

Effect of Cassava (*Manihot esculenta* Crantz) Stake Orientation and Planting Depth on
Planting Material Multiplication Ratio and Tuberous Root Yield.

By

Malumo Nawa

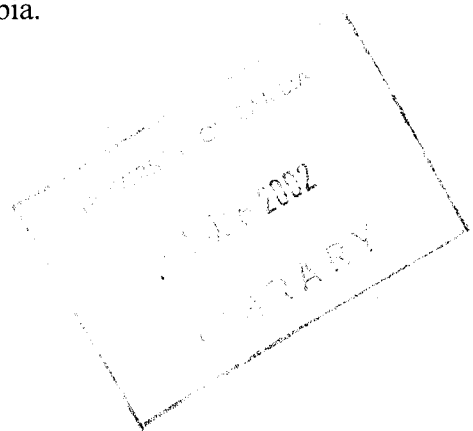
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DECLARATION

I, Malumo Nawa, declare that this thesis represents my own work and that it has not been previously submitted for a degree at this or any other university.

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ABSTRACT.

Cassava (*Manihot esculenta* Crantz) is a tuber crop grown widely in Zambia by small scale farmers as a staple carbohydrate. The crop offers many advantages but its potential has not been fully exploited. This failure has been in part due to poor production practices and the lack of improved planting materials. The crop is grown from stem cuttings of various lengths that are planted horizontally, vertically or at an incline at various planting depths. This does not favor the production of adequate planting material within a short time compared to other crops. Furthermore, this will affect its tuber yield. Therefore, the objective of this study was, to determine the effects of planting depth and stake orientation on planting material multiplication ratio and tuberous root yield of cassava. Two varieties of cassava; Bangweulu and L9.304/151 were used in the study. Stem cuttings, 30 cm long, were planted at depths of 5 cm, 10 cm, 15 cm and 20 cm in horizontal (0°), vertical (90°) or inclined position (45°). A Split-split plot design with four replications was used in the study. Varieties were in the main plots, while planting depths were the sub plots and stem orientations the sub-sub plots. Within the plots, the spacing was 1 m inter-row, and 1 m in the intra-row. Data collected included number of stems/planting station, plant height, number of tubers/plant, and tuber weight/ha. The results obtained revealed that the two varieties gave similar multiplication rates of 1:4 to 1:6. Planting the stakes vertically or at an incline gave more stems per station (2.0) than planting horizontally (1.5) and these gave higher planting material multiplication rates (1:6) horizontally planted ones (1:4). In addition, these plants gave more tubers per plant (6 tubers/plant) than those planted horizontally (3 tubers/plant). Significantly higher tuber weights (10.5t/ha to 9.4t/ha)

were obtained from vertically and inclined sown plants than horizontally ones (5.9t/ha). However, highest tuber yield (12.8t/ha) for Bangweulu was obtained when stakes were planted vertically but for L9.304/151 (8.1 to 10.6t/ha) when planted either vertically or on the incline. This study showed that the crop can be planted at depths of 5 cm to 20 cm without affecting its production of planting material and tuberous root yield but these stakes should be planted either vertically or inclined to obtain higher planting material multiplication rates and tuberous root yields.

Dedication

To my wife Juliet for the loneliness, my brothers and sisters for their love and my mother for her resilience.

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CHAPTER 1.

1.0 Introduction.

Cassava (*Manihot esculenta* Crantz) is the third most important tropical food crop after maize and rice. It contributes to the nutrition of over two hundred million people in the tropics (Bokanga and Otoo, 1991; Roca, 1989). World production of cassava is estimated at 158.1 million tons per year of which 72.7 million tons are produced in Africa. The major producers of cassava in the world are Brazil, Nigeria and the Democratic Republic of Congo while Thailand and Malaysia are the main exporters (FAO, 1988; Gebremeskel *et al*, 1986).

Although the crop is grown mainly as a subsistence food crop, a considerable part of the world production is used for animal feed, industrial starches and alcohol fuels

(Ospino and Wheatley, 1990). The use of cassava in the livestock industry has been mainly in the European Union. In Zambia, cassava is mainly grown in Luapula, Northern , North Western and Western Provinces, though it is grown on a smaller scale in all the other provinces (Soenarjo and Chitundu, 1997a). Currently the crop is being promoted as food security crop throughout Zambia because of its ability to adapt to a wide range of adverse soil and environmental conditions (Ngoma *et al*, 1998).

In many parts of the country the crop is grown from local varieties. This advocacy of cassava has led to an increase in the demand for improved planting material (Soernajo and Chitundu, 1997a). The Root and Tuber Improvement Program (RTIP) based in Mansa was mandated to develop and distribute improved cassava varieties in Zambia.

The crop is currently propagated from stem cuttings of varying lengths. This type of propagation does not favour rapid production of planting material compared to the use of seed and as such it is hampering expanded production of the crop in the field. Furthermore, the bulkiness of the crop hampers easy distribution of these planting materials to farmers at the right time and in adequate amounts (Jorge, 1992 and Otoo, 1996), a situation prevailing in Zambia. This has resulted in continued use of local varieties; and coupled with poor management very low yields of less than 5.0 tons per hectare have been observed (Minde *et al*, 1998) compared to 32 t/ha that our improved varieties can yield (Soernajo and Chitundu, 1998a).

Currently, there are a number of cassava varieties grown in Zambia. These are either planted vertically or inclined at various planting depths although in other countries the crop may be planted horizontally (Soernajo and Chitundu, 1998b). The choice of the planting method differs from place to place and is largely determined by ease of planting, harvesting and expected yield (Annor-Frempong, 1991). These planting methods have been reported to affect crop performance (Onwueme and Charles, 1994).

However, research so far done on the effects of these planting methods on the growth and yield of cassava is not conclusive. The International Institute of Tropical Agriculture (IITA)/ Program National Manioc (PRONAM) (1978) observed that horizontally planted cuttings produced more stems per station and therefore give more planting material. The effects of stem orientation on yield are also conflicting. Others have reported that horizontally planted stakes gave higher tuber yields than the other methods while others have reported that vertical or inclined sown plants gave higher yields (Godo, 1984; Umah, 1978). Still others have observed no yield differences among these stem orientations (Gurnah, 1974 and Keating *et al*, 1980).

Results on the effects of planting depths on tuber yield are also not conclusive. Some have reported increase in yield with increase in planting depth while others have reported no yield differences for cassava planted from 5 to 25 cm depth (Castro and Holguin, 1979; IITA, 1990). It is in view of the above observations that a study to determine the effects of planting depth and stake orientation on planting material multiplication ratio and root tuber yield was conducted. Results of this study will help to determine the best planting depths and stem orientations for increased planting material multiplication and tuberous root yield in cassava.

CHAPTER 2.

2.0 LITERATURE REVIEW.

2.1 General description.

Cassava is a dicotyledonous plant, which belongs to the family Eupobiaceae. According to (Bradbury and Holloway, 1988, Kochhar, 1991 and Purseglove, 1969), the plant originated from Mexico and Brazil but has since spread to many parts of tropical Africa and South America. In Africa, cassava was introduced by the Portuguese four hundred years ago (IITA, 1998).

