate protein and vitamins rich food crops in the enset production system. Livestock can also complement this production system by contributing directly to dietary needs, providing manure for soil improvement and generating cash. Thus, future research and development studies need to include a strong component that alleviates constraints to livestock productivity.

To increase the productivity of enset in a sustainable way, research on the enset production system should be conducted in a multidisciplinary and co-ordinated manner. The recent decision of the Ethiopian government to consider the enset as a national commodity crop and allotting funds for its research is encouraging. Because the country has limited resource and manpower for enset research, effort must be made to bring the crop to the attention of international organisations such as INIBA (International Network for the Improvement of Banana and Plantain).

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Summary

Introduction

Agriculture is the main economic activity in Ethiopia. Private subsistence peasants who still practice centuries old traditional methods of production with a very low productivity cultivate about 95% of the presently cropped land of the country.

The enset-planting complex of south and southwestern highlands is one of the four existing agricultural systems in Ethiopia. In these parts of the country, enset (*Ensete ventricosum* (Welw.) Cheesman) has been cultivated as (co-)staple food and supported higher population densities than any other farming system. Since the last three decades, however, because of population pressure, recurrent drought and occurrence of diseases, there has been degradation of natural resources and the indigenous production system failed to sustain the population.

In this study, the indigenous enset production methods and the plant characteristics and environmental factors influencing growth and production were analysed to identify yield potentials and constraints. Farm-based enset biodiversity was also analysed to develop a sound utilisation and conservation strategy. The ultimate goals of the study were to develop improved agronomic practices and enhance the use of the existing genetic diversity to increase food security and environmental sustainability.

Indigenous production methods and farm-based enset biodiversity

In Chapters 2, 3 and 4, indigenous production methods and on farm-based biodiversity of enset were analysed in Sidama, Wolaita and Hadiya ethnic regions. Methods of initiating suckers, frequency of transplanting, leaf pruning and planting pattern vary among the three regions. Farmers in Sidama start with a relatively dense plantation, without a definite pattern of planting, whereas in Wolaita and Hadiya, suckers undergo yearly transplanting in strict plant arrangements before well-developed plants are moved to the site where they will grow and mature. In Wolaita, to initiate suckers, a corm is split into two or four equal parts, whereas in Sidama and Hadiya without splitting the corm the central growing point is bored. Wolaita farmers severely prune enset leaves, whereas in Sidama and Hadiya except in dry seasons, severe leaf pruning is not practised.

Morphologically diverse enset clones were identified in Sidama (52), Wolaita (55) and Hadiya (59) regions. A combination of factors, including household resources, cultural background, population pressure and agro-ecology, influences the number of enset clones on a given farm. Since rich farmers have more resources, notably land, labour, and livestock (as a source of manure), they can plant more clones for their specific characteristics, even when they are low-yielding. Poor farmers, however, do not plant a

large number of enset clones, as some types do not perform as well as others, or need at least 3–4 years to reach a harvestable size. In all three regions, women proved to be more experienced in identifying enset clones than men.

In Chapter 3, 146 enset clones collected from different ethnic regions were characterised with AFLPs. Twenty-one duplication groups consisting of 58 clones were identified. Duplication could be ascribed to the variation in utilisation purposes and to the changing of vernacular names after exchange of clones between different ethnic regions. Although regions differ in their agro-ecological conditions, cluster analysis did not reveal substantial differentiation between the regions because of regular long distance exchange of clones.

In Chapter 4, farmers' characterisation methods based on morphological characteristics, use value and specific phenotypic characteristics were evaluated and compared with characterisation based on AFLPs. Twelve common characteristics frequently used by farmers for identification of enset clones were identified. Eleven duplication groups consisting of 23 enset clones were identified based on the farmers' characterisation method, suggesting that the farmers' method overestimated the biodiversity. Despite the weak, positive correlation, the comparison showed that some aspects of farmers' characterisation, such as absence of clear regional clusters and combining clones with various prefixes into a single group, corresponded well with the characterisation using molecular techniques. Duplicates identified by both farmers' method of classification and molecular analysis may be safely removed from a conservation programme. Variation in farmers' skill in discriminating between clones suggests that areas where people's culture is closely associated with, the crop should receive high priority for collecting materials or serving as sites for *in situ* conservation. Furthermore, the results suggest to include leaf colour, pseudostem colour, midrib colour, fibre quality, corm use and medicinal use when compiling a list of descriptors.

Yield potential

Important crop physiological parameters such as radiation use efficiency, canopy extinction coefficient, time course of radiation interception, and time course of leaf appearance and leaf area index were generated for different clones at different sites in Chapter 5. Yield potentials of different clones were estimated using these parameters and weather data, and compared with actual yield.

