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# Effect of manure amount and improved application technique at corm burial on the propagation of enset (*Ensete ventricosum*) suckers

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## ABSTRACT

*Ensete ventricosum* (enset) has been cultivated in Ethiopia since ancient times. It is a multipurpose, drought tolerant and food security crop. When burying enset corms for vegetative propagation, manure is usually placed on the soil surface. However, there is no research-based evidence to justify this practice. We hypothesised that enset sucker production would be enhanced by placing manure in the corm burial hole. We tested this hypothesis, investigated manure application rates per buried corm and tested the effect of supplying a small amount of inorganic fertilizer. Three enset cultivars (Endale, Gewada and Yanbule) were used. Ninety corm halves were buried in separate holes (N = 3), resulting in 1,389 individually recorded suckers. There were significantly more suckers and a larger total biomass when manure was placed with the corm than when spread on the top of the soil, thus corroborating the main hypothesis. The number of suckers and the biomass increased with increasing amounts of air-dried cow manure up to 4.0 kg DW per burial hole, while the size of the three largest suckers per buried corm increased further with 6.0 kg DW of manure. Supplying a smaller amount of manure (2.0 kg DW) or equal nitrogen amount from inorganic fertilizer increased the production, compared to the treatment with no fertilizer. In conclusion, we recommend that farmers should ideally bury the corm with 7-11 $dm^3$ of air-dried pulverized manure, thoroughly mixed with field soil; if manure is in short supply, burying even a small amount of it with the corm is beneficial.

Key words: Ethiopia, fertilization, food security, kocho, manure, planting technique, vegetative propagation

## INTRODUCTION

Enset [*Ensete ventricosum* (Welw.) Cheesman], Musaceae, has been a domesticated plant in Ethiopia since ancient times. Nowadays, this multipurpose crop is cultivated under rain-fed conditions over a wide range of altitudes, often in sustainable systems, agroforestry, or intercropped in home-gardens (Baker and Simmonds, 1953; Birmeta et al., 2002; Negash and Niehof, 2004; Tesfaye, 2008; Abebe et al., 2010). Despite being a close relative of the common banana (Bekele and Shigeta, 2011), all parts, except the fruits, of grown-up plants are utilised. Enset is a perennial food security crop, providing energy-rich storable food (e.g. the fermented *kocho*), being tolerant to droughts and giving high yields (Tsegaye and Struik, 2001;

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Zewdie et al., 2008; Bosha et al., 2016), and there is potential for much higher yields than those currently achieved (Tsegaye and Struik, 2003). In addition to food, enset provides fodder and fodder supplement (Mohammed et al., 2013; Nurfeta and Eik, 2014), fibres, traditional medicines (Yemataw et al., 2014), and may be utilised for industrial applications (Hirose et al., 2010). Farmers have stated that "enset is everything for us: it is our food, it is our plate, it is our house, it is our bed, it is our bag, it is our cattle feed and it is our medicine" (Yemataw et al., 2016). The food is from the corm, pseudostem and flower stalk, and the larger the plant, the more food, or other product, is obtained (Haile, 2014). Therefore, enset is usually harvested at the onset of flowering for maximum yield, but the whole plant or part of it can also be harvested when needed (Quinlan et al., 2016; Yemataw et al., 2016).

Farmers grow, harvest and prepare enset plants by indigenous methods (Pijls et al., 1995). They are often, especially for sprouting and early growth, planted close to the homestead, where about 65% of the household's organic resources are allocated (Amede and Taboge, 2007), which can partly explain why the soil nutrient status where enset is grown is superior to that in other areas of land use (Tensaye et al., 1998). Soil quality is probably also increased because enset plants are harvested individually and their roots, considerably longer and thicker than those of annual plants (Blomme et al., 2008), are left in the soil at harvest. Macropropagation (i.e. cloning by using a corm piece with the apical meristem removed) of Musaceae is recognized as a cost-efficient way to obtain planting materials (Ntamwira et al., 2017). When farmers bury enset corms for vegetative reproduction, manure is usually placed on the soil surface (Diro, 1997), claiming that corms will otherwise rot (personal communication with farmers). However, in a study on enset sprouting in relation to different corm pre-treatments, air-dried cow manure was placed inside corm burial holes, and the suckers produced were unexpectedly large (Karlsson et al., 2015), large suckers being preferred by farmers (Diro, 1997). For the growth of individually planted suckers, research trials have reported their promising response to a supply of inorganic fertilizers (Ayalew and Yeshitila, 2011), while such fertilizers are not reported to have been used for vegetative reproduction.

