Netherlands Journal of Agricultural Science 49 (2001) 81-94

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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Received 28 October 2000; accepted 13 June 2001

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 (Endale, 1997; Pijls *et al.*, 1995).

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 masl.

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 has 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 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/100 g, respectively. Fertilisers (0.10 t urea ha^{-1} y^{-1} and 0.10 t 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 one year old suckers produced in the nursery from the corm directly into the permanent field (T1), (ii) transplanting two years old transplants into permanent field after they had been raised from the corm nursery by transplanting into nursery beds (T2), (iii) transplanting three 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-year 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-year 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-year 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 & Struik, 2000). 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 sub-sample 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.

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

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 (Anonymous, 1990–1997) and Southern Nations, Nationalities, and the Peoples Regional Government Bureau of Agriculture (Anonymous, 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 (Anonymous, 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.

Table 1. Fresh weight (kg/plant) 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.

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.

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 (Figure 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 due to 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 (Figure 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 (Figure 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 the equation from the materials and methods section. 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. Compared to transplanting thrice, transplanting twice increased the dry matter yield of fermented kocho by 42, 45 and 30 percent 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 T3), whereas transplanting thrice reduced dry matter yield of kocho by 38 percent 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 percent 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.

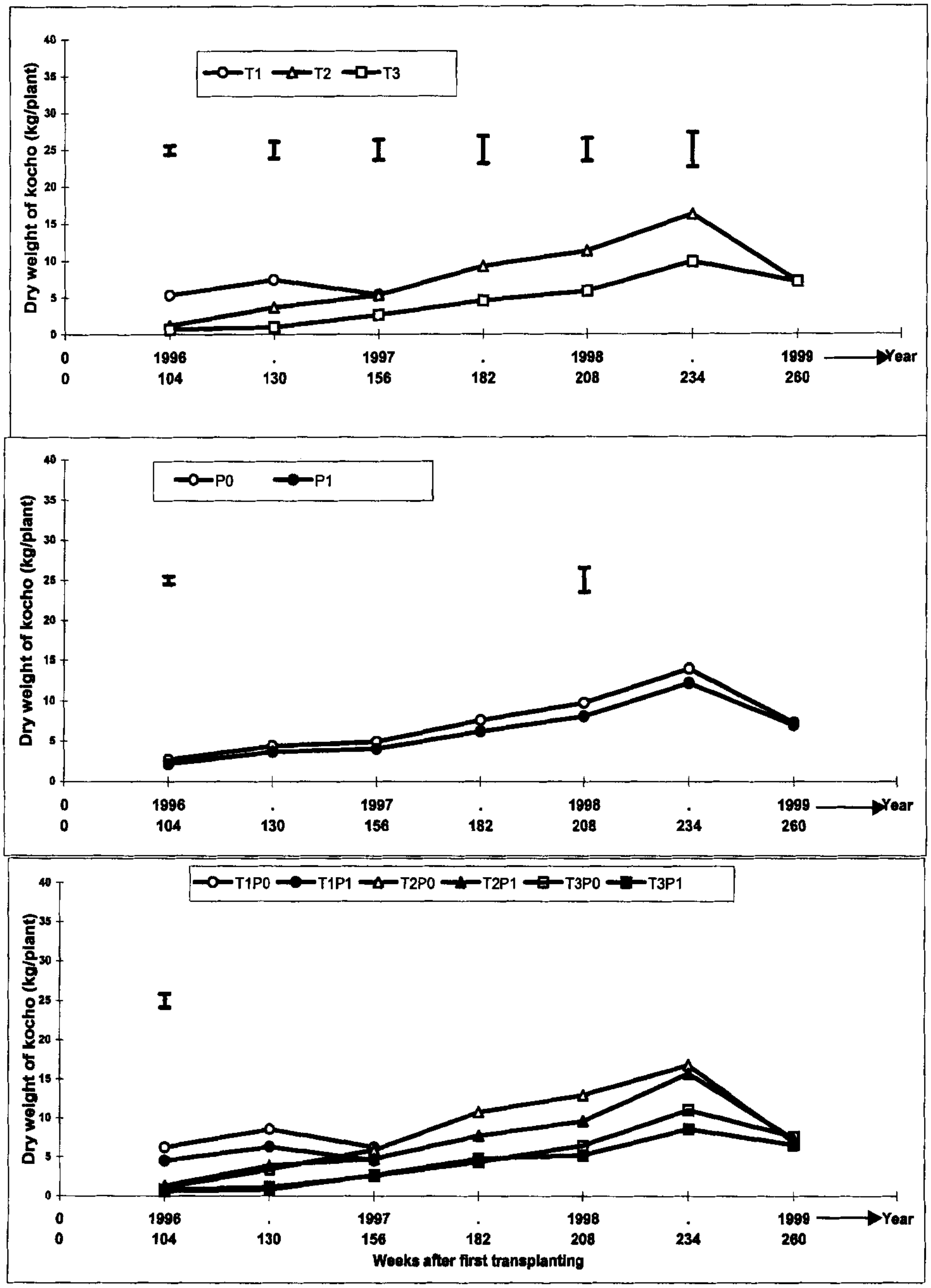

Figure 1. Effects of repetitive transplanting (T1=transplanting once; T2=transplanting twice; T3=transplanting thrice) and leaf pruning (P0=without pruning; P1=with pruning) on the development over time of the dry weight of kocho per plant. Vertical bars indicate LSD.

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 (A)	Leaf pruning (B)	Weeks after removal from the mother corm						
		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.