The maximum plant height and LAI were reached earlier in Awassa and Areka than in Hagereselam, associated with a higher leaf appearance rate because of higher temperature. The greater number of leaves per plant enhanced early interception of photosynthetically active radiation at Awasa or Areka compared to the situation at Hagereselam. The trend in fraction of intercepted photosynthetically active radiation

(PAR) was best described by a generalised logistic function. The mean PAR extinction coefficient ranged from 0.56-0.91 and the radiation use efficiency ranged from 1.43–2.67 g MJ^{-1}. Important yield potential differences existed between clones mainly because of differences in radiation use efficiency probably associated with viral infection. The average ratio actual yield : yield potential (0.24) suggests that much can be done to reduce the yield gap.

Yield improvement

In Chapter 6, the influence of repetitive transplanting and leaf pruning on dry matter and food production was investigated. Flowering was delayed by 130 weeks and 156 weeks in twice and three times transplanted enset plants compared to transplanting once. At 104 weeks after separating the suckers from the mother corm, the production per ha and per year for transplanting once was 148 and 25% of 'kocho' dry matter of transplanting twice or thrice, respectively.

Although transplanting enset suckers shortens the period until maturity and provides a reasonable yield soon after removing suckers from the mother corm, the dry matter yield of the harvestable parts and harvest indices at different stages of processing were increased and harvest and post-harvest losses were reduced as a result of repetitive transplanting (Chapter 7). Repetitive transplanting initially retarded the growth of the pseudostem and corm but later it increased the sink size and capacity and delayed flowering and thus senescence. At flowering, harvest indices based on fermented enset products of once, twice and three times transplanted enset suckers were 0.20, 0.35 and 0.25, respectively.

Repetitive partial leaf pruning (removal of four to five lower leaves at 6-month intervals) did not affect dry matter production rates of plant components and total dry matter of 'kocho' because of the high leaf appearance rate of enset, the large leaf area present and/or the compensation of reduced leaf area by the remaining leaves.

Yield comparison

The 'kocho' yield of enset, in terms of weight and energy under different crop establishment methods, was investigated and compared with the yield of other main starch crops in Chapter 8. The maximum fresh weights of 'kocho' after fermentation from enset plants transplanted once, twice and thrice were 25.9, 54.1 and 37.1 kg $plant^{-1}$, respectively. In terms of weight and energy per unit of time and area, enset is the highest yielding in the country, sweet potato is second, taro is third and Irish potato is fourth. Cereals yield much less. Moreover, enset can survive in areas with a prolonged dry season. The accumulation of water in its pseudostem and corm might help the plant to be physiologically more resistant to drought than other cereals or root and tuber crops.

General discussion

In the general discussion (Chapter 9), all the main results described in the previous Chapters are integrated. The importance of the indigenous cultivation methods, farm-based biodiversity and the analysis of yield potential and yield gap was further discussed. Chapter 9 also highlights yield-determining, -reducing and -limiting factors. Finally, the possibility of increasing yields by reducing the gap between actual yield and yield potential through improved cultivation methods is discussed.

This study combined indigenous technical knowledge, agronomic, physiological and molecular studies to sustain food security and environmental sustainability. It has contributed significantly to the understanding of the production methods and the genetic diversity. It has also investigated some strategies to reduce the gap between the actual yield and yield potential. Furthermore, it has underlined the relevance of physiological studies by generating basic physiological parameters. However, these new findings need to be confirmed and more, additional physiological parameters should be generated in future. The information gained in this study also helped to identify future research topics.

Samenvatting

Inleiding

Landbouw is de belangrijkste economische activiteit in Ethiopië. Kleine boeren, die slechts in hun eigen levensbehoefte voorzien en daarbij nog steeds op traditionele wijze telen, hebben ongeveer 95% van het akkerbouwareaal van het land in gebruik. Deze vorm van landbouw wordt gekenmerkt door een zeer lage productiviteit.

Ethiopië kent vier landbouwsystemen. Eén daarvan is het ensete-teeltsysteem, dat zich bevindt in het zuiden en zuidwesten van het land. Daar wordt het gewas ensete (*Ensete ventricosum* (Welw.) Cheesman) geteeld als hoofdgewas voor basisvoedsel of als één van de hoofdgewassen. Het ensete-teeltsysteem kan meer mensen per oppervlakte-eenheid van voedsel voorzien dan welk ander teeltsysteem dan ook. Gedurende de laatste drie decennia is er echter, vanwege de bevolkingsdruk, de herhaaldelijke droogte en het vóórkomen van ziekten, sprake van afbraak van de natuurlijke hulpbronnen. Daarom is ook dit inheemse productiesysteem de laatste tijd niet langer in staat de bevolking adequaat te voeden.