Enset farmers continue to use the traditional methods, which they know are functional, and it is understandable that they do not take risks by trying undocumented methods. However, there may be superior utilisation of resources, and management advice has to be supported by scientific knowledge and research to feed farmers' families to the highest possible potential (Brandt et al., 1997). Therefore, a study was conducted to elucidate the traditional method used for vegetative propagation. For efficient nutrient management in banana planting, it is recommended to place the fertilizer inside a fairly wide and deep hole (Tushemereirwe et al., 2001; Newley et al., 2008; IITA, 2014). Therefore, our hypothesis was that enset sucker production would be enhanced by placing fertilizers inside the hole for corm burial instead of on the soil surface. In addition, the study aimed to investigate the effect of the amount of manure and inorganic fertilizers for propagation, and hole preparation techniques for corm burial.

## MATERIAL AND METHODS

Corms from three enset cultivars were used: 'Endale', 'Yanbule' and 'Gewada', i.e. registered genotypes of landraces that have been utilised by farmers since historical times, all classified as early maturing (Yeshitila et al., 2011). The plants used were provided by Areka Research Centre (ARC; N07°04'02'', E37°41'22'', 1785 m a.s.l) in southern Ethiopia, where the cultivars had been reproduced vegetatively for many generations and the individuals had grown independently for three years. Forty-five (15 of each cultivar) similar-sized plants [average (SD) sizes: pseudostem circumference 74.82 (7.73) cm, pseudostem height 96.10 (10.96) cm, plant height 196.52 (17.53) cm, corm circumference 53.84 (6.02) cm, corm height 20.80 (1.98) cm and corm weight 6.70 (1.19) kg] were collected. The corms, with a 15 cm piece of pseudostem attached, were cut off and split vertically in half (approx. volume 1.8 $dm^3$ per piece), had the apical meristem removed, and were left in the open air under shade for 24 hrs, following the traditional corm burial procedure. The experimental area was 13.5 × 12 m, and the spacing between the centres of 90 planting holes was 1.5 m. The split corms were buried on April 1, 2015. The experimental area was surrounded by similar plantations of other corms obtained from the ARC, to avoid edge effects.

The soil from the plot (taken with 40 cm deep probes in 22 evenly distributed spots, and mixed) and thoroughly mixed air-dried cow manure were analysed (Tab. 1) by Hawassa Regional Soil Laboratory (a governmental standard laboratory), Hawassa, Ethiopia. The analyses methods were:

**Table 1.** Characteristics of local soil and air-dried cow manure used for vegetative propagation of enset (*Ensete ventricosum*) at Areka Research Center, southern Ethiopia

| Chemical composition | pH | Organic C (%) | Available P (mg kg$^{-1}$) | Available K (mg kg$^{-1}$) | Total N (%) | Exchangeable Ca (mg kg$^{-1}$) | Electrical conductivity (dS m$^{-1}$) |
|---|---|---|---|---|---|---|---|
| Soil | 5.9 | 1.1 | 5.8 | 58.5 | 0.10 | 940 | 0.04 |
| Manure | 7.6 | 4.0 | 39.0 | 117.8 | 0.33 | 1900 | 0.18 |

(*i*) a pH meter with a glass-calomel combination electrode for measuring pH of the supernatant suspension of 1:2.5 soil-to-water weight ratio, (*ii*) the wet digestion and oxidation method, and the approximation "organic matter equals organic carbon times 1.724" for organic C, (*iii*) Olsen's calorimetric method for available P, (*iv*) extraction with ammonium acetate followed by measurement with a flame photometer for available K, (*v*) a modified micro-Kjeldahl method for total N, (*vi*) extraction with ammonium acetate followed by measurement with an atomic absorption spectrophotometer for exchangeable Ca, and (*vii*) electrical conductivity measured in a soil-water mixture at a weight ratio of 1:2.5 for one hour. The soil texture was classified as sandy clay loam (determined by the hydrometer method for particles less than 2 mm in diameter: separating the fraction of sand [0.05-2.0 mm diameter], silt [0.002-0.05 mm diameter] and clay [<0.002 mm diameter]).