According to Purseglove (1969), the cassava plant is a shrubby, short-lived perennial crop with an erect stem and can grow up to 5 m high. The stems vary greatly in height and branching pattern. The branches are usually glabrous, slender with leaves towards the apex. Stems vary considerably in colour from whitish, dark brown to green.

The leaves are spirally arranged on the stem, each leaf subtended by 3 to 5 stipules. The length of the leaf stalk varies between 5 cm and 30 cm. The lamina is simple with a smooth margin but deeply palmate or lobed. The number of lamina lobes range from three to nine.

Cassava is a monoecious plant, flowering is frequent and regular in some cultivars while it is rare or non-existent in others. These flowers are borne on terminal panicles where the male flowers occur near the tip while the female flowers occur near the base.

The plant has adventitious roots from which tubers develop through the process of secondary thickening. The number, shape, size and colour of tuberous roots vary greatly from 5-10 tubers per plant (Cock, 1985 and IITA, 1990).

2.2 Agronomic requirements.

Cassava can be grown in a wide range of climatic conditions, although ideally, it is a lowland tropical crop. Presently the crop is widely distributed throughout the tropical and sub-tropical areas that are 20° N and S and below altitudes of 1500 m (FAO, 1988). The crop is very sensitive to chilling and does not perform well at temperatures below 16°C. Optimum temperatures are those between 25°C and 29°C.

The crop can grow in a wide range of rainfall belts ranging from 500 mm to 2500 mm per annum and on a wide range of soils so long as they are not waterlogged, saline or too stony. Sandy or loamy soils with a pH range of 5 to 9 are preferred as long as they are reasonably fertile. Furthermore, the crop has also been found to have a very high productivity per unit of land and labour than most other food crops.

Since cassava can be harvested almost throughout the year, the crop offers the advantage of supplying food especially during the hunger periods of the year (Nweke *et al*, 1991; UNIFEM, 1989). Following the removal of subsidies on agricultural inputs as well as the recurrent droughts in the recent years in the country, there has been wide promotion of cassava because of its ability to grow under drought conditions and without heavy dependence on chemical fertilisers (Ngoma *et al*, 1998).

2.3 Cassava propagation practices.

Cassava is mainly propagated from stem cuttings of varying lengths although it can also be grown from seed. Stem propagation has the advantage that the cuttings usually contain large carbohydrate reserves that result in high initial vigor and better crop establishment even under stress conditions compared to the use of true cassava seed (Iglesias and Hershey, 1991). However, this type of propagation has many shortfalls associated with it. When propagated vegetatively, cassava has a very low planting material multiplication rate of 1:10 compared to that of cereals of 1:200 (Otoo, 1996). It also has problems of diseases, storage and bulkiness in handling.

Despite these problems, vegetative propagation is still the most feasible alternative for small-scale farmers as compared to the use of seed. The use of seed results in heterogeneous off-springs and as such is mainly in breeding programs (Almekindera and Louwaars, 1999).

The problem of low multiplication of cassava coupled with its bulkiness in handling and transportation has led to reduced spread and distribution of improved cultivars to farmers at the right time and in adequate amounts. The result has been the continued use of local varieties whose yields are as low as 5 tons/ha.

In many traditional agricultural systems, cassava is inter-cropped with other crops such as maize, sorghum, cowpeas, and sweet potatoes. However, it is common to find cassava grown as a sole crop (Cock, 1985 and Purseglove , 1969). Cassava is planted on ridges, mounds or flat ground where the stem cuttings are either planted vertically, inclined or horizontally at different planting depths (Onwueme, 1978). Planting depth and stem orientation are some of the factors that may affect growth and yield of cassava.

2.3.1 Effects of planting depth on growth and yield of cassava.

Information on the effects of planting depth on production of planting materials and tubers is conflicting. Onwueme (1978) and IITA (1990) reported that planting cassava deeper gave higher tuber yields because a greater number of the buds will be buried in the soil from which the tubers can arise. They further indicated that more stems are also produced. This in turn will increase the quantities of planting material harvested as well as increasing tuber yields. Lopez and Vasquez (1982) on the other hand observed that planting depths of 5 to 25 cm did not affect the growth and yield of the crop. This was earlier observed by Holguin *et al* (1978) who found that under optimum conditions of

soil moisture, planting depth had no effect on growth and yield of the crop. However, planting depth cannot be increased indefinitely because of problems associated with harvesting if planting is done deep.

2.3.2 Effects of stem orientation on growth and yield of cassava.

The choice of the method of planting differs from place to place and is generally as a result of ease of planting, harvesting and expected yield (Annor-Frempong, 1991). Research results obtained by Chew (1974) and Harper (1973) showed that planting cassava horizontally gave the highest final establishment than vertically and inclined planted cuttings. This is because such cuttings are less likely to dry out as they are less exposed to dry conditions. However, Sinthuprama (1980) observed a complete opposite phenomena where horizontally planted cuttings gave the lowest establishment. He observed that horizontally planted stakes took too long to establish and therefore tended to rot thus reducing the final crop establishment. This is also in line with the findings of Castro and Holguin (1979) who observed that vertically sown plants gave higher establishment than the others because such plants easily sprout.

IITA/PRONAM (1978) reported that horizontally sown plants produced more stems per plant because of a larger number of buds exposed to sprouting. This is also confirmed by the findings of Toro and Atlee (1980). This increased number of stems per station will in turn increase the planting material multiplication ratio.

Research results on the effect of stem orientation on tuber yield are also not conclusive. Godo (1984), Gonzales (1973) and IITA/PRONAM (1978) found that vertically sown plants gave higher tuber yields than both horizontally and inclined sown plants. On the other hand, Gurnah (1974); Keating *et al*, (1980) and Sinthuprama (1980) observed no significant differences in tuber yield among these three stem orientations. Yet some studies have found that inclined sown plants gave higher yields (Rosas, 1969; Umah, 1978; Annor-Frempong, 1991). It is in view of these conflicting results that there is need to evaluate these local propagation practices in order to ascertain the best method to use in our locality for production of planting materials and tuber yields.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Site Selection

This experiment was conducted at the University of Zambia, School of Agricultural Sciences in the Field Station which is 15°23'S, 28°28'E and 1140 m above sea level. This was a field experiment carried out during the 1998/99 rainy season. The non-availability of extra planting materials restricted the study to one site.

The field was prepared by rotavating (shallow cultivation) with a tractor. Soil analysis was done to determine the initial fertility. Composite samples were collected using an auger from a depth of 0-20 cm at random sites across the field.

3.2 Experimental materials.

Two lines of cassava, Bangweulu and L9.304/119 used in the experiment were obtained from Mansa Technology Assessment Site in the Luapula province. Bangweulu is a local improved variety and is among the local varieties considered to be high yielding while L9.304/151 is a cross of a local variety, Nalumino and an elite material. This line is still undergoing some evaluations but has shown a positive yield potential.

3.3 Experimental design.

The two varieties were planted at four planting depths of 5 cm, 10 cm, 15 cm and 20 cm. Three stake orientations (horizontal, vertical and inclined) were adopted for the placement of the cuttings. These treatments were arranged in a Split-split design with four replications in which the varieties were assigned to the main plots, the planting depths to the subplots and the stem orientations to the sub-subplots. Each main plot was 3 m x 32 m while the subplot was 1 m x 16 m and the sub-subplot 1 m x 4 m.