In het onderzoek dat in dit proefschrift wordt beschreven werden de inheemse productiemethoden van ensete alsmede de plantkarakteristieken en omgevingsfactoren die van invloed zijn op groei en productie geanalyseerd, teneinde de opbrengstpotentie en de opbrengstbeperkende factoren vast te stellen. De bij de boeren aangetroffen biodiversiteit van ensete werd ook geanalyseerd teneinde een geschikte strategie voor benutting en bewaring van deze biodiversiteit te ontwikkelen. De uiteindelijke doelen van deze studie waren het ontwikkelen van verbeterde teeltmaatregelen en het bevorderen van de genetische diversiteit teneinde de voedselzekerheid te vergroten en de ecologische duurzaamheid te bevorderen.

Inheemse productiemethoden en biodiversiteit van ensete bij de boer

In de Hoofdstukken 2, 3 and 4 werden de inheemse productiemethoden en de bij de boeren aangetroffen biodiversiteit van ensete geanalyseerd. Dit gebeurde voor bepaalde gebieden, met verschillende bevolkingsgroepen, te weten Sidama, Wolaita en Hadiya. De methoden om uitlopervorming te initiëren, de frequentie van overplanten en het plantverband bleken tussen deze gebieden te verschillen. Boeren in Sidama beginnen met een tamelijk dichte stand, zonder een duidelijk plantverband. In Wolaita en Hadiya worden de uitlopers jaarlijks verplant totdat goed ontwikkelde planten kunnen worden uitgezet op de plek waar ze uiteindelijk zullen uitgroeien en rijpen. In Wolaita wordt de knol (cormus) in twee of vier gelijke delen gespleten om uitlopers te krijgen. In Sidama en Hadiya daarentegen wordt het centrale groeipunt van de knol uitgeboord zonder de knol te splijten. Boeren in Wolaita passen bladsnoei toe. Bladsnoei vindt in Sidama en Hadiya alleen plaats in droge tijden.

Er werden veel klonen van ensete gevonden die zich op basis van hun morfologie van elkaar lieten onderscheiden. In Sidama werden er 52 aangetroffen, in Wolaita 55 en in Hadiya 59. Het aantal ensete-klonen op een bepaalde boerderij hing af van een combinatie van factoren, waaronder de hulpbronnen van het huishouden, de culturele achtergrond, de bevolkingsdruk en de agro-ecologische omstandigheden. Rijke boeren beschikken over meer productiemiddelen, zoals land, arbeid en vee (als producent van mest). Rijke boeren kunnen het zich dan ook veroorloven een groter aantal verschillende klonen te verbouwen, ook als sommige rassen minder opbrengen dan andere. Arme boeren daarentegen planten minder verschillende klonen. Zij beperken zich tot de typen die het meest opbrengen dan wel die snel uitgroeien tot een grootte die het mogelijk maakt ze te oogsten. In alle drie gebieden bleken vrouwen beter in staat te zijn om de verschillende klonen te identificeren dan mannen.

In Hoofdstuk 3 werden 146 ensete-klonen die in verschillende gebieden waren verzameld, gekarakteriseerd met AFLPs. Er werden 21 duplicatiegroepen, bestaande uit in totaal 58 klonen, geïdentificeerd. Duplicatie kon worden toegeschreven aan de variatie in het gebruiksdoel en aan het veranderen van de naam in de lokale taal na het uitwisselen van klonen tussen verschillende bevolkingsgroepen. Hoewel de gebieden verschillen in agro-ecologische omstandigheden bleek een clusteranalyse geen substantiële differentiatie tussen de gebieden aan te tonen. Daarvoor werden de klonen te vaak en over te grote afstand uitgewisseld.

