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# Composting experiments in the BioVillage Project, Gurage Zone, Southern Ethiopia

**A documentation**, prepared by ***Jürgen Bierwirth***

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# I Introduction: Agricultural and socio-economic background of the project area

## I 1. Geographic location and climatic conditions

The composting trials were conducted close to the Mamede villages, Gurage Zone, South-West Ethiopa. The villages are located 8km east of the regional capital town Wolkite of the Gurage-Zone. The geographical location of the Mamede villages is 8°2'-8°11' latitude and 37°35'-35°54' longitude. Wolkite is located 163km south-west of Addis Ababa, the capital city of Ethiopia (VII Append. Fig. 21). The total land coverage of the villages is about 800 hectares. The altitude ranges from 1700m up to 1880m above sea level. The annual rainfall ranges between 950mm to 1400mm. The major share of the annual rainfall occurs during the months July to September. A short rainy season occurs normally between February and May, but is not reliable and (as in 2000) can completely be missing. Irregular distribution and amounts of rainfall are one of the major production constraints in the last decades. The annual mean temperature ranges between 18,5°C and 21°C (own estimation, derived from climate-data from the Wollisso climate station, 40km north-west of Wolkite). According to the Ethiopian definition of agro-climatic zones, the area belongs to the " Moist Weyna Dega " zone (Bekele et al., 1993).

## I 2. The farming system and the use of organic wastes in rural small scale farms

**I 2.1. Staple food crops** The farming system in the Gurage area around the town Wolkite is mainly based on the cultivation of ensete (*Ensete ventricosum* W. Cheesm.) as a subsistence food crop. The plantations are directly surrounding the homesteads. The average land size per household is between 0.3 and 0.6 ha. Further products from ensete are fibre, fodder and packaging materials.
Ensete plantations are generally inter-cropped with maize (*Zea mays* L.) and cabbage (*Brassica oleracea* var. ) during the rainy season. Small amounts of yam (*Dioscorea* spp.) and taro (*Colocasia esculenta* L.) are planted close to the houses.

The ensete cultivation system is mainly characterised by the steps of the transplanting system of the perennial ensete plants:
ensete plants are usually harvested at the age of 7 years. The cultivation period is divided into 4 growth stages (transplantations):

1. Vegetative multiplication:
   A three-year-old ensete plant is taken after the end of the rainy season out of the soil, is cut directly above root-level and is transplanted into a nursery plot close to the house. The centre of the remaining plant root base is erased and filled with soil. Within one year, between 40 up to 100 shoots are growing out of the remaining circle of "eyes" of the ensete-plant (VII. App. Fig. 10).

2. The shoots are divided by cutting and are transplanted into rows with a spacing of only a few centimetres within the row and of about 1 meter between the rows.

3. In the following year three these plants are transplanted again with a spacing of 1.0m up to 1.5 meters.

4. The final transplantation into plots with plant distances between 1.5 and 2m is done with the than three year old plants by replacing harvested ensete plants.
   Ensete is planted into small pits with a depth between 0.2 and 0.4m and a width between 0.6 and 1.5m.

After two or three years the soil between ensete-plants is manually overturned with a depth of 0.3m up to 0.4m with a two-pronged strong wooden tool reinforced by iron tips (VII App. Fig. 19).
According to the family size, between 120 and 200 ensete plants per year are harvested. Thus, on the plots for the final transplantation and harvesting, together a minimum of 400 to 600 plants (0.1-0.2ha) have to be grown to assure subsistence for a family with ensete products. Altogether a minimum area of 0.2 to 0.25ha of ensete is required for an average family of six people.
The whole plant is used to produce food, fibre, packaging material and fodder.
From the corm, the pseudo-stem and leaf-sheaths the starch-rich types of food (*kocho, bula* and *amicho*) are extracted (mechanically) and further processed (fermentation). With regard to the production of wastes, no

significant amounts of waste remain from the processing of harvested ensete plants, the fermentation process and cooking of the products. Totally, about 1kg fresh weight of waste occurs per harvested plant.

### I 2.2. Cash crops:

Additionally, plantations of chat (*Catha edulis* (Vahl) Forssk.), oranges (*Citrus sinensis* L.), lemons (*Citrus aurantiifolia* Swingle, (occasional: *Citrus medica* L.), coffee (*Coffea arabica*,), mango (*Mangifera indica* L.), avocado (*Persea americana* Mill.), casmir (*Casimiroa edulis*), banana (*Musa x paradisiaca* L.) and eucalyptus (*Eucalyptus globulus*) are important sources of cash income.
In the last few years, increasing amounts of additional land were ploughed and cultivated with annual crops. These were mainly sold as cash crops on the market (e.g. teff (*Eragrostris tef*) and niger seed (*Guizotia abyssinica* (L.F.) Cass.). Main constraints to expanding the production of annual crops have been the heavy black vertisols surrounding the villages and the lack of animal drought power (oxen) due to the lack of fodder and high prevalence of deseases (tick borne diseases, Trypanosomiasis)

### I 2.3 Organic fertilisation:

Ensete plants are usually transplanted into pits with a depth of 0.2m to 0.4m. Cattle dung, organic materials (dry grasses, dry ensete-leafes) and ashes from the cooking fire are placed directly around transplanted plants with priority given to the first and second year of growth. Ashes and plant-wastes are also placed around plants of the third and forth year.
The root basis of plants with an age of more than three years are places of "retreat" for earthworms during the dry season when the soil completely dries out up to a depth of 1 meter and more. Ensete-plants store high amounts of water and the stem-basis below soil surface provides always some wet and rotting tissue although the surrounding soil is already completely dried out. Within this rotting material, small numbers of epigeic living earthworms can be found.
Thus the pits around the ensete-plants are the earliest breeding places for earthworms at the beginning of the rainy seasons. After extreme dry conditions without the short rainy season in the first months of 2000, already two weeks after the onset of the rains in the beginning of May, large populations of young earthworms were found around the ensete plants in the Mamede village as well as in the town Wolkite. Because of the accumulation of organic materials, the ensete-pits convert themselves fast into small vermicomposting places. Farmers are generally aware of the positive effects of applying organic materials and ashes on plant growth and as a means of protection against soil erosion.
In the ensete plantations three weedings are done during the rainy season. Weeds are left growing up to a height of 0.3m to 0.7m and are then uprooted and left in the field as a mulch layer to protect the soil from erosion and rapid drying. Earthworms migrate and multiply very fast in this mulching layer.
One farmer (vice chairman of the 'Kebelle') commented, that the cultivation period of ensete until harvesting could be reduced from 7 to as little as 4 or 5 years, if additional high amounts of organic materials, including cattle dung, are applied around the ensete plants. Fertilisation trials with mineral fertilisers have shown that ensete is remarkably responding to Nitrogen and Phosphorous application (Uloro & Mengel, 1994). Nevertheless, since still enough organic fertilisers (cattle dung and leftovers from fodder) are available to maintain the nutritional status of the ensete plantations since many generations, mineral fertilisation is not yet used for ensete. Cash income is also one of the most limiting factors for farmers.