3.4 Planting

Cassava cuttings used in the study were 30 cm long. Planting was on ridges 30 cm high at 1 m intra-row and 1 m inter-row spacing. The field was planted on 24th December 1998.

3.5 Agronomic practices.

Compound D (10 N, 20 P₂O₅, 10 K₂O) was applied at the rate of 100 kg/ha at planting while Urea (46% N) was used 60 days after planting at the rate of 100 kg/ha. In both cases the fertiliser was applied as a side dressing 5 cm deep into the soil.

Weeding was done as necessary. The ridges were repaired when damaged by the rains during the season. Due to the early stoppage of the rains, supplementary irrigation was

done once per week to allow the crop to reach maturity. The crop was harvested in October (at 10 months).

3.6 Data collection.

Data on the number of days to 50% establishment and final establishment were collected on all the plants in each treatment while for the other parameters sampling was done where two plants were selected at random from each sub-sub plot and then tagged. A total of eight plants per treatment were used. The following data were collected during the growing season.

3.6.1 Number of days to 50% establishment.

The number of days from the time of planting to when 50% of all the stakes planted had established were recorded for each treatment. Plants were considered to have established when the cuttings had produced fully developed leaves.

3.6.2 Final plant establishment

All the plants that had established for each treatment were counted and expressed as a percentage of the total number of plants sown. This was done two months after planting when it was clear that no more plants could still sprout.

3.6.3 Plant height.

This was measured using a measuring tape. The length from the ground to the topmost growing point of the plant was measured.

3.6.4 Number of primary stems per planting station.

All the primary stems arising directly from each established cutting were counted and recorded. Primary stems were those that arose directly from the cutting before forming secondary branches and were big enough to be used as planting material at time of harvest. Two plants were selected at random from each experimental unit and tagged. All the yield components were upon these selected plants. A total of eight plants per treatment were used.

3.6.5 Planting material multiplication ratio.

The length of all the branches that were big enough to be used for planting were measured using a measuring tape. The multiplication ratio was determined as the fraction of the total length of plantable material of these branches to the length of cutting used in the experiment.

3.6.6 Weight of stems per station.

The stems and leaves of the sampled plants were weighed using a scale and then recorded.

3.6.7 Number of tubers per plant.

The number of tuberous roots from each sampled plant were counted and recorded.

3.6.8 Harvest index.

The stems and roots were weighed for each plant. The harvest index was expressed as the ratio of the weight of the tubers to that of the whole plant as follows;

HI= (WT / WP) x 100 where;

HI= Harvest Index.

WT= Weight of Tubers.

WP= Weight of whole Plant.

3.6.9 Tuber dry matter content.

From each treatment, 16 tubers were selected at random and then peeled. These were then cut into small pieces after which they were pounded into a fine paste. Four samples weighing 5 g each from each treatment were then put into moisture cans and oven dried at 100°C until a constant weight was reached. The samples were then weighed again to

determine the final weights. The dry matter content was determined as the ratio of the final weight to the initial weight as follows;

$$\text{Dry matter (\%)} = \frac{\text{Dry weight} \times 100}{\text{Fresh weight.}}$$

3.6.10 Weight of tubers per hectare.

All the tubers produced by each sampled plant were weighed using a scale. These were then converted to yield per hectare (tons/ha) for each treatment.

3.7 Data Analysis.

The analysis of variance (ANOVA) was carried out on the data collected using MSTATC program in order to detect the effects of the measured parameters on multiplication and yield of cassava. Where the treatments were significant, their means were separated using the Duncan's Multiple Range Test (DMRT).

CHAPTER 4

4.0 RESULTS

4.1 General Observations.

The soil had a good pH but had very low nitrogen and phosphorus levels while the potassium was high (Table 1). These low levels of nitrogen and phosphorus could therefore affect crop growth. The rains stopped early during the first week of March which leading to limited moisture during most of the crop cycle (Appendix A). Therefore, these problems could have greatly affected the results that were obtained.

Table 1. Soil characteristics of the University of Zambia Test Site used in the 1998/99 season.

Soil Characteristic	Value
pH (CaCl ₂)	5.34
Nitrogen	0.04%
Phosphorus	5.08 mg/kg
Potassium	0.92 me/100g
Sand	58%
Clay	28%
Silt	14%

4.2. Effect of variety, planting depth and stem orientation on days to 50% establishment.

Bangweulu took fewer days to establish (16 days) than L9.304/151 (21 days) (Table 3). The stem cuttings planted at 15 and 20 cm depth established earlier (17 days) than those at 5 and 10 cm (21) days. When planting depth in L9.304/151 was increased from 5 cm to 20 cm, this significantly ($p \leq 0.01$) reduced the time to establish from 26 to 17 days. Bangweulu, however, showed no response to these changes (Table 5).

Table 2. Analysis of variance for growth characteristics of two cassava varieties sown at four planting depths and three stem orientations at

UNZA in 1998/99 rainy season.

Source of variation	Days to 50% esta.	Final esta.	No.stems/station	Plant height (cm)	Stem weight (t/ha)	Multi. ratio	No.tubers/plant	Harvest index (%)	Dry matter (%)	Tuber weight (t/ha)
Replication	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Variety (A)	**	ns	ns	ns	ns	ns	ns	ns	**	ns
Planting depth (B)	**	ns	ns	ns	ns	ns	ns	ns	ns	ns
A x B	**	ns	ns	ns	ns	ns	ns	ns	ns	ns
Stem orientation (C)	**	*	**	ns	*	**	**	**	ns	**
A x C	**	ns	ns	ns	ns	ns	*	ns	**	*
B x C	**	ns	ns	ns	ns	ns	ns	ns	**	**
A x B x C	**	ns	ns	ns	ns	ns	ns	ns	**	*

** , * Significant at $p \leq 0.01$ and 0.05 respectively.

ns = non significant.

esta. = Establishment.

No. = Number

Multi. = Multiplication.

Table 3. Growth and yield components of two cassava varieties at UNZA in the 1998/99 rainy season.

Variety	Days to 50% esta.	Final esta.	No. stems/station	Plant height. (cm)	Stem weight (t/ha)	Multi. ratio.	No.tubers/ plant.	Harvest Index (%)	Dry matter (%)	Tuber weight (t/ha).
Bangweulu	16.1b ^z	95.57a	1.9a	103.8a	8.8a	5.5a	5.2a	0.48a	46.14a	9.55a
L9.304/151	21.3a	92.14a	2.0a	83.9a	6.4a	4.4a	4.6a	0.51a	44.77b	7.60a
Mean	18.7	93.86	2.0	93.9	7.6	5.0	4.9	49.89	45.46	8.58
C.V.(%)	10.57	11.71	21.91	50.93	97.46	64.53	74.78	12.14	2.22	105.26

z = Means in the same column followed by the same letter are not significantly ($p \leq 0.01$) different.

Table 4. Effects of planting depth on growth and yield components of cassava at UNZA in 1998/99 rainy season.