At burial, corms were planted in the local soil with either air-dried cow manure, with inorganic fertilizer (either DAP [18% N, 46% $P_2O_5$; Jordan Phosphate Mine Co. PLC] or NPS [19% N, 38% $P_2O_5$, 7% S; OCP, Morocco], combined with urea [46% N, CNAMPGC, Morocco]), or without added nutrients. The soil and manure were mixed thoroughly and softened (pulverized), achieving particle sizes approximating those of sand-grains (Karlsson et al., 2015), with DW density being 1,020 and 533 g dm$^{-3}$ for the soil and manure, respectively, in this form. The manure, in the amount of 2.0, 4.0 or 6.0 kg DW per buried parent corm piece, was mixed with the local soil and applied as 25%, 50% or 75% by volume of a 15 dm$^3$ bucket (i.e. 3.75 dm$^3$ [2.0 kg], 7.5 dm$^3$ [4.0 kg] and 11.25 dm$^3$ [6.0 kg] of manure), while 15 dm$^3$ (15.30 kg DW) of softened soil was used for the treatment without any nutrients added. Inorganic fertilizers were mixed with 15 dm$^3$ of softened soil and given in an amount in which available N was similar to that in 2.0 kg of manure (i.e. 5.2 g).

All six fertilizer treatments (0, 2.0, 4.0 and 6.0 kg of manure, DAP and NPS) were applied with corms buried in a wide and deep hole (40 cm wide, 50 cm deep) refilled first with a 10 cm layer of softened top soil, then the corm and the fertilizer-soil mix on top of it, completely embedding the corm piece, and finally filled up with the soil remaining from hole-digging. The same burial method with deep and wide holes, but with nutrients on the soil surface, was used with 4.0 kg of manure, and with NPS. The third burial treatment was with holes dug as narrow as possible (20 cm wide and 30 cm deep), and used with no fertilizer or with 4.0 kg of manure on the soil surface. For each of the ten treatments, three replicating corm halves of each cultivar were buried. After the burial, the field was subjected to the local weather condition only; daily precipitation and the maximum and minimum temperatures were recorded by the ARC's weather station (Fig. 1); the natural climate is savannah according to the Köppen-Geiger definition (Peel et al., 2007).

Suckers were harvested on January 18-31, 2016, ten months after corm burial. At harvest, the buried corms that had produced suckers were uprooted. For each sucker, pseudostem height (from the connection to the corm to the spot where the lowest green leaf detached from the remaining leaves), pseudostem midway circumference (circumference at half the pseudostem height), corm circumference, and leaf blade length and width of the longest leaf were recorded. For each sucker, pseudostem volume (cylinder: pseudostem midway radius$^2$ × π × pseudostem height), corm volume (sphere: radius$^3$

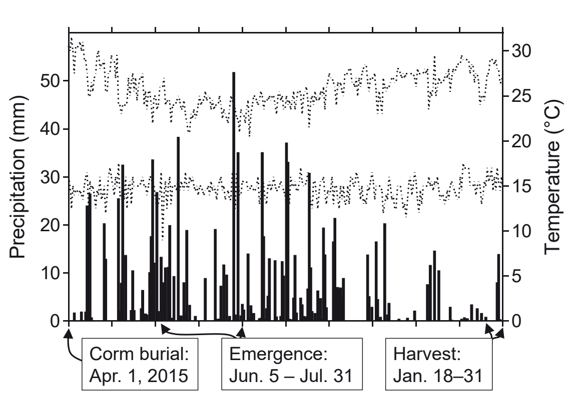


**Figure 1.** Daily weather during the period (Apr. 1, 2015 -Jan. 31, 2016) when *Ensete ventricosum* corms were buried for vegetative reproduction at Areka Research Centre, Ethiopia. Bars: precipitation, dotted lines: maximum and minimum temperatures

× π × 4 × 3⁻¹), and leaf blade area (rhombus: [length × width] × 2⁻¹) were calculated.

Statistical analyses were performed with Statistica 13 (Dell Inc., 2015). Response variables per buried corm half in individual planting holes were: (1) time to emergence of the first visible sprout, (2) total number of suckers, (3) total corm volume of suckers, (4) total pseudostem volume, and (5) total leaf area of the longest leaf per sucker. Analyses were also performed on (6) pseudostem volume of the second largest sucker per hole, and on (7) the sum of pseudostem and corm volumes of the three largest suckers per hole. Analyses 6 and 7 were performed to evaluate the largest suckers while avoiding bias due to random extremely large individual sprouts, which are sometimes developed together with unusually small remaining sprouts. Due to the mortality of sprouts emerged from four burial holes, full-factorial analyses could not be performed for all the treatments within one analysis. Initial analyses, one-way ANOVA, followed by the Tukey HSD test, were run with the cultivar average (N = 3 cultivars) and response variables 2-5. Thereafter, the two treatments with a "narrow" burial hole were excluded from further analysis because they did not differ from analogous treatments with a "wide and deep" hole ($p > 0.98$).