### I 2.4. Livestock:

The number of cattle per household is small with 2 to 7 per household. Cattle are kept in a separate section inside the houses at night. The main sources of fodder are communal grazing lands, grass plots between the homesteads and grass-weeds in chat-, ensete- and coffee-plantations. Small amounts of waste from harvesting ensete are additionally given as far as present. Fodder conservation is not yet practiced.
Cattle dung and fodder leftovers in the houses are removed every 3 days out of the house and are directly put around ensete-, chat- and coffee-plants. During the rainy season small amounts of cattle urine are channelled through a hole into a pit on the outside the housewall. The urine is directly used as a fertiliser. During the dry season high amounts of dry, nutrient-poor grasses from feeding are available.

Within the given production system only minor amounts of organic waste in the sense of completely misplaced, unused materials remain. Nevertheless optimisation of the system is a possible option. One idea is to improve nutrient cycling through reduction of losses and concentration of nutrients during the period from the mid of the rainy season up to December. In the course of the rainy season plant biomass is growing much

faster than it can be used by the cattle. This results in large amounts of grasses and weeds which are growing up and drying out in the dry season without being used effectively. Thus two possibilities occur to improve nutrient harvesting and cycling. First, methods of fodder conservation could be introduced. Secondly, beginning at the mid or end of the rainy season, composting of a part of the still nutrient rich biomass in the fields and on the grass plots, could result in reduced nitrogen losses through the production of a storable, nitrogen-rich, organic fertiliser that is ready for use in the beginning of the next rainy season. Discussions with farmers have supported the opinion that, within the plantations, this should not take place before the second weeding time to maintain the mulch layer with the above named positive effects.
An important source of organic waste, that is completely unused until now is human faeces (as far as latrines are present in the villages).

### I 3. Urban and agro-industrial sources of organic wastes in Ethiopia

- Agro-industrial sources:
  - coffee-processing (de-pulping), fruit-processing, sugarcane processing
- Urban sources:
  - slaughtering places: the rumen content of slaughtered cattle
  - hotels, compounds with rented rooms: kitchen wastes
  - wastes from latrines are not used at all; pumping is expensive and the wastes are normally thrown away somewhere into nature with high risk of contaminating water resources

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## II Experiments on composting methods and earthworm species

### II 1. Vermicomposting in flatbeds:

**II 1.1 Main goals**:
1. Epigeic living worm-species from different ecological environments were tested with regard to successful use in vermicomposting beds with different organic waste materials. Observed parameters are the migration rate of worms into the applied layer of wastes and successful multiplication.
2. Two mixtures of waste materials from town and from agricultural production were tested with regard to the effect on the worm multiplication.
3. The quality of the produced composts was analysed with regard to the quality as a plant growth media and nitrogen loss.

**II.1.2 Materials and Methods**
**II 1.2.1 Experimental design**
9 compartments with a size of 2.0m x 1.5m each were constructed with a metal roof for protection against the sun and rainfall. Vermicomposting beds were build up directly on the soil and consisted of a layer of starter material with the introduced worm populations and the layer of waste materials separated from the starter layer by PE-meshes with a mesh-width of 4mm. The height of the layers of the starter and waste materials were originally ca. 0.2m each.
4 vermicomposting beds with an area of 1.6m x 1.0m each were build up.
2 variants of wastes and 2 variants of worm populations were tested (see below).
2 control beds without worms were build up with the 2 types of waste materials.
The beds were watered from day 4 onward as needed after adding the waste layers (every 2nd to 4th day) with ca. 8 $l/m^2$.

**II.1.2.2 Worm species**
Earthworm-species from three different origins were collected.
1. The first ecological environment is the slurry outlet channel of the biogas-digester of the Biofarm in Addis Ababa. The earthworm environment can be mainly characterised by a continuos high moisture content and a mixture of partly decomposed slurry and soil.
The pH was neutral between 6.5 and 7 (at the end of the dry season).

2. The second environment is the place for disposal of organic wastes from the garden of the ILRI

compound, Addis Ababa. The organic material consists of cuttings from grasses, shrubs and trees. Worms were collected from the moist organic layer directly above the soil surface. The pH of the almost rotten material was neutral (7.0). About 800 worms were collected.

3. The third environment is the ensete plantations in the Mamede village / Gurage zone.
Worms were collected from the organic layer directly on top of the soil-surface and from the basis of the ensete plants out of partly rotten plant-material. At the bottom of ensete plants a small amount of rotting plant material is continuously present also during the dry season due to the extreme water retaining ability of ensete. Since only a small amount of plants were harvested during the time of setting up the composting beds, only a small number of worms (ca. 50-100) were collected directly from the ensete plants. Already 2 weeks after the onset of the rains (this year exceptionally in the beginning of May) the organic materials around the ensete plants were crowded with obviously epigeic earthworms. A large amount of worms (estimated no.: ca. 1000) were collected then. The pH of this environment in the beginning of June (beginning of the rainy season) was neutral to slightly alcalic between 6.5 and 8.

Worms from Mamede were added to the vermicomposting compartments together with the worms from the ILRI compound. This was done to assure sufficient worm populations in the respective compartments and since both populations were multiplying within deacying plant material in contrast to the population from the Biofarm which was originally multiplying in decaying biogas-slurry.

>From first observations two or more worm-species were mixed in all of the 3 populations that were used. Identification has still to be done.

**II.1.2.3 Waste materials**

Two different organic materials were used in separated composting beds.
1. The main type of organic waste, available at small scale farms in the Mamede/Gurage area, in the following called farm wastes (FW):
A mixture of dry grasses and cattle dung and fresh weeds. Due to the composition and way of preparation of food, which is based on products from ensete (*Kocho, Bula, Amicho*), no significant amounts of kitchen wastes are produced. From harvesting one ensete plant, only a very small amount of removals (ca. 1.0kg fresh weight) from the plant-basis are left over unused. The rest of the plant is completely used as food, fibre, packaging material and animal fodder.

Initial chemical waste properties:

| | |
|---|---|
| pH: | 7.0 |
| moisture content: | 56% |
| C/N ratio: | 20 to 30, average: 27 |
| total N: | 1.2% - 1.7%, average: 1,5%<br>(weight percentage of dry matter) |
| total P: | 1200ppm - 1800ppm, average: 1500ppm<br>(weight percentage of DM) |
| available P: | 600ppm - 760ppm, average: 660ppm<br>(weight percentage of DM) |

2. A sample of organic wastes of the town Wolkite, in the following called town wastes (TW):
A mixture of kitchen- and fruit-wastes and young chat-branches (*Catha edulis*), ensete leaves and grasses.
These wastes were collected from hotels and juice-selling houses in the town Wolkite.
Composition of fresh material (weight percentage):
65-75% fruit pulps, 20-30% Chat, 5-8% Ensete-leaves and grasses

Initial chemical waste properties:

| | |
|---|---|
| pH: | 4.0 to 4.5 |
| moisture content: | 78% |
| C/N ratio: | 12 - 23, average: 20 |

| | |
|---|---|
| total N: | 1.5% - 2.1%, average:1.8%<br>(weight percentage of DM) |
| total P: | 2000ppm - 2900ppm, average: 2300ppm<br>(weight percentage of DM) |
| available P: | 900ppm - 1100ppm, average: 1000ppm<br>(weight percentage of DM) |

**II 1.2.4. Measurements:**

The pH of the fresh waste materials was measured with test-strips (range 4.5 - 10.0, step 0.5) after shaking of 20 minutes (in the car on the 8km transport on non-asphalt roads).