Planting depth (cm)	Days to 50% esta.	Final esta.	No. stems/station	Plant height. (cm)	Multi. ratio.	Stem weight (t/ha)	No.tubers/ plant.	Harvest Index (%)	Dry matter (%)	Tuber wt. (t/ha).
5	20.8a ^z	89.96a	2.1a	93.8a	5.3a	7.90a	5.2a	41.56b	46.14a	9.56a
10	20.2a	96.61a	1.8a	94.8a	4.5a	7.13a	4.7a	49.19a	45.15a	7.38a
15	17.2b	90.58a	1.9a	94.6a	5.0a	8.31a	5.1a	50.30a	45.07a	9.56a
20	16.7b	98.28a	2.0a	92.4a	5.0a	7.02a	4.6a	49.52a	45.46a	7.79a
Mean	18.7	93.86	2.0	93.9	5.0	7.59	4.9	49.88	45.46	8.57
CV(%)	21.02	17.14	26.49	23.80	30.44	40.40	43.38	14.16	3.98	45.17

^z = Means in the same column followed by the same letter are not significantly ($p \leq 0.01$) different.

Table 5. Interaction of varieties and planting depths on number of days to 50% establishment of cassava at UNZA. in 1998/99 rainy season.

Planting depth (cm)	Variety		Mean
	Bangweulu	L9.304/151	
5	15.8b ^z	25.9a	20.8a
10	16.1b	24.3a	20.2a
15	15.8b	18.5b	17.2b
20	16.9b	16.5b	16.7b
Mean	16.1	21.3	18.7

C.V. (%) = 21.02.

z = Means across varieties and planting depth followed by the same letter are not significantly different ($p \leq 0.01$).

There were significant differences ($p \leq 0.01$) among the stem orientations for the number of days to 50% establishment (Table 2). Plants sown horizontally took longest time to establish (27 days) (Table 6). The earliest (12 days) plants were those planted inclined with the vertically planted ones being intermediate at 17 days.

Table 6. Effects of stem orientation on growth and yield components of cassava varieties at UNZA. in 1998/99 rainy season.

Stem orientation.	Days to 50% est.	Final est.	No. stems/plant	Plant height. (cm)	Stem weight. (t/ha)	Multi. ratio.	No. tubers/ plant.	Harvest Index	Dry matter (%)	Tuber weight. (t/ha).
Horizontal	27.2a ^z	87.93b	1.5b	84.28a	6.44b	4.1b	2.9b	0.42b	45.60a	5.88b
Vertical	17.1b	96.20a	2.1a	82.77a	8.84a	5.5a	6.5a	0.51a	45.05a	10.45a
Inclined	11.9c	97.44a	2.2a	84.67a	8.78a	5.3a	5.4a	0.50a	45.72a	9.39a
Mean	18.7	93.86	2.0	83.90	7.59	5.0	4.9	0.47	45.46	8.57
CV(%)	19.97	14.46	31.23	20.24	48.45	42.45	42.45	13.04	3.76	53.29

z = Means in the same column followed by the same letter are not significantly ($p \leq 0.01$) different.

A significant interaction ($p \leq 0.01$) was also observed between the varieties and stem orientations (Table 2). For both varieties, the number of days to 50% establishment were reduced from horizontal through vertical to inclined planting (Table 7). In Bangweulu, changing the stem orientation from horizontal to either vertical or inclined position reduced the number of days to 50% establishment by 16 days. On the other hand, for the variety L9.304/151, changing the stem orientation from horizontal to vertical reduced the days to 50% establishment by 5 days while changing from vertical to inclined reduced time by 10 days. In L9.304/151 inclined sown plants establishment 15 days earlier than those sown horizontally. For both varieties, horizontally sown plants took 27 days to establish, but for vertically sown plants the variety L9.304/151 established 12 days earlier than Bangweulu while for plants sown at an inclined position, Bangweulu established 3 days earlier than L9.304/151.

Table 7. Interaction of varieties and stem orientations on the number of days to 50% establishment of cassava at UNZA. in the 1998/99 rainy season.

Variety	Stem orientation			Mean
	Horizontal	Vertical	Inclined	
Bangweulu	26.9az	11.1cd	10.5d	16.1
L9.304/151	27.6a	23.1b	13.3c	21.3
Mean	27.2	17.1	11.9	18.7

C.V. (%) = 19.97

z = Means across varieties and stem orientations followed by the same letter are not significantly different ($p \leq 0.01$).

Significant interactions ($p \leq 0.01$) between planting depths and stem orientations were observed for the number of days to 50% establishment (Table 8). At all the orientations, increasing the planting depth tended to shorten the time to establishment especially for the horizontally and vertically planted plants (29 to 24 days and 21 to 14 days, respectively). Those planted on the incline did not show any significant reduction. This delay was more pronounced for horizontally and vertically sown plants while plants sown on the incline maintained the 12 day period to establishment at all the depths.

Table 8. Interaction of planting depths and stem orientations on number of days to 50% establishment in cassava at UNZA in 1998/99 rainy season.

Planting depth (cm)	Stem orientation			Mean
	Horizontal	Vertical	Inclined	
5	29.1a ^z	21.4cd	12.0e	20.8
10	28.6a	20.1d	11.9e	20.2
15	24.4bc	13.6e	13.5e	17.2
20	26.8ab	13.1e	10.3e	16.7
Mean	27.2	17.1	11.9	18.7

C.V. (%) = 19.97.

z = Means across planting depths and stem orientations followed by the same letter are not significantly different at ($p \leq 0.01$).

4.3 Effect of variety, planting depth and stem orientation on final crop establishment (%).

The final crop stand was similar between the varieties and no differences occurred among the planting depths. Significant differences ($p \leq 0.05$) were observed in the stand count at harvest among the stem orientations. The vertical and inclined stem orientations had a higher plant stand count (97%) than the horizontal (88%) (Table 6).

No significant interactions were observed between the varieties and stem orientations or between the planting depth and stem orientation as well as among the varieties, planting depths and stem orientations.

4.4 Effects of variety, planting depth and stem orientation on number of primary stems per planting station.

The number of primary stems produced per plant were not significantly different for the two varieties (Table 3). Similarly, the planting depths did not significantly affect the number of primary branches per station. There was also no significant interaction between the varieties and planting depths observed. However, significant differences ($p \leq 0.01$) were observed among the stem orientations on the number of primary stems that were produced per station. Vertically and inclined planted cuttings produced significantly more primary stem (2.0/plant) than horizontal (1.5/plant) planting.

The interactions between the varieties and stem orientations as well as planting depth and stem orientation were not significant (Table 6).

4.5 Effect of variety, planting depth and stem orientation on plant height (cm).

Bangweulu grew taller (104 cm) than L9.304/151 (84 cm). However, the difference between the varieties was not significant (Table 3). Both the planting depth and stem orientation did not affect the plant height of the two varieties (Table 4 & 6). No significant interaction between variety and planting depth, variety and stem orientation as well as between planting depth and stem orientation were seen.

4.6 Effect of variety, planting depth and stem orientation on stem weight per station.

Differences in stem weights between the two varieties were similar (Table 2). However, Bangweulu produced bigger stems (8.8 t/ha) than L9.304/151 (6.4 t/ha) (Table 3). The planting depth did not affect the stem size.