Time to emergence from the ten treatments and cultivars (N = 3 buried corms) was analysed with full factorial two-way ANOVA. The effect of manure amount (applied with the corm inside a wide and deep hole) was analysed with full factorial two-way ANOVA on response variables 2-5: three cultivars × four manure amounts with three replicates (N = 3 buried corms) on log-transformed data. Response variables 6 and 7 were analysed with linear regression as a function of manure amount. Possible effects of the placement of fertilizer and size of the burial hole were analysed with ANOVA for characteristics 2-5 and, due to mortality in four cases, with average cultivar responses as replicate (N = 3 cultivars). To compare overall responses, the relative cultivar average per characteristic (calculating performance per individual parent corm half as a relative value of the average from all corms and treatments for each characteristic 2-7) was used as response variables to cultivar × treatment in two-way ANOVA. For significant factors, ANOVA was followed by the Tukey HSD test.

## RESULTS

In Ethiopia, there was a drought during the season in which the experiment was established (BBC, 2016),

**Table 2.** Average time (days (SD)) to emergence of the first visible sprout after parent corms of three cultivars of enset (*Ensete ventricosum*, Musaceae) were buried at Areka Research Centre, Ethiopia, on Apr. 1, 2015, and subjected to natural weather conditions (Fig. 1). Air-dried cow manure, 2.0, 4.0 or 6.0 kg DW; 4.0 kg, equal to 7.5 $dm^3$, was applied as part of a 15 $dm^3$ soil-manure mix. The inorganic fertilizers DAP and NPS were combined with urea and provided in an amount of N equivalent to 2.0 kg manure. N = 3, 90 planting holes in total; emergence occurred from all planting holes. Minimum and maximum time to first emergence after corm burial was 65 and 121 days, respectively. There was no statistically significant effect of treatment or cultivar on time to emergence (Tab. 3)

| Cultivar | Treatment at corm burial | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | None | None, narrow[1] | 2.0 kg manure | 4.0 kg manure | 4.0 kg manure, above[2] | 4.0 kg manure, narrow[1] | 6.0 kg manure | DAP | NPS | NPS, above[2] | Cultivar overall average |
| Endale | 99 (9.5) | 104 (7.9) | 98 (17.9) | 80 (26.0) | 75 (17.3) | 84 (32.2) | 96 (13.5) | 98 (7.9) | 80 (14.6) | 97 (9.2) | 91 (17.5) |
| Gewada | 96 (17.0) | 101 (21.2) | 102 (7.1) | 79 (59.3) | 98 (22.2) | 99 (12.6) | 83 (24.4) | 97 (22.5) | 97 (19.4) | 95 (26.0) | 95 (23.3) |
| Yanbule | 90 (22.5) | 74 (15.3) | 95 (21.1) | 95 (20.8) | 94 (15.1) | 82 (22.1) | 86 (18.5) | 87 (23.4) | 90 (18.1) | 107 (8.2) | 90 (18.0) |
| Treatment overall average | 95 (15.5) | 93 (19.6) | 98 (14.6) | 85 (34.9) | 89 (19.2) | 88 (22.2) | 88 (17.8) | 94 (17.6) | 89 (16.8) | 100 (15.4) | 92 (19.6) |

[1]Narrow: the burial hole was dug to a size able to only accommodate the corm. Otherwise, holes were dug deep and wide, and refilled with soft soil. When manure was used for a narrow hole, it was applied above[2].
[2]Above: the treatments had manure/fertilizer placed on the soil surface; otherwise it was buried in contact with the corm in the burial hole

and the soil at the ARC was dryer than normal at corm burial and during early sucker development: the 153 days in March-July 2015, i.e. from one month before corm burial until the last emergence (Fig. 1), received 659 mm of precipitation distributed over 62 days, while analogous data for 2014 were 863 mm and 92 days, respectively (ARC's weather station). Emergence occurred 65-121 days after corm burial; the average time to emergence was 91.9 (SD 19.6) days (Fig. 1, Tab. 2). There was no significant effect of cultivar or treatment on time to emergence (Tab. 3). The emergence rate was 100%, but the sprouts from four burial holes (4.4% of buried parent corm pieces) had died before harvest; 95.6% of included parent corm pieces had developed suckers fit to be transplanted for further growth. The mortality rate was too low to enable analysis of a possible correlation with the treatments.