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 percent 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 (Anonymous, 1995–1997) and Platt (1977). Twice transplanted enset plants increased energy production rate by 80

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 per m^2) (based on average spacing)	Edible portion (%)	Dry matter (%)	Edible dry matter (g per m^2 per harvest)	Growth period (days)	Edible dry matter (g m^{-2} day^{-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] CSA, Average of eight years (Anonymous, 1990–1997)

[c] SNNPRG Bureau of Agriculture, Planning Service (Anonymous, 1998–1999)

and 27 percent 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 (Table 4). The average energy production rate from the three enset crop establishment methods was about 286 and 172 percent 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 percent 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.

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 per m^2)	kJ/100 g of edible yield	Energy production (kJ per m^2)	Energy production rate (kJ m^{-2} day^{-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]Anonymous (1995–1997) and [b]Platt (1977)

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 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 & 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 due to 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.

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 (Anonymous, 1997) reported values of 23.5, 30.6 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 & Ertiro (1996) reported a value of 44.2 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 SNNPRG, 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 spreads, 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 & Rumawas (1996) reported the world's highest average energy production rate from sweet potato with a value of 43 kJ m^{-2} day^{-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 & Sandford (1991), Pijls *et al.* (1995) and Shank & Ertiro (1996) concluded that enset gives higher yield per unit space and time than any other crop. On the other hand, 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; Anonymous, 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 pest problems, transplanting enset suckers or transplants more than twice might increase the susceptibility of the enset plant to 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.

Acknowledgements

The authors thank the Norwegian Universities Committee for Development Research and Education (NUFU) and the Ethiopian Science and Technology Commission for granting funds to execute the research. Also, we thank Mr. Amsalu Gobena and Mr. Asmamaw Zemene for assisting in data collection.

References

Anonymous, 1990–1997. Area and production for major crops. Central Statistical Authority (CSA), Ethiopia, Addis Ababa.

Anonymous, 1997. Enset sample survey results. Central Statistical Authority (CSA), Ethiopia, Addis Ababa, 106 pp.

Anonymous, 1995–1997. Food composition table for use in Ethiopia, part III. Ethiopian Health and Nutrition Research Institute (EHNRI), Addis Ababa, 34 pp.

Anonymous, 1998–1999. Basic agricultural information. Southern Nation Nationalities and Peoples Regional Government Bureau of Agriculture Planning and Programming service, Awassa, 95 pp.

Asnaketch, W., 1997. The ecology and production of *Ensete ventricosum* in Ethiopia. Doctoral thesis, Swedish University of Agricultural Sciences, Uppsala, 129 pp.

Bezuneh, T., 1984. Evaluation of some *Ensete ventricosum* clones for food yield with emphasis on the effect of length of fermentation on carbohydrate and calcium content. *Tropical Agriculture* (Trinidad) 61: 111–116.

Brandt, S.A., A. Spring, C. Hiebsch, G. Yntiso, E. Tabogie, M. Diro, G. W/Michael, S. Tesfaye, J.T. McCabe & M. Shigeta, 1997. The tree against hunger: Enset-Based Agricultural Systems in Ethiopia. American Association for the Advancement of Science with Awassa Agricultural Research Centre, Kyoto University Centre for African Area Studies and University of Florida. Directorate for International Programs. Washington, DC, 56 pp.

Cannell, M.G.R., 1989. Food crop potential of tropical trees. *Experimental Agriculture* 25: 313–326.

Endale, T., 1997. Morphological characterisation of enset (*Ensete ventricosum* Welw. (Cheesman)) clones, and the association of yield with different traits. MSc. thesis, Alemaya University of Agriculture, Alemaya, Ethiopia, 89 pp.

Flach, M. & F. Rumawas, (Eds.), 1996. Plant resources of South-East Asia. No 9: Plants yielding non-seed carbohydrates. Backhuys Publishers, Leiden, 237 pp.

Kefale, A. & S. Sandford, 1991. Enset in North Omo region, Farmers' Research Project Technical Pamphlet No.1, Farm Africa, Addis Ababa, 49 pp.

Makiso, T., 1976. Study on the yield of enset. Sixth Annual Research Seminar. Institute of Agricultural Research, Holetta Research Station, Ethiopia, pp. 246–254.

Platt, B.S., 1977. Tables of representative values of foods commonly used in tropical countries, Special Report Series. Medical Research Council, London, No. 302, 46 pp.

Pijls, L.T.J., A.A.M. Timmer, Z. Woldegebriel & C.E. West, 1995. Cultivation, preparation and consumption of enset (*Ensete ventricosum* (Welw.) Cheesman) in Ethiopia. *Journal of the Science of Food and Agriculture* 67: 1–11.

Shank, R. & C. Ertiro, 1996. Enset crop assessment. United Nations World Food Programme, Bureau of Agriculture, Southern Nations, Nationalities, Peoples' Regional State UNDP Emergencies Unity for Ethiopia, Addis Ababa, Ethiopia, 56 pp.

Smeds, H., 1955. The ensete planting culture of eastern Sidamo, Ethiopia. *Acta Geographica* 13: 1–39.

Stanley, S., 1966. Enset in Ethiopian economy. *Ethiopian Geographical Journal* 4: 30–37.

Tsegaye, A. & P.C. Struik, 2000. Influence of repetitive transplanting and leaf pruning on dry matter and food production of enset (*Ensete ventricosum* (Welw.) Cheesman). Field Crops Research 68: 61–74.

Vergara, B.S., R. Lilis & A. Tanaka, 1964. Relationship between length of growing period and yield of rice plants under limited nitrogen supply. *Soil Science and Plant Nutrition* 10: 15–21.

Wada, G. & P.C.S. Cruz, 1989. Varietal difference in nitrogen response of rice plants with special reference to growth duration. *Japanese Journal of Crop Science* 58: 732–739.