Significant differences ($p \leq 0.05$) were, however, observed among the stem orientations (Table 2). Stem weights for vertically and inclined sown plants were significantly higher (8.8 t/ha) than for horizontal planted ones (6.4 t/ha) (Table 6).

4.7 Effect of variety, planting depth and stem orientation on planting material multiplication ratio.

The amounts of planting material produced in the two varieties were similar. Planting depth did not affect the production of planting material. Furthermore, no significant interactions were seen between the varieties and planting depths.

Stem orientation significantly ($p \leq 0.05$) affected the production planting material. Plants planted horizontally gave lower planting material ratio (1: 4) than vertically and inclined planted ones (1:6) (Table 6).

There were no significant ($p \leq 0.05$) interactions between varieties and stem orientations as well as among the varieties, planting depths and stem orientation.

4.8 Effect of variety, planting depth and stem orientation on number of tubers per plant.

Similar number of tubers per plant were produced by the two varieties and no differences in the number of tubers were observed among the planting depths. In addition, there were no significant interactions between the varieties and planting depths.

The plants that were planted vertically and on the incline produced significantly ($p \leq 0.01$) more tubers per plant (6.0) than horizontal plants (3.0) (Table 6). Planting Bangweulu vertically gave significantly more tubers per plant (7.0) than planting it either horizontally or on the incline (5.0) (Table 9) while, for L9.304/151, planting either vertically or on the incline gave more tubers (6.0) than planting horizontal (2.0). No significant interactions were observed either between planting depth and stem orientations or varieties, planting depths and stem orientations.

Table 9. Interaction of cassava varieties and stem orientations on the number of tuberous roots produced at UNZA. in 1998/99 rainy season.

Variety	Stem orientation			Mean
	Horizontal	Vertical	Inclined	
Bangweulu	3.6cd ^z	7.2a	4.8bc	5.1
L9.304/151	2.2d	5.7ab	6.0ab	4.6
Mean	2.9	6.4	5.4	4.9

C.V. (%) = 48.04

^z= Means across varieties and stem orientations followed by the same letter are not significantly different at ($p \leq 0.05$).

4.9 Effect of variety, planting depth and stem orientation on harvest index.

The two varieties produced similar harvest indexes and no significant differences in the harvest indexes were observed among the planting depths. There was also no significant interaction between the varieties and planting depths.

The harvest indexes for vertically and inclined sown plants were significantly ($p \leq 0.05$) higher (0.51 and 0.50) respectively) than horizontal (0.41) (Table 6). No significant interactions between the varieties and stem orientations or planting depths and stem orientations were observed. Furthermore, no significant interactions were also observed among the varieties, planting depths and stem orientations (Table 2).

4.10 Effect of variety, planting depth and stem orientation on tuber dry matter (%)

Bangweulu produced a significantly ($p \leq 0.01$) higher tuber dry matter (46%) than L9.304/151 (45%) (Table 3). There were no significant differences in tuber dry matter produced by the plants at all the planting depths and among the stem orientations. However, tubers of Bangweulu from horizontally and inclined plants gave significantly ($p \leq 0.01$) higher tuber dry matter (47%) than vertical ones (44%) (Table 10) while for L9.304/151, vertically and inclined planted plants slightly gave more tuber dry matter (46%) than horizontal ones (44%).

Table 10. Interactions of cassava varieties and stem orientations on dry matter content of cassava at UNZA in 1998/99 rainy season.

Variety	Stem orientation			Mean
	Horizontal	Vertical	Inclined	
Bangweulu	47.21a ^z	44.49cd	46.71ab	46.14a
L9.304/151	43.98d	45.61bc	44.73cd	44.74b
Mean	45.60	45.05	45.72	45.44

C.V. (%) = 3.73

^z= Means across varieties and stem orientations followed by the same letter are not significantly different ($p \leq 0.01$).

There were also significant ($p \leq 0.01$) interactions among planting depths and stem orientations (Table 2). When the planting depth was increased from 5 to 20 cm, the tuber dry matter content reduced from 48% to 42% while for vertical plants it reduced from 47% to 44%. However, for inclined plants this increased the dry matter from 44% to 47% (Table 11). Significant interactions ($p \leq 0.01$) were observed among varieties, planting depths and stem orientations.

Table 11. Interaction of planting depths and stem orientations on tuber dry matter content of cassava at UNZA. in 1998/99 rainy season.

Planting depth (cm)	Stem orientation			Mean
	Horizontal	Vertical	Inclined	
5	47.74a ^z	47.16a	43.51de	46.14a
10	45.03cde	43.90de	46.51abc	45.15a
15	46.51cde	44.34de	45.58cde	45.07a
20	41.74de	44.78cde	47.28ab	45.46a
Mean	45.60	45.05	45.72	42.42

C.V (%) = 3.73

^z= Means across planting depths and stem orientations followed by the same letter are not significantly different at ($p \leq 0.01$).

4.11 Effect of variety, planting depth and stem orientation on weight of tubers .

The weight of the tubers produced in the two varieties was similar and no significant difference in the weight of the tubers was observed among the planting depths. There were also no significant interactions between the varieties and planting depths.

Vertically and inclined sown plants yielded significantly ($p \leq 0.01$) more tuberous roots (10.5 t/ha) than horizontal (5.9 t/ha) (Table 6). In both varieties, horizontal placement of the cuttings gave the lowest tuber yield although this was worse in L9.304/151 (4.1t/ha). Bangweulu yielded significantly ($p \leq 0.01$) higher when planted vertically (12.8 t/ha) than when planted at an incline or horizontally (8.0 t/ha) (Table 12). L9.304/151 yielded more when planted either at an incline or vertically (10.6 t/ha) than horizontally (4.0 t/ha).

Table 12. Interactions of cassava varieties and stem orientations on tuberous root weight of cassava at UNZA in 1998/99 rainy season.

Variety	Stem orientation			Mean
	Horizontal	Vertical	Inclined	
Bangweulu	7.63b ^z	12.82a	8.22b	9.55
L9.304/151	4.13c	8.10b	10.57ab	7.59
Mean	5.88	10.45	9.39	8.57

C.V. (%) = 53.29

z= Means across varieties and stem orientations followed by the same letter are not significantly different ($p \leq 0.01$).

There was a significant ($p \leq 0.05$) interaction between planting depths and stem orientations (Table 2). Tuberous root yield remained almost constant for horizontally planted stakes despite changes in the planting depth (6 t/ha) (Table 13 and Graph 1) while for inclined planted stakes the yield was similar at 5 to 10 cm depths (10 t/ha), highest at 15 cm (12.9t/ha) but lowest at 20 cm depth (5.6 t/ha). However, for vertically planted stakes lowest yields were from plants at 10 cm depth (7.4 t/ha), but when the planting depth was increased from 10 cm to 20 cm, this increased the tuber yield up to 12.6t/ha. There were also significant ($p \leq 0.05$) interactions among the varieties, planting depths and stem orientations but these were not consistent.

Graph 1. Interactive effect of planting depth and stem orientation on tuberous root yield of cassava at UNZA in 1998/99 rainy season.