At harvest (10 months after burial), there were 1,191 suckers (average pseudostem and corm volume 0.58 $dm^3$ (SD 1.18) and 0.0071 (SD 0.0045) $dm^3$, respectively) with green leaves emerged above the soil, and an additional 198 below ground (average pseudostem and corm volume 0.020 $dm^3$ (SD 0.028) and 0.0027 (SD 0.0012) $dm^3$, respectively) from 86 of the 90 buried halves of mother corms whose suckers did not wilt after emergence. The aboveground cormlings had on average 3.5 (SD 1.7) green leaves, the longest leaf per original corm being on average 98.9 (SD 37.7) cm long, with a leaf blade area of 5.3 (SD 4.97) $dm^2$.

There was a significant effect of manure on total production (Tab. 3), with the highest production in response to 4.0 kg (7.5 $dm^3$) of manure (Fig. 2). For the largest cormlings per planted corm piece, there was a significant linear correlation with the amount of manure provided, with the highest production in response to 6.0 kg (11.25 $dm^3$) of manure (Fig. 3). There was a significant positive effect of burying manure together with the corm instead of placing it on the soil surface (Tab. 3, Fig. 4). When comparing burial holes dug as narrow as possible with wide and deep holes regarding the number of suckers, total corm volume, total pseudostem volume and leaf area, there were no significant differences ($p$ = 0.991-1.000 and 0.981-1.000 for treatments with and without manure, respectively).

The relative performance in response to treatment was significantly higher for 4.0 kg (7.5 $dm^3$) and 6.0 kg (11.25 $dm^3$) of manure placed with the corm, compared to all the other treatments (Tab. 3, Fig. 4). Planting without fertilizer gave significantly lower results than all the other combinations except when NPS was placed on the soil surface (Fig. 4). When

**Table 3.** Two-way ANOVA on time to emergence and sucker production ten months after *Ensete ventricosum* parent corms were buried in the field with different amounts of softened, pulverized, air-dried cow manure (0, 2.0, 4.0 or 6.0 kg DW [applied as 0, 25, 50 or 75% of 15 $dm^3$ and mixed with local soil]) or with inorganic fertilizers, with the fertilizer buried together with the corm or spread on the soil surface. Three cultivars, Endale, Gewada and Yanbule, were used; their corms were split in half, with the apical meristem removed before burial. F-values and $p$ significance notation ($^{ns}$ $p > 0.05$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$) are shown

| Subject | Factor | Df | Number of suckers | Corm volume | Pseudostem volume | Leaf area | Time[1] or Relative performance[2] |
|---|---|---|---|---|---|---|---|
| Time to emergence (N = 3 replicating corms) | Cultivar | 2 | – | – | – | – | $0.42^{ns}$ |
| | Treatment | 9 | – | – | – | – | $0.46^{ns}$ |
| | C × T | 18 | – | – | – | – | $0.54^{ns}$ |
| Manure amount (N = 3 replicating corms) | Cultivar | 2 | $34.08^{***}$ | $12.09^{***}$ | $3.52^{*}$ | $7.07^{**}$ | – |
| | Amount | 3 | $46.05^{***}$ | $13.59^{***}$ | $5.87^{**}$ | $11.73^{***}$ | – |
| | C × A | 6 | $2.65^{*}$ | $1.08^{ns}$ | $0.46^{ns}$ | $0.65^{ns}$ | – |
| Fertilizer placement (N = 3 cultivars) | Fertilizer | 1 | $49.91^{***}$ | $17.90^{**}$ | $6.54^{*}$ | $11.53^{**}$ | – |
| | Placement | 1 | $45.16^{***}$ | $18.97^{**}$ | $8.62^{*}$ | $14.28^{**}$ | – |
| | F × P | 1 | $49.10^{***}$ | $20.92^{**}$ | $3.48^{ns}$ | $9.81^{*}$ | – |
| Overall treatment effect (N = 6 characteristics) | Cultivar | 2 | – | – | – | – | $1.42^{ns}$ |
| | Treatment | 7 | – | – | – | – | $36.65^{***}$ |
| | C × T | 14 | – | – | – | – | $6.64^{***}$ |

[1]Time from corm burial to emergence of first visible sprout.
[2]Relative performance per cultivar was calculated from each plant's characteristics recorded at harvest