In Hoofdstuk 4 werden de methode waarmee de boeren hun rassen karakteriseren, en die gebaseerd is op morfologische kenmerken, de gebruikswaarde en de specifieke fenotypische eigenschappen geëvalueerd en vergeleken met de karakterisering op basis van een AFLP analyse. Twaalf algemene eigenschappen werden door boeren veelvuldig gebruikt om ensete-klonen te onderscheiden. Elf duplicatiegroepen bestaande uit 23 klonen werden geïdentificeerd op basis van de boerenmethode van karakteriseren. Dit geeft aan dat boeren de biodiversiteit mogelijk overschatten. Ondanks de slechts zwakke, positieve relatie toonde de vergelijking aan dat sommige aspecten van de karakterisering door de boeren (zoals afwezigheid van duidelijke regionale clusters en het samenbrengen van klonen met hetzelfde voorvoegsel in een enkele groep) goed overeenkwamen. Duplicaten van klonen die zowel met de boerenmethode als met de AFLP methode als zodanig zijn aangeduid kunnen veilig worden verwijderd uit het bewaarprogramma. Er werden verschillen waargenomen in het vermogen van boeren om onderscheid te maken tussen de klonen. Dit suggereert dat bij het verzamelen van materiaal of het aanwijzen van plekken waar *in situ* bewaring moet plaatsvinden de aandacht zich vooral moet richten op die gebieden waarin de cultuur nauw verbonden is met het ensete-gewas.

Daarnaast lijken de resultaten aan te geven dat een bruikbare lijst van descriptoren in elk geval de eigenschappen bladkleur, kleur van de schijnstengel, kleur van de middennerf, vezelkwaliteit, benutting van de knol en gebruik als medicijn moet bevatten.

Opbrengstpotentieel

Het onderzoek beschreven in Hoofdstuk 5 leverde concrete waarden op voor belangrijke gewasfysiologische parameters zoals stralingsbenuttingsefficiëntie, de lichtextinctiecoëfficient van het gewas, de ontwikkeling in de tijd van de stralingsonderschepping en van de bladverschijning, en de bebladeringsindex (LAI) voor verschillende klonen en verschillende locaties. Het opbrengstpotentieel van de verschillende klonen werd geschat op basis van deze parameters en van weersgegevens, en vergeleken met actuele opbrengsten.

De maximale planthoogte en de LAI werden vroeger bereikt in Awassa en Areka dan in Hagereselam. Dit hield verband met een hogere snelheid van bladverschijning als gevolg van een hogere temperatuur. Het grotere aantal bladeren per plant zorgde voor een grotere onderschepping van fotosynthetisch actieve straling in Awassa of Areka dan in Hagereselam. De ontwikkeling in de tijd van de fractie onderschepte straling werd het best beschreven met behulp van een gegeneraliseerde logistische functie. De gemiddelde extinctiecoëfficient van fotosynthetisch actieve straling was 0,56–0,91 en de stralingsbenuttingsefficiëntie lag tussen de 1,43 en 2,67 g MJ^{-1}. Er bestonden tussen klonen aanzienlijke verschillen in opbrengstpotentieel, vooral vanwege verschillen in stralingsbenuttingsefficiëntie. Deze verschillen hielden waarschijnlijk verband met een virusinfectie. De gemiddelde verhouding tussen actuele opbrengst en opbrengstpotentieel was 0,21. Deze lage waarde geeft aan dat er nog veel mogelijk is om het gat tussen opbrengstpotentieel en actuele opbrengst te overbruggen.

Opbrengstverhoging

In Hoofdstuk 6 werd de invloed van herhaaldelijk overplanten en van bladsnoei op de drogestofproductie en de voedselproductie onderzocht. De bloei werd bij tweemaal overplanten 130 weken en bij driemaal overplanten 156 weken uitgesteld ten opzichte van éénmaal overplanten. De opbrengst per hectare en per jaar voor het gewas dat slechts éénmaal was overgeplant was 104 weken na het losmaken van de uitlopers van de moederknol 148% van de 'kocho' drogestofopbrengst van tweemaal overgeplante uitlopers en 25% van driemaal overgeplante uitlopers.

Het overplanten van ensete-uitlopers verkort de periode tot aan rijpheid en levert kort na het verwijderen van de uitlopers van de moederknol een redelijke opbrengst. Herhaaldelijk overplanten geeft echter een toename van de opbrengst aan oogstbare delen en doet de oogstindexen gedurende verschillende fasen van het verwerken en bewaren van de oogst toenemen. Bovendien geeft het een verlaging van de verliezen tijdens de oogst en tijdens de conservering. Herhaaldelijk overplanten geeft aanvankelijk een vertraging van de groei van de schijnstengel en van de knol. Later doet het echter de 'sink'grootte en de 'sink'capaciteit toenemen en stelt het de bloei (en dus het afsterven) uit. Bij de bloei waren de oogstindexen gebaseerd op gefermenteerde ensete-producten voor éénmaal-overgeplant materiaal 0,20 voor tweemaal-overgeplant materiaal 0,35 en voor driemaal-overgeplant materiaal 0,25.