Samples of 0.35kg to 0.6kg from the waste layer were taken after 0, 7, 14 and 28 days. The samples were dried with a solar box at about 60-70°C until being air-dry.

The air-dry samples were analysed for pH, electric conductivity, ash content, organic matter, total N, total P, organic carbon and soluble P at the ILRI soil laboratories, Addis Ababa.

Derived parameters are the mass loss and the total N-loss, calculated from the changes in the P-concentration and N/P ratio respectively. Since phosphorous is not easily leached and volatile, phosphorous is taken as the tracer to calculate the total loss of other elements and the total organic material (it is assumed that the total amount of P is constant).

The worm populations were counted 30 days after setting up the waste layer. The whole waste layer was taken from the bed with the PE-net and the complete worm population within the layer was counted. According to initial measurements with a 20ml glass-cylinder with an accuracy of 0.1ml the worm-size of each worm was classified into of the following 7 classes: <0.1ml; 0.1 - 0.15 ml; 0.15 - 0.2 ml; 0.2 - 0.25ml; 0.25 - 0.30ml; 0.30 - 0.35ml; >0.35ml. The worm length was accordingly between 1cm and 12cm. The mass density of the worms was set to 1g/cm$^3$ (1g/ml) with regard to the calculation of the biomass development (The real mass density is only very slightly above 1g/cm$^3$).

Conical fly traps were constructed with a base surface area of 0.06m$^2$ and placed directly upon the compost surface to catch young flies, that developed in the waste layer (VII App. Fig. 20). Three traps were placed on a compost surface of 1.5m$^2$

**II 1.3 Results**

**II 1.3.1. Development of the worm populations**

**II 1.3.1.1 Influence of the waste material on multiplication rates**

Obvious differences in the properties of the waste materials with regard to the suitability as a habitat for earthworms were detected.

Fruit wastes from the town have an initial acidic pH of 4.0 to 4.5 which is not suitable for most tropical epigeic earthworms who prefer a pH between 5.5 and 8.0 (E. Aranda et al. 1999). The effect of the application of fresh and pre-composted fruit wastes on the worm behavior was tested with an box-experiment described in detail under II 4. It was observed, that the worms escaped to the periphery of the beds while in the center a compacted and slimy area developed from the fruit pulps. Thus, without overturning of the material the re-entry of the worms takes a long time, although the measured pH was changing to 6.0-6.5 after 1 week and to 7.0 to 7.5 after 2 weeks.

The farm waste mixture had initially an neutral pH of 7.0 and higher average C/N ratio of 27 (town wastes:20). Worms migrated already after 2 days into the fresh waste layer.

The total number and biomass of worms and the number of worms per dm$^3$ in the waste layers after 30 days on the composting beds are shown in Tab. 1.

With both types of worm populations the number worms that entered into the waste layer were distinctly higher in the "farm waste mixture" compared to the town wastes. This result was extremely impressive for the worm population originated from ILRI/Mamede ( Tab.1; Fig.1).

Within this waste layer the population consisted of a high percentage of young individuals as shown in the size disribution (Fig.2,3) and thus represented a dynamically growing population.

| waste material | town waste | town waste | farm waste | farm waste |
|---|---|---|---|---|
| origin of worm population | Biofarm | ILRI+Mamede | Biofarm | ILRI+Mamede |
| no. of worms /density (1/litre) | 34 / 0.5 | 135 / 2.0 | 81 / 1.2 | 1613 / 22 |
| total biomass of worms g (g/l) | 6 (0.08) | 24 (0.33) | 14 (0.19) | 173 (2.36) |

**Table 1:** Worm populations after 30 days in the waste layers of the vermicomposting beds.

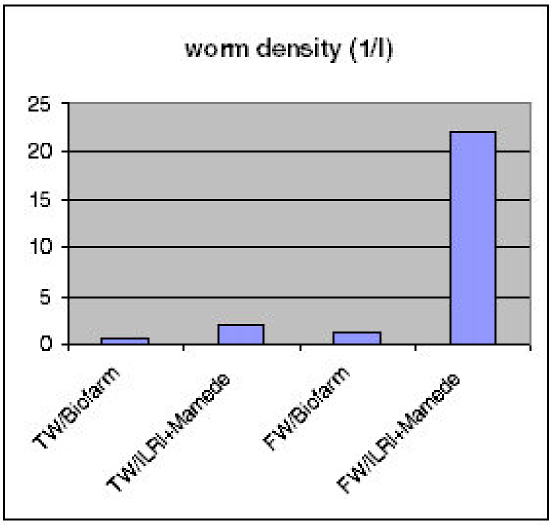


**Fig. 1:** Number of worms per litre in the waste layers of the vermicomposting beds after 28 days (TW: town waste; FW: farm waste).

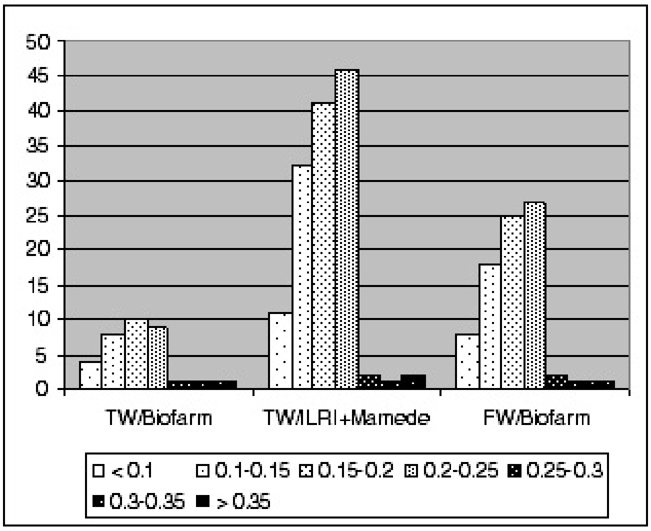


**Fig.2:** Number of worms and size distribution in the waste layers of the vermicomposting beds after 28 days (TW: town waste; FW: farm waste)

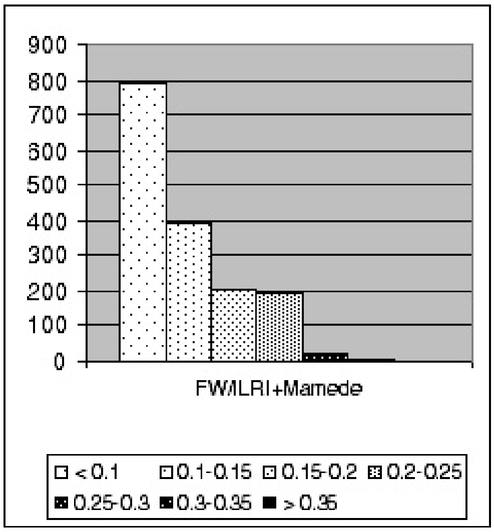


**Fig.3:** Number of worms and size distribution in the farm waste layer of the ILRI/Mamede worm population after 28 days (TW: town waste; FW: farm waste)

### II 1.3.1.2 Influence of the type of worm population on the multiplication rates

After 30 days, within both waste types the worm populations from ILRI / Mamede were greater than the Biofarm populations. Within the town waste layers the ILRI/Mamede populations were 4 times and within the farm waste 20 greater than the Biofarm populations (Table 1; Figure 1,2,3).