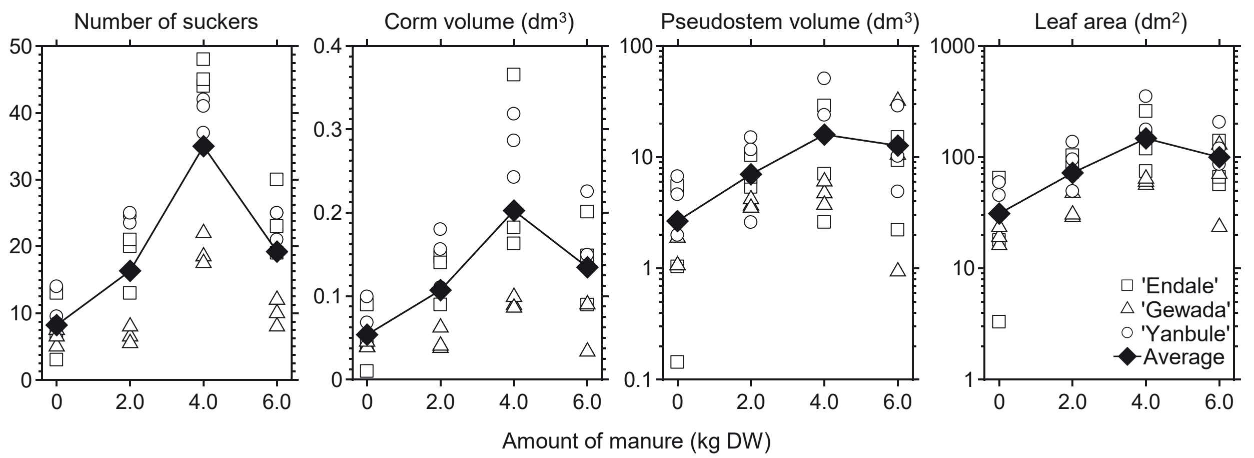


**Figure 2.** Records of sucker production ten months after corm pieces (halves) of *Ensete ventricosum* (cultivars Endale, Gewada and Yanbule) were buried in the field with different amounts of air-dried, pulverized, cow manure; 4.0 kg DW, equal to 7.5 dm$^3$, and the manure was mixed with soil to 15 dm$^3$. Number and volume records are in total per buried corm piece, and leaf area is the sum of areas of the longest leaf of each sucker. Note the logarithmic scale on the y-axis of two graphs. Y-axis units are shown at the top of the graphs

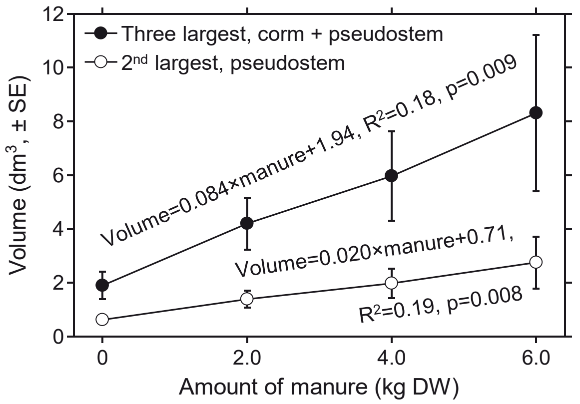


**Figure 3.** Volume (average for three cultivars) of the corm plus pseudostem of three largest suckers and of the pseudostem of the second largest sucker per parent corm piece (halves) of *Ensete ventricosum* cultivars Endale, Gewada and Yanbule ten months after burial with different amounts of air-dried, pulverized, cow manure (4.0 kg, equal to 7.5 dm$^3$) applied as part of a 15 dm$^3$ soil-manure mix