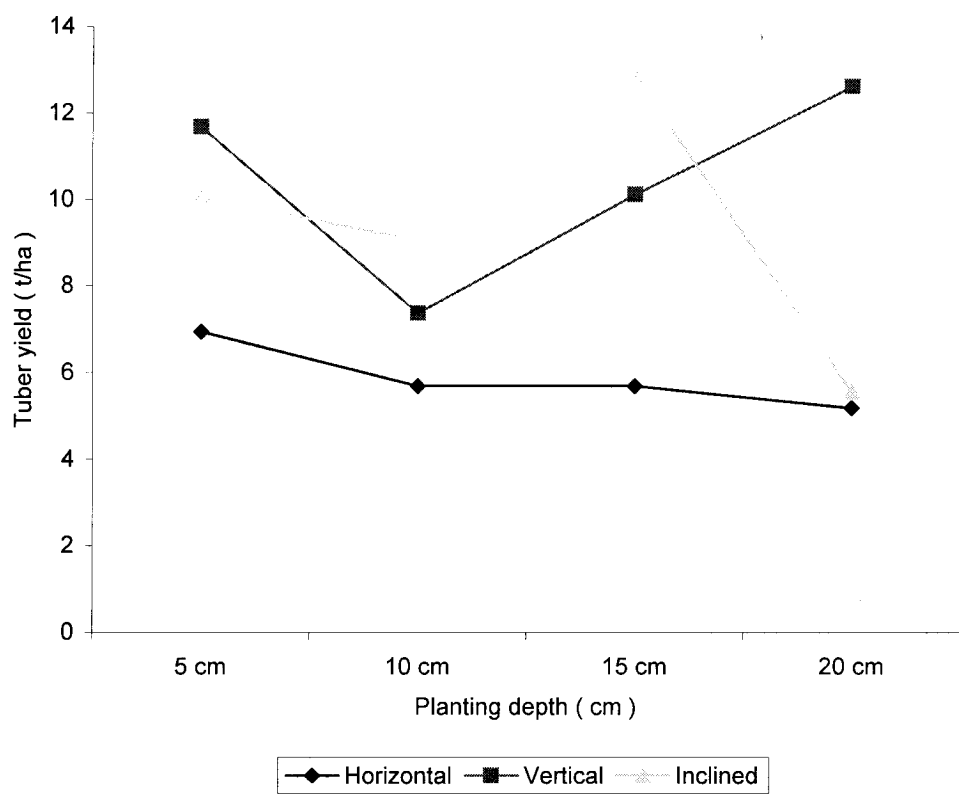


Table 13. Interactions of planting depths and stem orientations on tuber weight of cassava varieties at UNZA in 1998/99 rainy season.

Planting depth (cm)	Stem orientation			Mean
	Horizontal	Vertical	Inclined	
5	6.94bc ^z	11.69ab	10.06abc	9.56
10	5.69c	7.37bc	9.06abc	7.38
15	5.69c	10.13abc	12.88a	9.56
20	5.19c	12.63a	5.56c	7.79
Mean	5.88	10.45	9.39	8.57

C.V.(%) = 53.29

^z= Means across planting depths and stem orientations followed by the same letter are not significantly different ($p \leq 0.01$).

CHAPTER 5

5.0 Discussion

5.1 Effect of variety, planting depth and stem orientation on crop establishment.

The two varieties differed greatly in their number of days to 50% establishment. Bangweulu established earlier (16 days) than L9.304/151 (21 days). These differences in time to establishment could be as a result of genetic differences in root initiation and development (Ghosh *et al*, 1988).

Planting the stem cuttings deeper, generally hastened crop establishment (Table 4). This observation could be as a result of changes in soil moisture arising from differences in soil depth. Soil moisture at shallow depths is more affected by ambient conditions than at deeper layers and as such cuttings planted deeper will have more conducive soil moisture than those at shallower depths therefore establish faster (Keating and Evenson, 1979). Bangweulu was less sensitive to changes created by different planting depths than L9.304/151 as evidenced by its establishment at almost the same time in all the planting depths. These varietal differences in response to planting depths would point to differences in assimilate amounts in the cuttings. Ekanayake (1993) and Whyte (1985) observed that for cassava the early stages of growth before the leaves are fully grown, root and shoot formation depends on stored assimilates in the cutting. This, however, was observed not to be the only important factor as the cassava plant would also need adequate moisture in the soil for its sprouting and final establishment (Ghosh *et al*, 1988).

The possible favorable soil moisture conditions created by the deeper planting in the study, therefore, favoured the variety with adequate assimilates to sprout and establish earlier and within similar period regardless of the planting depth.

Horizontally planted plants established last (27 days) followed by vertically planted ones (17 days) while inclined planting established first (12 days). These differences in time to establishment among the stem orientations could be due to differences in hormonal action especially auxins (Indole Acetic Acid) that are known to affect root initiation and development (Bleasdale, 1984; Hartman and Keyster, 1968). Therefore, the movement and concentration of hormones in these different stem orientations could have led to differences in time of establishment. The formation of roots in stem cuttings is dependent on hormones moving down from buds at the younger portion to the older portion of the cutting as well as on concentration of these hormones (Onwueme and Charles, 1994; Williams, 1979). Increasing the hormone concentration has shown to speed up rooting in stem cuttings (Hartman and Kester, 1968). The differences in the surface areas of the cuttings that were exposed to root formation in these orientations may have likely affected the time to sprouting. These surface areas reduced from horizontally through vertically to inclined sown plants. Greater surface areas on which these hormones were acting to initiate root formation and development tended to delay the time to establishment. Therefore, possibly the action of these hormones was highest in inclined planted stakes followed by those planted vertically and lastly those planted horizontally. Furthermore,

light is known to accelerate breaking of dormancy of the buds, therefore, vertical and plants on the incline were exposed to the sunlight and were able to sprout faster (Hartman and Kester, 1968).

The final crop establishment was similar for the two varieties despite differences in time to establishment (Table 3). The final establishment was also similar for the four planting depths. This is because inherently live buds have to sprout if the soil conditions do not disadvantage the slower sprouters such as L9.304/151. When conditions lead to rotting and drying out, then slower sprouters would have poor final establishment.

Differences among stem orientations for the final crop establishment were observed (Table 6). Horizontally placed cuttings had lower final establishment (88%) than those of inclined and vertical positions (97% and 96% respectively). These differences were due to favourable conditions for sprouting, and therefore growth, presented by vertical and inclined planting. Chances of the stem cuttings to rot are high in horizontally planted cuttings (Sinthuprama, 1980) which besides other unfavourable sprouting conditions, in turn would affect the final crop establishment. The results of this study point to the above as the reason for differences among stem orientations for final crop establishment.

5.2. Effect of variety, planting depth and stem orientation on vegetative growth and development.

The two varieties had similar plant heights (Table 3). This could be the inherent expression of the varieties. Planting depth and stem orientation did not affect plant height (Tables 4 and 6) despite the fact that they affected time to establishment. This is because growth of the crop could have been affected by competition of plants both within and between rows (Larcher, 1995). Growth of cassava is very slow following establishment and plants that established faster in the experiment may not have had significant advantages in their competing abilities later on (;Bleasdale, 1984 and Larcher, 1995 and Squire, 1990).

