African Journal of Agricultural Research Vol. 4 (1), pp. 021-027, January, 2009
Available online at http://www.academicjournals.org/AJAR
ISSN 1991-637X

Full Length Research Paper

Impact of water stress on fresh tuber yield and dry matter content of cassava (*Manihot esculenta* Crantz) in Côte d'Ivoire

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Accepted 12 December, 2008

The production and transformation of cassava (*Manihot esculenta* Crantz) roots are increasing in Côte d'Ivoire. Characteristics of cassava, at different times of planting and harvesting were studied. For the September plantings, the local cultivar produced less than the improved varieties but maintained a superior dry matter content. In the June plantings, there was no significant difference in fresh root weight. In June planting, the fresh tubers yields showed significant increases up to the harvest after 15 months (43.1 t ha^{-1}) and declined thereafter about 37.01 t ha^{-1} at 18 months, while dry matter were highest from September plantings with 37.32% at 12 months and regularly reduced until 18 months about 33.18%. The highest dry matter content of cassava tubers is attained when the water stress does not exceed one period in the first 6 months. Dry roots yields were highest (15.27 t ha^{-1}) when roots were harvested in September, but continued to decrease up to 12.59 t ha^{-1} in December with June planting. These findings suggest that the best time to harvest cassava is September if the aim is to transform cassava into "*attiéké*" for example. Dry roots yield is markedly influenced by environmental conditions, especially water stress immediately before root harvest.

Key words: Cassava, seasons, water stress, yields, Côte d'Ivoire.

INTRODUCTION

In Côte d'Ivoire, cassava is grown on about 80% of the national territory and is the major food crop after yam (2'800'000 tons/year) with an annual production of 1'700'000 tons (FAO, 2006). Cassava is principally consumed as meals like, *attiéké* (couscous), *placali*, (paste) and *fufu* (boiled roots) with consumption increasing, especially in the urban zones, with *attiéké* the most popular form (Assanvo et al., 2006).

According to Santisopasri et al. (2001), cassava plants which undergo water stress in the first six months after planting, produce low yields. Due to the increasing demand for locally produced starch by the food industry there is a need for more information on optimal time for planting and harvesting cassava. Cassava roots can be stored in the ground, but are highly perishable after harvest, and hence farmers tend to harvest roots when they are needed (Iglesias et al., 1997; El-Sharkawy, 2004; Ceballos et al., 2004).

Cassava production is a major concern for the rural po-

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pulations of the Centre of Côte d'Ivoire. In *baoulé* country, yam and cassava represent nearly 80% of the consumed food products. These two crops are grown by most farmers (Janin, 2001). Cassava is grown as the last crop in the rotation, before returning to fallow and provides food in periods of temporary shortages (May-August) (Ceballos et al., 2004). The low availability in tubers (keen urban demand) is due to the shortage of labour in the field (Janin, 2001). The farmers are not only interested in the fresh root production: as most of the cassava is processed into flours, meals and semolina the dry matter content is of paramount importance (Bakayoko, 2007). Many cassava varieties are being tested (Bakayoko, 2007) with a view to finding the most productive ones. The farmers need to know which varieties are the best and also the optimum times for planting and harvesting them in the "soudano-guineennes" areas of the Côte.d'ivoire.

A major abiotic constraint to cassava production in Africa is drought. In much of the continent, the cassava growth cycle is interrupted by 3-6 months of drought. Most information available on cassava production constraints in Africa comes from agronomics studies where the crop was evaluated only once at the harvest time. To understand the complex interactions between the plant and the prevailing climatic conditions, a dynamic point of view is needed. The present study was an attempt to try to identify the ideal cassava plant and harvest under local conditions.

MATERIAL AND METHODS

Site description

Experiments were carried out in the experimental field (altitude 150 m, 06°40´N, 05°09´W) of the Swiss Centre for Scientific Research, in Bringakro, located at 180 km in the North from Abidjan (Côte.d'Ivoire). It is an area of forest –savanna mosaic where the soils are moderately unsaturated ferrallitic sandy soil and characterized by high percentages of fine sands and a low thickness of humus. The area is characterized by an equatorial climate of transition with two maximum and two minimum, a major rainy season (from March to July) with a mean precipitation about 850 mm, a small dry season (from July to August), a small rainy season (from September to October) which gives approximately 185 mm and a major dry season (from November to February). The dry harmattan wind blows from December to February during the great dry season. Annual mean precipitation was 1153 mm from 2002 to 2003 with an average temperature about 26°C, average relative humidity about 77% and a monthly total solar radiation of about 394 MJ m^{-2}. The plot area is on a weak slope (1 to 2%). After a short fallow period of 2 months which followed upon a preceding yam, the ground was primarily covered by *Imperata cylindrica* (Poaceae), *Chromolaena odorata* (Asteraceae), without coarse elements, with organic remains and casts of earthworms (*Hyperiodrilus africanus* (Oligochaeta, Eudrilidae)) on certain places.