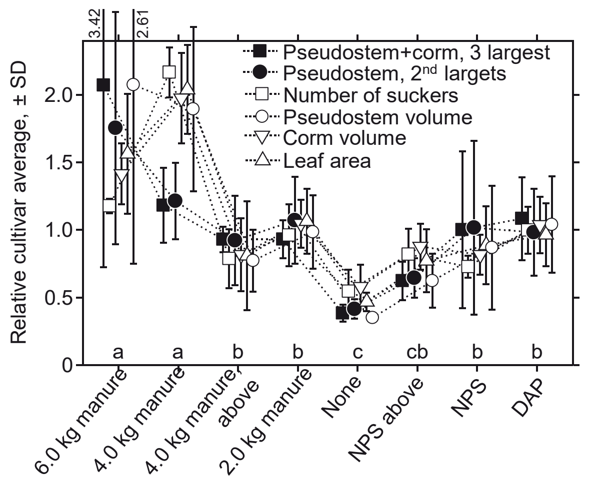


**Figure 4.** Relative response (performance per parent corm relative to the average of each characteristic) to different corm burial methods in terms of sucker production by three *Ensete ventricosum* cultivars. Manure was pulverized air-dried cow manure, 4.0 kg DW, equal to 7.5 dm$^3$, applied as part of a 15 dm$^3$ soil-manure mix; "above" treatments had manure/fertilizer placed on the soil surface, otherwise it was buried with the corm. The inorganic fertilizers DAP and NPS were combined with urea and provided an amount of N equivalent to 2.0 kg of manure. Different letters on the x-axis show significant ($p < 0.05$) differences between treatments

4.0 kg (7.5 dm$^3$) of manure was placed on the soil surface, the result was not significantly different from the results for 2.0 kg DW (3.75 dm$^3$) of manure or any of the inorganic fertilizers (DAP or NPS in equal amount of N as 2.0 kg DW manure) when these were buried with the corm (Fig. 4).

## DISCUSSION

The emergence rate from the 90 buried corm halves was 100% despite the fact that the amount of precipitation and the number of days with precipitation were only about 75% of the normal, which is a possible explanation for the wilting of suckers from four parent corm pieces after emergence. However, the fraction of buried corm halves that had developed suckers (95%) was higher than the about 75% expected by farmers (Diro, 1997). High emergence and sucker development rates (100%) in field research had also been reported by Karlsson et al. (2015). The higher emergence in those research trials compared with farmers' expectations could possibly be that the research studies had the apical meristem removal performed by one experienced and careful person, used equal and well-prepared burial holes, and selected equal and suitable corms for propagation. Corm size or corm piece size may also be a factor of importance for the emergence rate; it has been shown that corms with a volume of about 4 $dm^3$ and parted into quarters can result in 100% emergence (Karlsson et al., 2015), but also smaller corms and corm pieces should be studied to gain knowledge on emergence and establishment potential.

The condition of the hole dug at corm burial may affect emergence and establishment: the depth can protect the corm piece from surface drought and the width can provide room for soft soil for better root development. In this study, the emergence and establishment rates were high, and the four groups of newly emerged suckers that wilted constituted too small a sample to allow conclusion as to the burial hole condition, treatment or cultivar as possible factors in this regard. The two treatments with narrowly dug holes showed no significant differences from analogous wide and deep holes with softened top-soil in terms of sucker development. This may have been an effect of the ARC's field having a soil that was generally suitable for root expansion, by being soft and porous because of many years and seasons of soil cultivation. Thus, the physical growth conditions were probably favourable regardless of the size of the dug-out hole. In a farmer's field, it is more likely that a hole will be dug in a compact soil. Therefore, the effect of planting hole design and soil preparation at corm burial should be further studied to be able to formulate proper, more detailed, management advice.

When air-dried manure was mixed with soil and applied with the corm at burial, the response to manure amount resembles the well-known dose-response effect, e.g. of nitrogen amount in potato cultivation (Vos, 2009), regarding the number of suckers, total corm and pseudostem volume, and leaf area per parent corm piece (Fig. 2), peaking when 4.0 kg (7.5 $dm^3$) of manure (50% of a 15 $dm^3$ bucket with local soil) was added, which can be explained by the uptake efficiency decreasing as application rate increases (Lehrsch and Kincaid, 2007). For the size of the largest suckers per hole (pseudostem volume of the second largest sucker and for the sum of the three largest suckers' corm + pseudostem volume per planted corm piece), volume increased linearly with increasing amount of manure over the included range of air-dried manure mixed with soil (Fig. 3). Thus, when a high amount of manure (6.0 kg or 11.25 $dm^3$, being 75% of a 15 $dm^3$ bucket with local soil) was available, the largest suckers benefitted from the surplus (Fig. 3), probably due to rapid development of early emerging suckers gaining advantage in the competition, while the overall performance of suckers per buried corm piece was highest when an intermediate amount (4.0 kg or 7.5 $dm^3$) of manure was applied (Fig. 2). The response to inorganic fertilizers was similar to the response to manure when a similar amount of nitrogen was applied inside the burial hole with the corm (Fig. 4).