### II 1.3.2. Changes of the chemical properties of the compost-layer in time

**Mass loss:**

| | 7 days | 14 days | 28 days |
|---|---|---|---|
| town waste | 0% | 5% | 24.5% |
| farm waste | 0% | 5% | 28% |

**Tab. 2:** The calculated mass loss of the town wastes and farm wastes during the first 4 weeks of vermicomposting.

**pH:**

| | 0 days | 2 days | 7 days | 14 days | 28 days |
|---|---|---|---|---|---|
| pH of the town wastes | 4.0 - 4.5 | 5.0 - 5.5 | 6.0 - 6.2 | 7.0 - 7.5 | 7.5 - 8.2 |
| pH of farm wastes | 6.5 - 7.5 | 7.0 - 7.5 | 7.5 - 8.0 | 8.0 - 8.3 | 8.0 - 8.4 |

**Tab. 3:** The change of the pH of the town wastes and farm wastes during the first 4 weeks of vermicomposting.

**Salt concentration:**

The salt concentration (electric conductivity) was constant through the whole tested period. The electr. conductivity of the town waste was between 2.7 and 3.2 mS/cm (average: 3.0) and the electr. conductivity of the farm waste was lower between 1.6 to 2.4 (average: 2.0).

**C/N ratio:**

| | 7 days (stand. dev.,n=4) | 14 days (stand. dev.,n=6) | 28 days (stand. dev.,n=6) |
|---|---|---|---|
| town waste | 21.0 (3.0) | 19.0 (0.6) | 14.0 (1.7) |
| farm waste | 28.2 (7.0) | 27.1 (1.3) | 20.1 (1.2) |

**Tab.4:** The change of the C/N ratio of the town wastes and farm wastes during the first 4 weeks of vermicomposting.

**Total Nitrogen loss (N/P ratio):**

| | 0 days (stand. dev.,n=3) | 7 days (stand. dev.,n=3) | 14 days (stand. dev.,n=6) | 28 days (stand. dev.,n=6) |
|---|---|---|---|---|
| N/P ratio: town waste | 8.0 (1.48) | 8.3 (1.54) | 8.0 (1.27) | 7.9 (0.69) |
| calculated N-loss town waste | 0% | -3.7% | 0% | 1.25% |
| N/P ratio: farm waste | 9.2 (1.24) | 9.14 (0.53) | 9.30 (1.3) | 7.62 (1.17) |
| calculated N-loss farm waste | 0% | 0.3% | 1% | 17.2% |

**Tab.5:** The calculted nitrogen loss (derived from the N/P ratio) of the pH of the town wastes and farm wastes during the first 4 weeks of vermicomposting.

**Plant available P:**

| | 0 days (stand. dev.,n=3) | 14 days (stand. dev.,n=4) | 28 days (stand. dev.,n=6) |
|---|---|---|---|
| soluble P<br>town waste | 1100 (142) | 1004 (140) | 1203 (137) |
| soluble/total P ratio<br>town waste | 41% (4%) | 38% (4.5%) | 37% (5%) |
| farm waste | 570 (98) | 646 (66) | 717 (86) |
| soluble/total P ratio<br>farm waste | 42% (6%) | 43% (5%) | 36% (3.5%) |

**Tab. 6:** The change of the plant available (soluble) phosphorous and soluble/total phosphorous ratio of the town wastes and farm wastes during the first 4 weeks of vermicomposting.

| | mass loss | total N (% DM) | total P (% DM) | C/N ratio | N/P ratio | soluble P (ppm of DM) | soluble/total P ratio | total nitrogen loss |
|---|---|---|---|---|---|---|---|---|
| vermicompost (TW) | 24.5% | 2.3 | 0.30 | 14.0 (1.7) | 7.9 (0.69) | 1203 (137) | 37% (5%) | 1.5% |
| pile (TW) | 42% | 2.20 | 0.37 | 14.2 (1.7) | 6.2 (1.1) | 1450 (460) | 44% (10%) | 24.8% |
| combined method (TW) | 38% | 2.50 | 0.36 | 12.5 (0.6) | 6.68 | 1420 (209) | 42% (4%) | 12.5% |
| vermicompost (FW) | 28% | 1.56 | 0.21 | 20.1 (1.2) | 7.62 (1.17) | 717 (86) | 34% (6%) | 17.2% |

**Tab. 7:** The total N and P content, the C/N ratio, N/P ratio and soluble P for the used materials and copmosting methods after 28 days of composting.

**Fly populations**
In the town waste layers of the vermicomposting beds a considerable number of flies (house flies) developed throughout the whole first 3 weeks of composting. Biting fly species were not caught, which might also have been due to the absence of human beings and animals in the nearby surrounding.

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## II 2 Hot-rottening compost

### II 2.1 Main goals

1. As a second composting method for organic wastes, a thermophilic piling method with a 12 to 14 days period of intensive hot rottening was used to assure fast hygienisation of the material. Total nitrogen losses and the change of available phosphorous during the composting process of town wastes were determined in comparison with the vermicomposting method.
2. The second aim was to study the effect of the two composting methods on the fly multiplication within the compost.

Part of piles were added to an additional vermicomposting bed after 12 days ( see II 3. Combined hot-rottening and vermicomposting).

### II 2.2 Materials and Methods

Two of the above named, roof protected compartments were used to test a hot-rottening piling method.
As waste material, town wastes in the same composition than those used for the vermicomposting beds were used.
Piles with a trapezoid cross-section, a height of about 0.8m and a width of about 1.0m at the base were set

up. The piles were overturned after 2, 6 and 10 days to provide aeration and to turn the outer layers into the centre to assure thorough heating of the whole material.
Self-heating from microbial activity up to 70 to 80°C in the centre of the piles occurred for a period of 7 to 10 days. 12 days the initial piling, the temperature within the piles was less than 45°C. Successive, within three weeks, four piles were set up. Measurements were conducted successively on the four piles.
The piles were watered from day 4 onwards as needed (every second to 4th day).

**Measurements:**
Samples of the fresh material and after 4, 7, 14 and 28 days were taken, air dried (II 1.2.4.) and analysed at the ILRI soil laboratories, Addis Ababa. The pH, electric conductivity, ash content, organic matter, total N, total P, organic carbon and available P was analysed. The pH of the fresh material was additionally measured with test-strips.