Herhaaldelijke bladsnoei (verwijderen van de vier of vijf laagst ingeplante bladeren met intervallen van 6 maanden) had geen invloed op de snelheden van drogestofproductie van verschillende plantdelen of van de totale droge stof van 'kocho', omdat de snelheid van bladverschijning hoog was, omdat er een grote bladoppervlak aanwezig was of omdat bladverwijdering werd gecompenseerd door grotere activiteit van het overgebleven blad.

Opbrengstvergelijking

In Hoofdstuk 8 werd de opbrengst van ensete aan 'kocho', in termen van gewicht en energie, bij verschillende methoden van vestiging van het gewas, onderzocht en vergeleken met de opbrengst van andere zetmeelgewassen. De maximale opbrengsten van vers materiaal 'kocho' na fermentatie van ensete-planten die éénmaal, tweemaal of driemaal waren overgeplant waren respectievelijk 25,9, 54,1 en 37,1 kg per plant. In termen van gewicht en energie per eenheid oppervlakte en tijd, gaf ensete de hoogste opbrengsten in Ethiopië. De zoete aardappel staat op de tweede plaats, taro is derde en de (gewone) aardappel is vierde. Granen geven veel lagere opbrengsten. Naast dit hoogopbrengend vermogen kan ensete overleven in streken met langdurige droogte. De opslag van water in de schijnstengel en de knol kan er wellicht voor zorgen dat de plant fysiologisch meer resistent is tegen droogte dan de granen of andere wortel- en knolgewassen.

Algemene discussie

In de algemene discussie (Hoofdstuk 9) worden de belangrijkste resultaten uit de voorgaande hoofdstukken geïntegreerd. Het belang van de inheemse teelttechnieken en de biodiversiteit op de boerderij en de analyse van opbrengstpotentieel en van de kloof tussen opbrengstpotentieel en actuele opbrengst worden verder besproken. Hoofdstuk 9 belicht ook de belangrijkste opbrengstbepalende, opbrengstlimiterende en opbrengstreducerende factoren. Tenslotte worden de mogelijkheden van opbrengstverhoging door de kloof tussen opbrengstpotentieel en actuele opbrengst te verkleinen door verbeterde teeltmaatregelen, besproken.

Het in dit proefschrift beschreven onderzoek combineert inheemse technische kennis met agronomische, fysiologische en moleculaire studies teneinde de voedselzekerheid en de ecologische duurzaamheid te verbeteren. De studie heeft in belangrijke mate bijgedragen aan het begrijpen van de productiemethodes en aan de kennis van de genetische diversiteit. Er zijn ook enkele strategieën onderzocht om het gat tussen opbrengstpotentieel en actuele opbrengst te verkleinen. Bovendien heeft de studie het belang onderstreept van fysiologisch onderzoek dat informatie heeft opgeleverd over een aantal elementaire fysiologische parameters. De nieuwe informatie moet echter nog wel nader worden bevestigd en additionele fysiologische kengetallen moeten in de toekomst worden gegenereerd. De informatie die in de onderhavige studie werd verworven, hielp ook thema's voor toekomstig onderzoek aan te duiden.

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Curriculum vitae

Admasu Tsegaye was born on 11 August 1960 in Gamo Goffa, Ethiopia. After finishing his high school he joined the Awassa College of Agriculture in 1978 and graduated with Diploma in Horticulture. After working in Ministry of State Farms, he joined the Alemaya College of Agriculture and graduated with a Bachelor degree in Plant Science in 1984. He worked at the Institute of Agricultural Research and the Awassa College of Agriculture for some years and then joined the Wageningen Agricultural University and graduated with an MSc in Crop Science, specialisation Crop Production, in 1991. He worked as a lecturer and researcher for the Awassa Agricultural College and again returned to the Wageningen Agricultural University for his PhD Studies in November 1996. He also attended specialised training courses in various countries and institutes to upgrade and diversify his knowledge, namely: Training in tissue culture techniques at IITA, Nigeria; Training in Food, Nutrition and Agriculture, Egerton University, Kenya; International Course on Planning, Management and Extension of Agricultural Projects, CINADCO, Israel; Training on Methods and Techniques of Project Management, ZIPAM, Zimbabwe; Training on Higher Education Management, Addis Ababa, Ethiopia; and Training on Advanced Tissue Culture, ARC, Roodeplaat, Pretoria, South Africa. Besides teaching and research in Plant Sciences, Admasu has worked in various positions: Head of Production and Research at Ministry of State Farms, Horticultural Section Head, Head of Research and Farm Centre and Vice-Dean for Administration, Finance and Development at the Awassa College of Agriculture. Furthermore he has worked as a consultant for NGO's. Admasu is married and is currently a father of two daughters.