Vegetable material and experimental design

Fourteen (14) improved cassava varieties (*96/1632, 97/4763, 97/4769, 97/3200, 97/0162, 97/4779, 98/0510, 98/2132, 98/0505, 98/2101, 98/0002, 98/0581, TME7 and TME419*) IITA (International Institute of Tropical Agriculture) in Ibadan, Nigeria introduced to Côte.d'ivoire in June 2002 and one (1) local cultivar control (*Anader2*) were used as planting material. The 14 new varieties, considered as most outstanding, according to recent evaluations of the IITA, have contents of matter dries above 30%, an output in fresh tubers greater than 25 t ha^{-1}, a low or average content in hydrocyanic acid. These varieties are resistant to the African cassava mosaic virus (ACMV) according to the IITA. The local variety is well appreciated by the local populations. The trial was established as a split plot design, with planting period as the main plot and variety as the subplot. Both main and subplots were arranged into randomized complete blocks in 4 replications. The basic plots were single rows of 40 plants; making a basic plot size of 40 m^2. Planting was done on ridges spaced 1 m apart. 40 mature stem cuttings about 15-20 cm long, were hand planted on the crests of ridges on June 06^{th}, 2002 and on September 12^{th}, 2002, then, at the same dates in 2003. No fertilizers, herbicides or plant protection measures were applied. Harvesting was done 12, 15 and 18 months after planting, and data were collected on fresh total and marketable root yields and dry matter content. Dry matter was determined by drying 250 g root pieces at 104°C until final weight was reached.

Statistical analysis

Means were calculated by sub-plot. The data were then subjected to analysis of variance according to the experimental design (linear model with interactions) by SAS® software (SAS Institute Inc, Cary, NC, the USA). When the effects were significant, means were compared using Student-Newman-Keuls method (Dagnelie, 2003).

RESULTS

There were no significant differences between improved varieties and local cultivar for the June planting about fresh root yields. On the other hand, for September planting, the local cultivar produced less at all harvests (17.23, 20.1 and 16.35 t ha^{-1} at 12, 15 and 18 months, respectively) than *98/2132* produced 42.05 and 44.92 t ha^{-1} at 12 and 15 months, respectively and *98/2101* produced 62.9 t ha^{-1} at 18 months. Varieties *97/3200, 97/4763, 97/4769, 98/2132* and *97/4779* produced the highest yields, at all the periods.

The mean cassava yield in tuberous roots increased regularly until the 15 month (40.05 and 43.10 t ha^{-1} at 12 and 15 month, respectively) before falling at 18 months (37.01 t ha^{-1}) for June planting. For September planting, the increase continued until the 18^{th} month (31.38, 34.25 and 37.13 t ha^{-1} at 12, 15 and 18 months, respectively). The yield of the September planting at 18 months was similar to that of the June planting (Table 1).

No improved variety produced dry matter contents in the tuberous roots significantly higher than those observed in the local cultivar. When cassava was planted in