### II 2.3 Results

**II 2.3.1. Moisture content:**
The moisture content changed in average from initial 78% to 54% in the piles (Fig. 5).

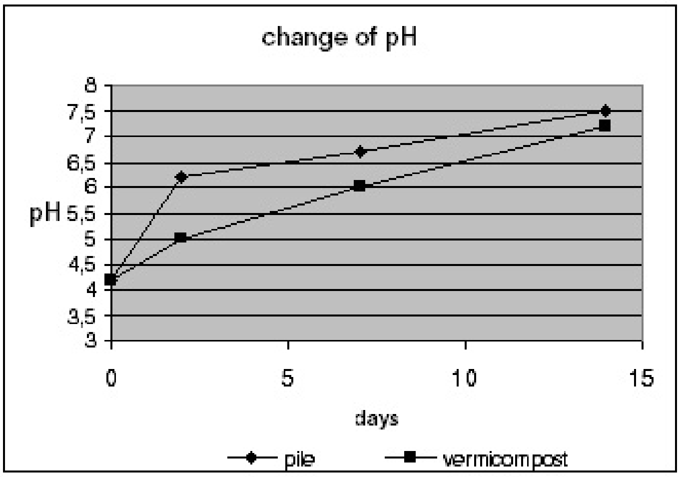


**Fig. 4:** The change of the pH during the first two weeks in piles and vermicomposting beds of town wastes.

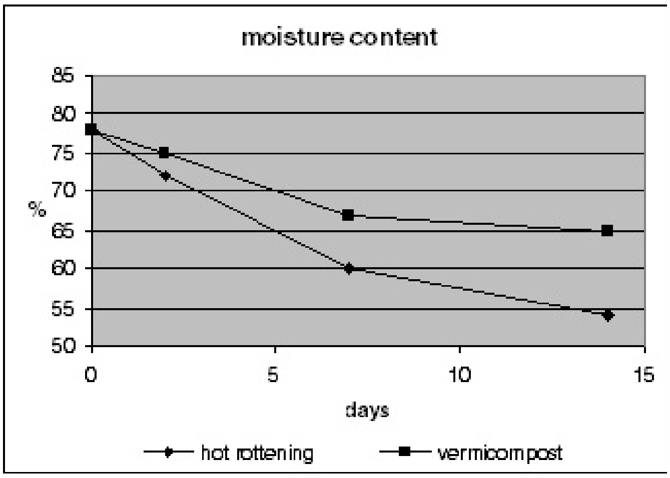


**Fig. 5:** The change of the moisture content during the first two weeks in piles and vermicomposting beds of town wastes.

**II 2.3.2. pH:**
The pH in the piles changed within in 2 days from 4.0 - 4.5 up to 6.0 - 6.5 (Fig. 4). After 1 week the pH was neutral ( 7.0 ).

| | 0 days | 2 days | 7 days | 14 days | 28 days |
|---|---|---|---|---|---|
| pile compost | 4.0 - 4.5 | 6.0 - 6.5 | 6.5 - 7.0 | 7.5 - 8.0 | 8.0 - 8.5 |
| vermicomposting beds (town wastes) | 4.0 - 4.5 | 5.0 - 5.5 | 6.0 - 6.2 | 7.0 - 7.5 | 7.5 - 8.2 |

**Tab. 8:** The change of the pH of the town wastes during the first 4 weeks within the piles and in the vermicomposting beds.

**II 2.3.3. Mass loss:**

| | 7 days | 14 days | 28 days |
|---|---|---|---|
| mass loss | 6% | 31% | 42% |

**Tab. 9:** The mass loss of town wastes during the first 4 weeks of composting in piles. (calculated from the change of P-concentration)

### II 2.3.4. C/N ratio:

| C/N ratio | 0 days (stand. dev.,n=4) | 7 days (stand. dev.,n=6) | 14 days (stand. dev.,n=6) | 28 days (stand. dev.,n=6) |
|---|---|---|---|---|
| town waste | 21.2 (3.0) | 21.8 (2.6) | 16.7 (2.5) | 12.7 (1.5) |

**Tab. 10:** The C/N ratio of the town waste during the first 4 weeks of composting in piles.

### II 2.3.5. Salt concentration:

The salt concentration (electric conductivity) was constant throughout the whole tested period. The electr. conductivity of the composted town waste was between 2.5 and 3.2 mS/cm (average: 3.0) within the piles.

### II 2.3.6. Total Nitrogen loss (N/P ratio):

| | 0 days (stand. dev.,n=3) | 7 days (stand. dev.,n=6) | 14 days (stand. dev.,n=6) | 28 days (stand. dev.,n=6) |
|---|---|---|---|---|
| pile | 7.8 (1.33) | 7.6 (1.54) | 7.1 (1.78) | 5.9 (0.69) |
| calculated N-loss pile | - | 2.7% | 8.8% | 24.8% |
| vermicompost | 8.0 (1.48) | 8.3 (1.54) | 8.0 (1.27) | 7.9 (0.69) |
| calculated N-loss vermicompost | 0% | -3.7% | 0% | 1.25% |

**Tab. 11:** The N/P ratio and calculated N-loss of the town waste during the first 4 weeks of composting in piles and on vermicomposting beds.

### II 2.3.7. Plant available P:

| | 0 days (stand. dev.,n=3) | 14 days (stand. dev.,n=4) | 28 days (stand. dev.,n=6) |
|---|---|---|---|
| soluble P: pile (ppm) | 1120 (330) | 1250 (390) | 1450 (460) |
| soluble/total P ratio: pile (ppm) | 45% (8%) | 40% (7%) | 44% (10%) |
| soluble P: vermicompost (ppm) | 1100 (142) | 1004 (140) | 1203 (137) |
| souluble/total P ratio: vermicompost | 41% (4%) | 38% (4,5%) | 37% (5%) |

**Tab. 12:** The soluble P concentrations and soluble/total P ratio the town waste during the first 4 weeks of composting in piles and on vermicomposting beds.

### II 2.3.8. Fly populations

The fly larvae moved fast to the periphery of the piles and thus were only partly killed through the heat inside he piles. Compared to the vermicomposting beds, the total surface area is smaller and the fast microbial conversion reduces attractiveness of the wastes for flies to lay new eggs as proved with the combined composting method. Overturning of the piles in the first days is an factor to reduce fly multiplication.

## II 3 Combined hot-rottening compost and vermicomposting

### II 3.1 Main goals

1. To test the efficiency of intensive thermophilic pre-composting of the town waste material to improve the physical and chemical properties with regard to later vermicomposting and worm multiplication.
2. To compare the sole pile-composting method with a combined vermicomposting method with regard to losses of nitrogen and the effect on the amount of plant-available phosphorous.

### II 3.2 Materials and Methods

One roof protected compartment was used for vermicomosting town wastes after a period of 10 - 12 days of thermophilic pre-composting in piles (hot rottening, see II 2.2). 1/3 of the piles were taken away after 10 to 12 days and put on a vermicomposting bed (see II 1.2) with a worm population from the ILRI-compound.

**Measurements:**
After a total composting time of 4 weeks, samples from the waste layer were taken and analysed (see II 1.2.4). The worm density was counted from a 5 litre sample of the waste layer, after 20 days on the vermicomposting bed.