These plant heights reported are similar to those obtained by the Root and Tuber Improvement Program (RTIP, 1998) where the height for Bangweulu under various nutrient levels ranged from 95.8 to 101.5 cm. However, cassava is known to reach plant heights of 240 cm in 24 months.

The two varieties produced (2.0 stems/station) and at all planting depths (Tables 3 and 4). When planted either vertically or on incline, the plants gave a higher number of stems per station (2.0 stems/plant) than planting horizontally (1.5 stems/plant) (Table 6). This difference seem to be explained by the factors that led to the differences in the final crop establishment, which was indicated by the number of shoots per plant.

As mentioned above, the favourable sprouting and development conditions under vertical and inclined planting could have also allowed for more stems under these stem orientations.

These results are similar to those of Leihner and Castro (1979) who found that the number of primary stems per plant in cassava ranged from 2.2 to 2.6 per plant. It was observed that more buds had actually sprouted per plant but as the plants grew most of them could not pick up. Cock (1985) and Milthorpe and Moorby (1975) observed this phenomena in cassava and Irish potato respectively where development of side shoots was inhibited by the bigger shoots. Increasing the number of stems per plant seems only possible by inhibiting this apical dominance.

The amount of stems produced by the two varieties were 8.8 t/ha and 6.4 t/ha for Bangweulu and L9.304/151 respectively (Table 3). This indicates that the two varieties had similar growth. Same number of stems were produced at all the planting depths because of the effects of apical dominance as reported by Leihner and Castro (1979) and Cock (1985) fixed the sink in terms of number of stems per plant regardless of changing growing conditions. To this end, therefore, subsequent assimilation will be similar for similar size of sinks. In the absence of any other factors discriminating the stem weights at any planting depth, stem weight will be the same. The stem weights obtained in this experiment were, however low because the crop was harvested at 10 months, earlier than in other studies. The higher amounts of stems produced in vertically and inclined planted

cuttings of 8.8 t/ha each are due to the fact that vertically and inclined planted cuttings produced more stems per plant than horizontally sown plants (6.0t/ha) (Table 6). Besides the lower number of stems per plant associated with horizontally planted cuttings, the stems from this stem orientation were also observed to be non-branching. Therefore, vertically and inclined sown plants had higher leaf areas than horizontally planted cuttings. This then increased the production and accumulation of photosynthates in these stems (Squire, 1990). That being the case, the higher stem weights from vertically and inclined plantings were expected.

The multiplication ratios of the two varieties were similar 1:6 and 1:4 for Bangweulu and L9.304/151 respectively (Table 3). This is explained by similarities in plant heights and number of stems per plant between the two varieties. At all the planting depths, the multiplication ratio was 1:5 (Table 4). This is so because these plants had similar plant heights and number of stems. Because vertically and inclined planted stakes produced more stems per station, these gave higher multiplication ratios of 1:6 and 1:5 respectively compared to 1:4 for horizontally planted stakes. These multiplication ratios were similar to those obtained by Leihner (1984) who found that at plant densities of 10,000 plants per hectare, the multiplication ratio of cassava was 6. The multiplication ratios in this experiment would have increased with time especially for vertical and inclined sown plants where branching was very pronounced if harvesting were delayed. Horizontally sown plants had the lowest multiplication ratio because these plants did not branch at all resulting in fewer branches and hence low multiplication ratio.

5. 3 Effect of variety, planting depth and stem orientation on tuber parameters.

The two varieties produced 5 tubers per plant each at all the planting depths (Tables 3 and 4). These results are in agreement with what was observed by Lopez and Vazquez (1982) where tuber production was similar for planting depths of 5 to 25 cm. This is because tuber production is largely dependent on genotype and assimilate supply (Whyte, 1985). Changes in planting depth did not affect plant development and as such did not affect tuber development. Plants planted on the incline and vertically gave 5 to 7 tubers per plant while those planted horizontally gave 3 tubers per plant. These differences in the number of tubers are associated with the branching exhibited by the plants. Plants that are heavily branched are known to depress tuber growth than those that are moderately branched (Aziz,1983), however, there is need to maintain a certain amount canopy in order to provide an adequate photosynthetic apparatus for tuber production (Tan, 1985 and Squire, 1990). Therefore, it seems that the higher number of stems per station produced in vertically and inclined sown plants gave favourable plant canopies that produced more photosynthates to support tuber growth than horizontally sown plants.

Since the two varieties produced similar stem weights and tubers, they gave similar harvest indexes (49% and 52% for Bangweulu and L9.304/151 respectively). Similarly, at all the planting depths, the harvest indexes were not significantly different since planting depth did not affect the growth and development of the crop. Vertically and inclined sown plants produced higher harvest indexes because these plants had bigger

canopies that favoured more accumulation of assimilates in the tubers than those planted horizontally.

The differences in tuber dry matter content between Bangweulu (46%) and L9.304/151 (45%) was because of genetic differences between them (Burton, 1989). The changes in dry matter as a result of the interaction between varieties and the stem orientations were not consistent and were not directly related to the tuber yield obtained. These variations in dry matter could be explained by the fact that the partition of dry matter between the leaves and tubers can be greatly influenced by the environment. The high levels of shading in cassava plants may then affect partition of dry matter and therefore, great variations in dry matter content are expected between the plants (Burton, 1989). Because of these great variations, selection of high yielding cassava varieties using tuber dry matter content as an indicator is less helpful Mahungu *et al*, (1991). Since planting depth and stem orientation at planting does not affect photosynthesis of the plant then they do not affect tuber dry matter.

The two varieties produced similar tuber weights (9.6 and 7.6 t/ha). This may indicate that the varieties had similar sink strengths resulting in similar accumulation of assimilates in the tubers (Tan, 1985). Planting depth did not have any significant effect on the amount of tubers produced because it did not affect growth of the crop. Vertically and inclined planted stakes produced more tubers (10.5 to 9.4 t/ha) than the horizontal planting (5.9 t/ha). Cock *et al*, (1979); (1984) and Williams (1979) found that sink

strength in cassava increased with an increase in the number of tubers. Therefore, since vertically and inclined sown plants produced higher number of tubers than horizontally sown plants, this led to an increase in the partition of photosynthates to these tubers leading to increased tuber weights. In addition, such plants produced larger canopies that were able to produce adequate photosynthates to support tuber development. In the two varieties, the increased number of tubers gave greater tuber weights. Bangweulu, planted vertically gave highest tuber yield (12.8 t/ha) and L9.304/151 (8.0 to 10.6 t/ha) when planted vertically or on incline. Increasing the planting depth from 5 cm to 20 cm for horizontally sown plants did not affect the yield. Under horizontal and inclined placements, increasing planting depth slightly reduced the yields while under vertical the highest yield was at 20 cm depth (12.6t/ha). This observation confirms that planting depth does not affect the yield of cassava as observed by Castro and Holguin (1979). Planting depth seems to play a major role only in the establishment of the crop (Sinthuprama, 1980). This is because cassava roots can grow up to 80 cm deep and extract water from greater depths than those that the cutting was initially inserted at (Squire, 1990).

CHAPTER 6

6.0 CONCLUSION.

From this experiment it can be concluded that cassava planted vertically or at an incline gives more planting material and tuber yields. Bangweulu should be planted vertically while L9.304/151 should be planted either vertically or at an incline. The crop can be planted from 5 cm to 20 cm depths without adversely affecting its production of planting material and tuber yield, however, stakes at an inclined should be planted at 10 to 15 cm depths and vertical stakes at 15 cm to 20 cm depths.