The traditional method for manure application is to place it on, or close to, the soil surface after burying the corm, a method used by Diro et al. (2002), who applied 4 kg of manure in a circle about 10 cm from the buried corm covered with soil. However, Karlsson et al. (2015) obtained unexpectedly large suckers when air-dried manure, thoroughly mixed with soil, was applied inside the burial hole together with the corm. In our study, when 4.0 kg (7.5 $dm^3$) of air-dried, softened manure was placed either with the parent corm or at the soil surface, the result clearly showed that air-dried manure placed together with the corm at burial was beneficial for sucker development (Tab. 2, Fig. 4). The same pattern was obtained with the inorganic fertilizer, where burying NPS with the corm was significantly superior to no fertilization, while NPS at the soil surface gave results that were not statistically different from those of the treatments with either no fertilizer or NPS buried (Fig. 4). For banana, a close relative of enset (Li et al., 2010; Bekele and Shigeta, 2011), planting into a fairly wide and deep hole, and mixing the applied fertilizer with top soil inside the hole before planting is recommended (Tushemereirwe et al., 2001; Newley et al., 2008; IITA, 2014). There is now strong evidence that also enset management advice should recommend fertilization in contact with the corm when burying for propagation (Fig. 4). By placing the manure down with the corm instead of at the soil surface, sucker production of any landrace or cultivar would improve relative to the traditionally expected result (Fig. 4).

Farm yard manure, as opposed to inorganic fertilizers, provides increased organic matter and biological activity in soils, thus may increase growth rates by other means than fertilization only, such as improved moisture holding capacity (Bulluck et al., 2002; Bayu et al., 2006; Singer et al., 2007; Hepperly et al., 2009). However, even when only little fertilization was used, the enset plants benefitted from it, regardless of its form (Fig. 4). The soil was dry because of little precipitation before and after corm burial (ARC's weather station), and air-dried cow manure was used. Therefore, the moisture status may have been relatively equal between the treatments with organic and inorganic fertilizers, the main moisture provider thus being the buried parent corm, probably down-playing the water-holding effect of the organic fertilizer. It has been shown that watering, starting at corm burial and continued until sprouting, leads to earlier emergence and more evenly sized suckers (Karlsson et al., 2015). The seasonal dry period could considerably alter enset growth not only because of water availability to the plant but because low soil water content affects the mobility and mineralization of soil nitrogen (Zewdie et al., 2007; Zewdie et al., 2008). Further details on growth rate in response to soil fertility and fertilization should be investigated by conducting studies in different environments in which enset is cultivated or could potentially be cultivated.

There were significant effects of the cultivar factor on the actual plant characteristics but not on relative performance (Tab. 2). The cultivars are known to differ, for example, 'Endale' produces a high number of suckers but has, on average, smaller suckers, as also shown by Karlsson et al. (2015). However, the same fertilization management advice can be given for different cultivars because the relative response is consistent (Tab. 2, Fig. 2). Farmers prefer large suckers for a strong start to further growth, and a large leaf area indicates good potential for plant development and growth. Thus, it is important to manage enset corm burial for propagation efficiently, achieving the highest production from the resources used.

## CONCLUSIONS

In conclusion, the recommendation for enset management should be changed and clearly communicated to farmers. In the vegetative propagation of enset, nutrients should be placed inside the burial hole, not on the soil surface. The total sucker production was highest when the buried corms were supplied with 7.5 $dm^3$ of air-dried cow manure, while the size of the largest suckers per hole was highest with 11.25 $dm^3$ of the manure. Total sucker production and sucker size, 10 months after corm burial, increased when supplied with even a smaller amount of air-dried cow manure (3.75 $dm^3$) or inorganic fertilizer (DAP or NPS), equal to 5.2 g N per buried corm piece. Farmers should be advised to use 4-6 kg DW (i.e. 7-11 $dm^3$, or 50-75% of an ordinary 15-20 litre bucket) of air-dried, pulverized manure, thoroughly mixed with softened field soil and placed directly inside the corm burial hole for the propagation of enset. However, if only little fertilizer of any kind is available at the farm, it will still be beneficial to use it; it should be applied inside the burial hole, together with the corm or corm piece prepared for propagation, and not on, or close to, the soil surface.

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## AUTHOR CONTRIBUTIONS

A.B. – performed the practical work and L.M.K. – the statistical analyses. All the authors contributed equally to planning the study, interpreting the results and writing the paper.

## CONFLICT OF INTEREST

Authors declare no conflict of interest.

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