Conical fly traps were constructed with a base surface area of $0.06m^2$ and placed directly on the compost surface to catch young flies, that developed in the waste layer. Three traps were placed on a compost surface of $1.5m^2$

### II 3.3 Results

Worms entered very fast into the precomposted material which was also proved in detail in the box-experiment (see II 4). In a 5 litre sample of the waste layer after 18 days on the vermicomposting bed, the worm density was 18 worms/litre which was only slightly below the respective density in the farm-waste flat bed (22 worms/l, Tab. 1). Although the concentration of worms in the starter material was almost two times higher at the beginning of the experiments compared to the other vermicomposting beds, this gives at least a good indication, that worm development was better compared to the fresh town wastes wich resulted in a worm density of only 2 worms per litre (Tab. 1).
After a total composting time of 28 days the chemical properties were in the range of the results for the piling method except for the calculated nitrogen loss which was intermediate between the sole vermicomposting and pile methods (Tab. 13).

| | mass loss | pH | C/N | total nitrogen loss | soluble P | soluble/total P ratio |
|---|---|---|---|---|---|---|
| combined method | 38% | 8.0-8.5 | 12.5 (0.6) | 12.5% | 1420 (209) | 42% (4%) |
| vermicompost | 24.5% | 7.5 - 8.2 | 14.0 (1.7) | 1.5% | 1203 (180) | 37% (5%) |
| pile | 42% | 8.0 - 8.5 | 12.7 (1.5) | 24.8% | 1450 (460) | 44% (10%) |

**Tab. 13:** The chemical properties of town wastes after 28 days of composting on piles,on vermicomposting beds and with a combined method.

**Fly multiplication:**
After 10 - 12 days of intensive hot rottening, no significant new development of fly-larvae was observed in the fruit waste material.

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## II 4 Box-experiment

### II 4.1 Main goals

1. To quantify the growth-rate (multiplication-rate) and biomass development of a selected worm population.

2. To observe more in detail the influence of fresh and pre-composted fruit wastes on the worm behaviour and multiplication.

**II 4.2 Materials and Methods**

Four wooden boxes were constructed with a size of 0.45m x 0.45m x 0.35m (w x l x h). The bottom and top were left open. The bottom was covered with a metal screen of mesh size 1.3mm in order to allow good aeration and to prevent worms and compost from falling out. A layer of 0.06m (10 litres) of starter-material with 200 worms ( 20 worms / litre) was filled into the boxes on the wire-meshes. Worms were sorted out by hand out of starter material and were counted. One control box was filled with starter material without worms.

The worm-mass was measured by adding 20 worms together into a glass-cylinder (250ml) with an accuracy of 1ml, partly filled with water and by measuring of the raise of the volume. Thus the worms were not injured and the mass could be measured exactly enough since the mass density of worms is almost exactly 1g/ml.

Four light "inlay"-boxes were constructed from metal wire covered with plastic. The bottom is covered with a PE-net with a mesh-width of 4mm. The inlay boxes were fitting exactly into the wooden boxes. The waste-materials were placed inside and were thus separated from the starter-material by the PE-net in a way that the worms still can easily pass through. The top was covered by plastic (not air-tight) to prevent birds from entering the boxes and to reduce evaporation.

The initial number of worms per box was 200 (20 worms per litre) with an average worm-mass of 0.16g (max.: 0.8g, min.: 0.03g).

A layer of 10cm (13 litre) of waste materials were added into the inner boxes:

1. weed-samples from ensete-fields of farmers in Mamede
2. fresh fruit wastes (pulps) from juice-houses in Wolkite
3. pre-composted fruit-wastes (8 days hot composting in a pile)
4. control: pre-composted fruit-wastes (8 days hot composting in a pile)

**Measurements:**

Worms at the surface between the layers were counted every 4 days immediately after lifting up the inner box.

The total number of worms in the starter layer and the waste layer after 28 days was counted through sorting out by hand. According to measurements with a 20ml glass-cylinder with an accuracy of 0.1ml the worm-size of each worm was classified into of the following 7 classes:

<0.1ml; 0.1 - 0.15 ml; 0.15 - 0.2 ml; 0.2 - 0.25ml; 0.25 - 0.30ml; 0.30 - 0.35ml; >0.35ml. The worm length was accordingly between 1cm and 12cm.

**II 4.3 Results**

The number of worms, visible on the surface of the starter layer and entering into the waste material directly after lifting up the inner box, is shown for the first 28 days in Fig. 6.

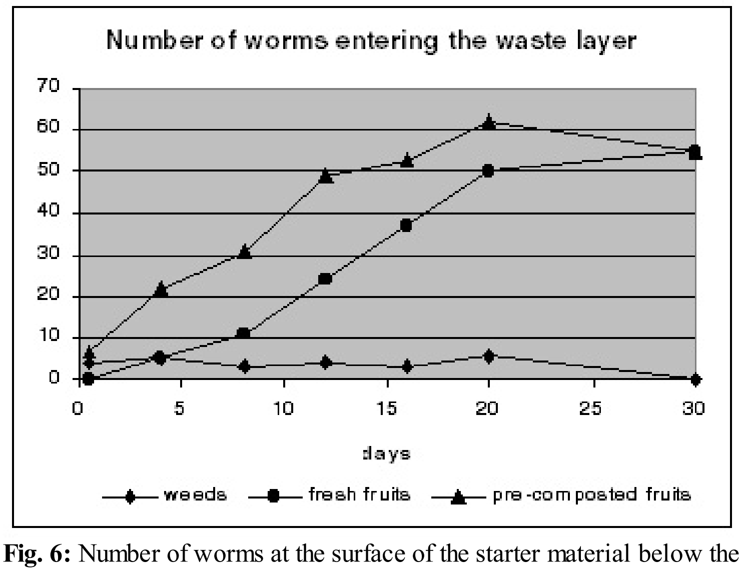


**Fig. 6:** Number of worms at the surface of the starter material below the PE-net (counted every 4th day).

Worms entered the pre-composted wastes already after 2 days while the first worms entered into the fresh fruits after 10 days. It was assumed that the weeds didn´t attract the worms mainly due to the loose structure and the very low relative dry matter content of the weeds.
Within the layer of fresh waste of fruit-pulps several slimy areas were found after 4 days and in general the material tended to build a compacted, partly anaerobic layer. During the first days the worms avoided the fresh wastes. It was assumed that this was mainly due to the low pH.
Nevertheless within the well aerated environment of the boxes, after 14 days, the worms successfully migrated into the fruit wastes and multiplied fast afterwards, as the result after 28 days shows (Fig. 8)
The total worm biomass increased by 225 - 230% within 4 weeks from 30g to 68g and 70g per box in the fruit wastes and the pre-composted fruit wastes.
The age structure (size distribution) showed very "young" populations in the waste layers and in average "older" populations in the starter layers in both cases (Fig. 7,8).
A small amount of worms developed from cocoons previously produced in the starter material which resulted in a small number of worms in the control-box.