However, this study was not able to determine the effects of moisture and soil type on the sprouting, growth and yield of the crop. There is also need to evaluate a number of varieties in order to assess their response to these factors.

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APPENDIX A

Rainfall distribution during the 1998/99 agricultural season at UNZA.

Month	Number of rain days	Rainfall amount (mm)
November	4	66.8
December	7	98.3
January	12	194.1
February	10	189.4
March	4	20.4
Total	37	569.0

APPENDIX B

ANOVA for days to 50% establishment

Source	Df	SS	MS	F -Value
Replication	3	50.542	16.847	0.1309
Factor A	1	640.667	640.667	0.0010**
Error	3	11.750	3.917	
Factor B	3	315.375	105.125	0.0030**
AB	3	431.583	143.861	0.0006**
Error	18	279.042	15.502	
Factor C	2	3884.896	1942.448	0.0000**
AC	2	578.396	289.198	0.0000**
BC	6	280.688	46.781	0.0078**
ABC	6	286.854	47.809	0.0069**
Error	48	671.167	13.983	
Total	95	7430.958	7430.958	

Coefficient of Variation: 19.97%

APPENDIX C

ANOVA for final plant establishment

Source	Df	SS	MS	F -Value
Replication	3	846.337	282.112	2.3356
Factor A	1	282.769	282.769	2.3411
Error	3	362.357	120.786	
Factor B	3	1274.280	424.760	1.6423
AB	3	432.866	144.289	0.5579
Error	18	4655.469	258.637	
Factor C	2	1712.485	856.242	4.6506*
AC	2	228.994	114.497	0.6219
BC	6	1713.664	285.611	1.5513
ABC	6	753.550	125.592	0.6821
Error	48	8837.469	184.114	
Total	95	21100.239		

Coefficient of variation: 14.46%

APPENDIX D

ANOVA for number of stems per planting station

Source	Df	SS	MS	F-Value
Replication	3	1.646	0.549	2.9811
Factor A	1	0.010	0.010	0.0566
Error	3	0.552	0.184	
Factor B	3	1.313	0.438	1.6258
AB	3	0.302	0.101	0.3742
Error	18	4.844	0.269	
Factor C	2	8.318	4.159	11.1160**
AC	2	0.036	0.018	0.0487
BC	6	2.766	0.461	1.2320
ABC	6	2.089	0.348	0.9304
Error	48	17.958	0.374	
Total	95	39.833		

Coefficient of variation: 31.23%

APPENDIX E

ANOVA for plant height

Source	Df	SS	MS	F -Value
Replication	3	927.566	309.189	0.1693
Factor A	1	9584.007	9584.007	5.2464
Error	3	5480.291	1826.764	
Factor B	3	91.091	30.364	0.0779
AB	3	465.241	155.080	0.3978
Error	18	7017.470	389.859	
Factor C	2	64.585	32.293	0.1120
AC	2	400.791	200.396	0.6951
BC	6	3056.422	509.404	1.7669
ABC	6	3499.341	583.224	2.0230
Error	48	13838.353	288.299	
Total	95	44425.158		

Coefficient of variation: 20.24%

APPENDIX F

ANOVA for planting material multiplication ratio

Source	Df	SS	MS	F -Value
Replication	3	31.277	10.426	1.0167
Factor A	1	30.016	30.016	2.9273
Error	3	30.762	10.254	
Factor B	3	7.637	2.546	1.1160
AB	3	3.779	1.260	0.5523
Error	18	41.057	2.281	
Factor C	2	37.320	18.660	4.2081**
AC	2	3.300	1.650	0.3720
BC	6	33.095	5.516	1.2439
ABC	6	35.547	5.925	1.3360
Error	48	212.850	4.434	
Total	95	466.640		

Coefficient of variation: 42.44%

APPENDIX G

ANOVA for stem weight per planting station

Source	Df	SS	MS	F -Value
Replication	3	2.700	0.900	0.9069
Factor A	1	1.438	1.438	1.4492
Error	3	2.977	0.992	
Factor B	3	0.277	0.092	0.4712
AB	3	0.391	0.130	0.6642
Error	18	3.532	0.196	
Factor C	2	1.069	0.535	2.8381
AC	2	0.490	0.245	1.3001
BC	6	1.075	0.179	0.9413
ABC	6	0.765	0.128	0.6772
Error	48	9.041	0.188	
Total	95	23.755		

Coefficient of variation: 57.19%

APPENDIX H

ANNOVA for number of tuberous roots per plant

Source	Df	SS	MS	F -Value
Replication	3	189.031	63.010	4.6819
Factor A	1	7.042	7.042	0.5232
Error	3	40.375	13.458	
Factor B	3	7.760	2.587	0.9091
AB	3	18.396	6.132	2.1550
Error	18	51.219	2.845	
Factor C	2	211.141	105.570	19.0056**
AC	2	37.224	18.612	3.3507*
BC	6	62.005	10.334	1.8604
ABC	6	38.339	6.390	1.1503
Error	48	266.625	5.555	
Total	95	929.156		

Coefficient of variation: 48.04%

APPENDIX I

ANOVA for harvest index

Source	Df	SS	MS	F –Value
Replication	3	1841.885	613.962	1.1715
Factor A	1	11.711	11.711	0.0223
Error	3	1572.180	524.060	
Factor B	3	18.041	6.014	0.0692
AB	3	85.324	28.441	0.3271
Error	18	1565.224	86.957	
Factor C	2	1672.214	836.107	7.3610**
AC	2	434.321	217.161	1.9118
BC	6	172.213	28.702	0.2527
ABC	6	908.660	151.443	1.3333
Error	48	5452.162	113.587	
Total	95	13733.936		

Coefficient of variation: 22.49%

APPENDIX J

ANOVA for tuber dry matter (%)

Source	Df	SS	MS	F-Value
Replication	3	2.666	0.889	0.8687
Factor A	1	44.554	44.554	43.5556**
Error	3	3.069	1.023	
Factor B	3	17.017	5.672	1.7311
AB	3	7.455	2.485	0.7584
Error	18	58.979	3.277	
Factor C	2	8.200	4.100	1.4250
AC	2	80.192	40.096	13.9356**
BC	6	150.319	25.053	8.7074**
ABC	6	108.002	18.000	6.2562**
Error	48	138.107	2.877	
Total	95	618.558		

Coefficient of variation: 3.73%

APPENDIX K

ANOVA for tuberous root weight

Source	Df	SS	MS	F -Value
Replication	3	882.559	294.186	3.0686
Factor A	1	123.080	123.080	1.2838
Error	3	287.606	95.869	
Factor B	3	98.838	32.946	1.8462
AB	3	95.510	31.837	1.7840
Error	18	321.219	17.846	
Factor C	2	471.131	235.565	9.5895
AC	2	164.916	82.458	3.3567
BC	6	241.387	40.231	1.6377
ABC	6	370.828	61.805	2.5160
Error	48	1179.118	24.565	
Total	95	4236.192		

Coefficient of variation: 19.97%