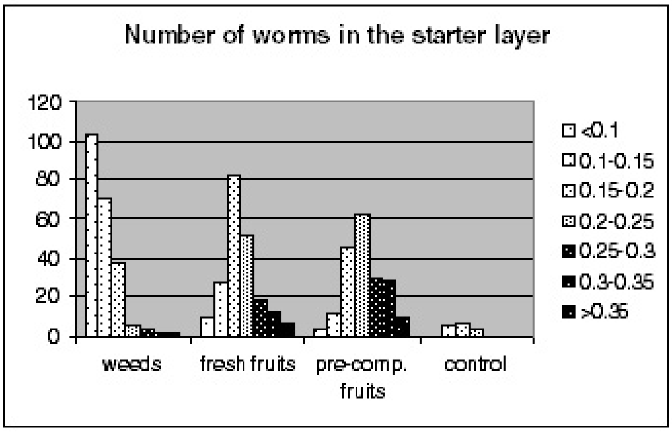


**Fig. 7:** Number and size distribution of the worms in the starter layers after 28 days.

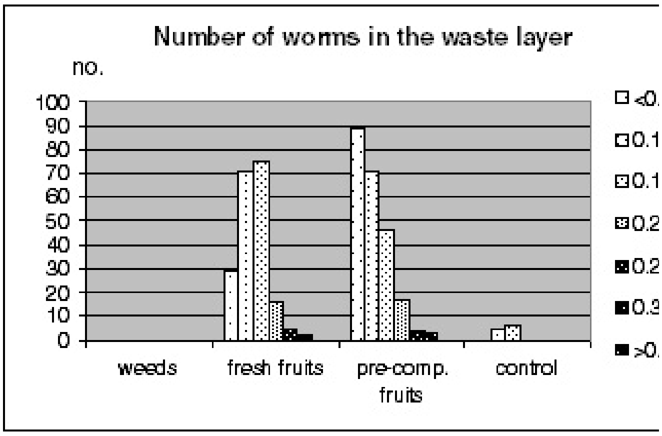


**Fig. 8:** Number and size distribution of the worms in the waste la after 28 days.

## III Discussion

**Vermicomposting experiments:**
1. The ILRI/Mamede worm populations have shown better performances concerning the migration into and multiplication within the waste layers of both waste types. The demonstrated differences indicate, that further collection and selection of worm populations are an important task with regard to successful establishment vermicomposting systems. Comparison and evaluation of worm populations can be conducted under more easily controllable conditions with box-experiments as described in II 4.

2. Direct vermicomposting of town wastes has created more problems concerning fast worm multiplication and sanitation compared to the farm wastes. This was due to the chemical as well as physical properties. The advantages of intensive thermophilic pre-composting in piles are discussed more in detail under II 3.4.

3. The contents of the macro-nutrients nitrogen and phosphorous of the farm waste as well as of the town waste (II 1.2.3.) are within an acceptable range to produce a good quality compost (Edwards and Burrows, 1988; Mustin, 1987). The N and P concentrations in the farm waste was relatively lower because of the high percentage of nutrient poor, dry grasses.
The initial optimal C/N ratio should range between 25 to 30 to avoid high percentages of nitrogen volatilisation (Edwards and Burrows, 1988; Bertoldi et al., 1984) and fast decomposition by microbes. Thus the initial C/N ratio of the town wastes was below the lower limit of the optimal range, which contributed to a considerable nitrogen loss within the first 28 days of composting in piles through high microbial activities (Tab. 7). The nitrogen loss in the vermicomposting beds was low, but the maturing of the compost with regard to the physical properties was also less advanced compared to the piling and the combined method after 28days.

The C/N ratio of a commercial plant growth media should be below 18 to avoid nitrogen immobilisation (Kehres, 1991). After 28 days composting time, only the farm wastes were above that range, which should be reached with the further maturing processes.

4. An enhancement of the percentage of soluble phosphorous through the vermicomposting process, as mentioned in Aranda et al.(1999) was not observed within the first 28 days of vermicomposting (Tab. 6). The results for soluble P for the pile and the combined composting variants were slightly higher but without significant differences because of the high deviation of the results.

**Pile composting method:**
Composting in piles has shown several advantages namely the faster change of the physical properties (structure), suppression of fly multiplication and sterilisation through heat. This positive effects are mainly dependent on sufficient pile sizes, overturning of the pile within the first 2 weeks of the intensive hot rottening phase, and sufficient watering to keep a minimum water content for microbial activities later on.
A negative effect of the pile composting method is the greater loss of nitrogen.

**Combined composting method:**
The physical structure and pH (7.2 to 7.7) of the waste material after 10 to 12 days of hot rottening was more suitable for earthworm multiplication than the fresh material.
The total loss of nitrogen over the period of 28 days was intermediate between the pile and the vermicomposting method. The total nitrogen loss given in table 13 is a rough estimation, calculated from the N/P ration of the waste material (using the phosphorus as a tracer element). Taking into account the advantages of intensive pre-composting of the town wastes (sanitation, physical structure, fast worm development), the nitrogen loss seems to be in an acceptable range. Nitrogen loss through ammonia volatilization occurs increasingly in the thermophilic composting period together with a rising pH (Körner et al., 1999) and through overturning of the compost heaps. Fruit wastes have initially a low pH and a high content of sugars and other easily decomposable carbohydrates. Thus, the microbial multiplication and heating of the material is rising very fast. It can be assumed that the low pH will reduce the ammonia volatilization in the first 2 days and the highest losses (especially through overturning of the heap) will occur from the 4 $^{th}$day onward.

**Box experiments:**
The results show clearly, that the used worm-species avoided to enter fresh plant-materials and especially the fruit-wastes.
Thermophilic pre-composting in a pile has several positive effects for "problem"-wastes like fruit-pulps due to the high microbial activity:
The initial pH is changed fast from 4.0 to 4.5 up to 6.5-7.0 after 7 days. Several described tropical epigeic worm-species are preferring a pH between 6 and 8.5 (Edwards and Lofty, 1976).
With two times overturning of the pile (2 and 6 days after setting up), the structure and moisture content of the town waste material was found to be suitable for further vermicomposting already after 8-10 days. Without pre-composting, the fruit-wastes tended to build a compact and slimy layer were favourable breeding places for fruit-larvae for 2-3 weeks. Within the pre-composted wastes fly larvae were only rarely found. This was observed both in the boxes as well as in the flat beds in the field (II 1., II 3.).
With a total biomass increment of 225-230% within 4 weeks the used worm population from the ILRI compound has an satisfactory multiplication rate within the used organic wastes.

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## IV Conclusions and recommendations

**IV 1. The worm populations** from the ILRI compound and the Mamede villages are promising candidates for the use in vermicomposting systems since they migrated fast into the waste layers and had satisfactory multiplication rates. Species identification, testing and further selection of species in terms of efficiency and multiplication rates have to be conducted.
The described method of experiments with small composting boxes is an appropriate method with regard to further selection of worm populations and testing of waste materials.

**IV 2. Fast hygienisation and good structural and chemical properties for subsequent vermicomposting** of problem-wastes can be achieved **through an intensive thermophilic pre-composting phase** in heaps with a duration of 8 to 14 days. A main precondition for hot rottening of wastes is the availability of enough waste material at one collection time (e.g. one day), so that sufficient pile sizes and self-heating through microbial activity can be assured. Pile sizes should be at minimum 1,2m in height and 1,5m in width, better more (e.g. 1.6m x 2.2m). Detailed descriptions and planning guides are given also in Dalzell et al. (1987). Overturning of the pile is necessary to provide good aeration.
In order to suppress efficiently the multiplication of flies within the compost close to the pile-surface, it is necessary to turn the piles from outside to inside a short time after initial heating (e.g. 1 day) and then again at least 1 time after another 3 to 5 days.

**IV 3. Options to improve nutrient-cycling in the farming system:** Following the moisture-, nutrient- and biomass production dynamics of the dry and rainy season, a nutrient harvesting system through fodder conservation after the mid of the rainy season is an option to be tested on farm level. Surplus of organic material at this time might be converted into a nutrient rich, storable compost which can be used at the beginning of the next rainy season as an organic fertiliser and to mix a high quality plant growth media for seed germination and tree seedlings. Thus, priority could be given to the application in plant nurseries for vegetables, fruit trees and coffee seedlings and young ensete plants, since in general not enough organic material is available to provide large scale fertilisation of annual crops.

**IV 4. Appropriate composting methods according to the type and origin of wastes:**

**Sole vermicomposting** should be conducted where:
1. Enough water or waste water is available
2. Wastes with high moisture content are constantly produced (e.g. biogas slurry)
3. Waste material is constantly produced in small amounts (hot rottening is not possible)

This conditions are especially fulfilled, if a combination with a biogas digester is used to exploit the energy content of organic wastes first. The production of biogas makes the collection of wastes additionally economically sensible. Energy production and costs are an increasing problem in Ethiopia. Prices for fossile energy have risen dramatically and deforestation became to a severe problem in the whole country.
A **combination of hot rottening and vermicomposting** is proposed to be used in cases where:
1. Enough waste material occurs in short periods of time. This is the main general pre-requisite to be able to set up pile sizes with a sufficient size, so that advantages of efficient self-heating, fast sterilisation and fast change of the chemical and physical properties through microbial activities can take place.
2. Waste materials are difficult for direct vermicomposting because of an inadequate pH and/or physical structure or high contamination with weeds.
3. Sanitation aspects and attraction of flies to lay eggs inside the compost are a problem because of the location and the type of waste.
4. Enough water or waste water is available to assure irrigation of the vermicomposting beds.

**Sole composting in piles** should be conducted if:
1. Large amounts of wastes are available at a time
2. The composting area is limited
3. Sanitation aspects and attraction of flies to lay eggs inside the compost are a problem.
4. Sufficient amounts of water/waste water are not available to conduct vermicomposting. ( The flat bed vermicomposting method needs 2.2 to 3 times more space per unit of waste. The larger surface of flat beds implicates also a much higher need of irrigation water during the dry season. )

**IV 5. Potential waste sources for composting and biogas production in Ethiopia**

**Town wastes:**
- toilets (after biogas digestion)
- slaughtering places: (rumen contents)
- hotels, juice houses: kitchen wastes, toilets

- compounds without large garden area and rented rooms: kitchen wastes, toilets

**Agro-industrial wastes:**
-Coffee processing
-Sugarcane industry
- fruit processing (jams and juices)

**Farm wastes (Gurage zone):**
- Biogas slurry from jointly used cattle barns
- Surplus biomass at the end of the rainy season as far as it cannot be used for fodder conservation

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# VII Appendix

## 1. Graphcs and photos

Fig. 9: Farmers houses with a mango tree in the Mamede village, gurage Zone

Fig. 10: Young shoots from single ensete corms placed in nursery patches next to the house.

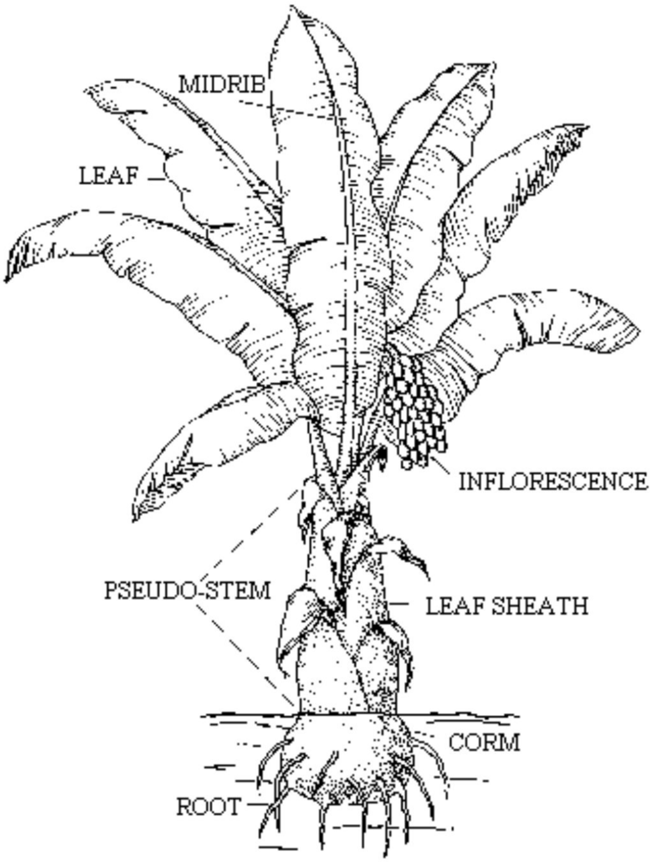


Fig. 11: Harvesting of an ensete plant

Fig. 12:

Fig. 13:

Fig. 14: Cross-section through the pseudo-stem.

Fig. 15: Scraping of ensete leaf sheaths to seperate fibre from starch rich contents

Fig. 16: Fermentation hole for the ensete food products; lined with ensete leaves.

Fig. 17: Fermentation hole, covered air-tight with ensete leaves and weighted with stones.

Fig. 18: Mincing of the fermented ensete product.

Fig. 19: Farmer with the two-pronged wooden tool to turn over the soil manually.

Fig. 20: Fly trap on the compost surface.

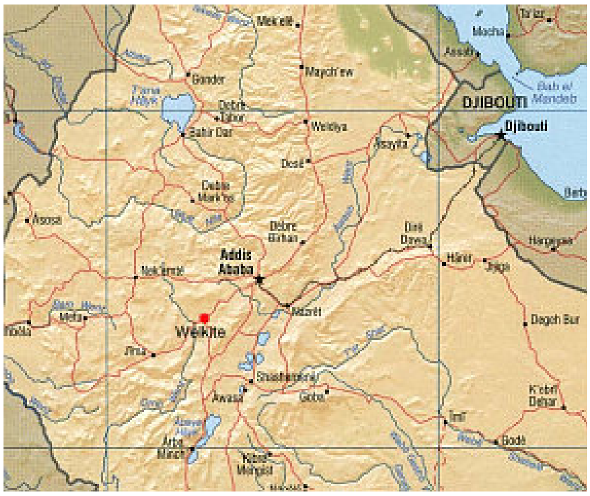


Fig. 21: Location of Welkite in Ethiopia.