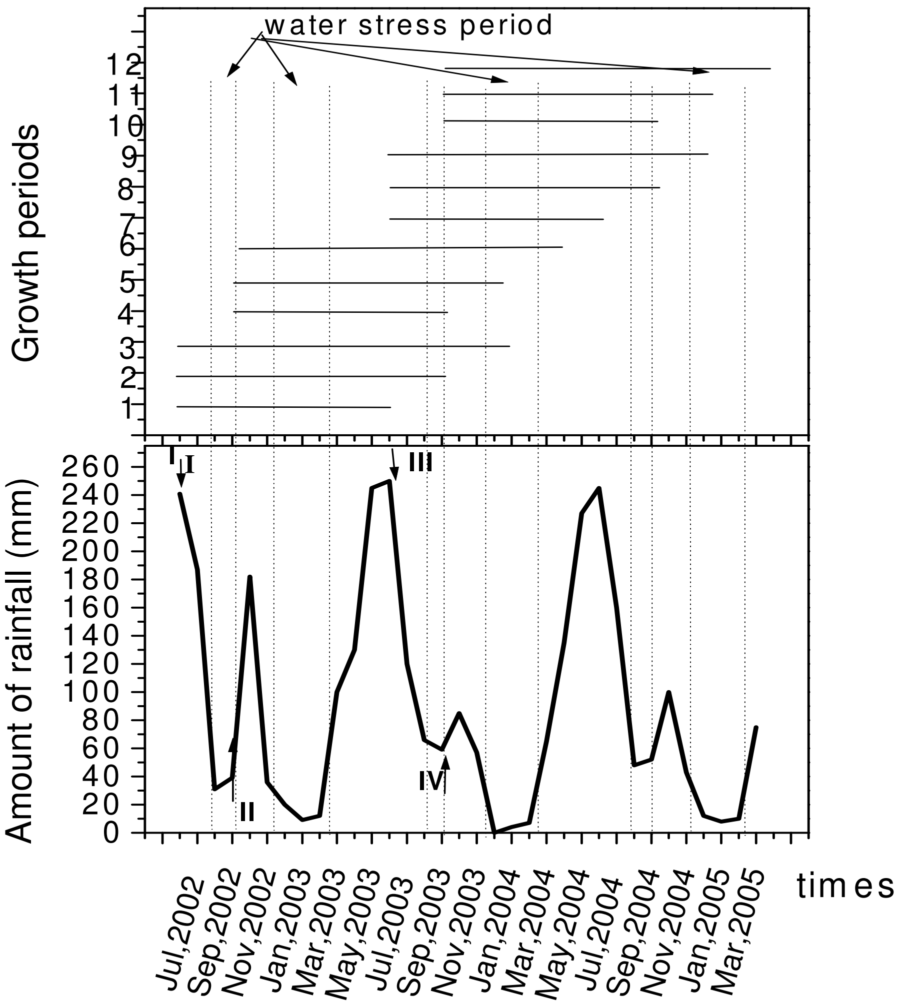

Figure 1. Amount of rainfall during the growth period and harvest time of cassava grown with stress water period. The arrows (I, II, III and IV) indicate the beginning of planting for each crop.

June, the average dry matter rate increased between 12 and 15 months before falling (34.73, 35.43 and 34.02%, at 12, 15 and 18 months respectively). The September planting produced the highest dry matter contents, then this rate regularly decreased (37.32, 35.25 and 33.18% at 12, 15 and 18 months, respectively) (Table 2).

The Table 3 shows the water stress periods during each growth period. The maximum percentage root dry matter (37.32%) was obtained when cassava was planted at the beginning of the small rainy season (September) and roots were harvested in September at 12 months after planting.

The growing period of the plant extended through two rainy seasons separated by a period of comparative drought like a water stress period (Figure 1).

The root dry matter yield increased regularly until the 15th month (13.90 and 15.27 t ha^{-1} at 12 and 15 months, respectively) before falling at 18 months (12.59 t $^{ha-1}$) for June planting. For September planting, the increase continued until the 18th month (11.71, 12.07 and 12.32 t ha^{-1} at 12, 15 and 18 months, respectively).

DISCUSSION

It comes out from this study that old variety (*Anader 2*) is less productive than new improved varieties with September planting. This situation is explained by the fact that the recurring selection applied into IITA, consists in transmitting in new varieties some interest agronomic characters coming beforehand selected parents. June plantings provided root yields higher than those obtained with September plantings. This result is in agreement

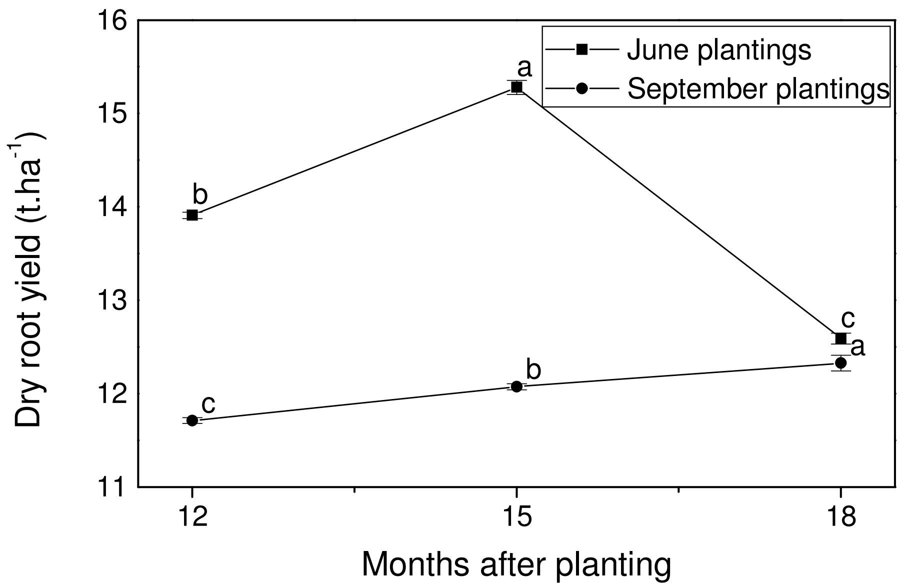

Figure 2. Relation between dry root yield and months after planting in field-grown cassava. Bars = ± SE; Positions on a curve followed by different letters are significantly different at $p < 0.05$.

agreement with the observations according to which the highest fresh roots correspond to planting dates where the total amount of water received is highest (Santisopasri et al., 2001). According to Lal (1980), the excess of ground moisture can unfavourably affect the development of the roots, growths, water consumption and its useful effect. The unfavourable effects are accentuated when the roots development is inhibited by the strong compactness of the ground or its low total porosity.

Concerning fresh roots yields (September planting), the performance of improved varieties, compared to the local variety, may be explained by the capacity of these cultivars to grow under minimal water conditions contrary to the local variety which needs a higher water quantity. The conditions immediately before harvesting the root are important and the effect are demonstrated in root dry matter content and in root dry matter yield. Both root dry matter content and root dry matter yield are highest when the roots are harvested in September at the beginning of the small rainy season. It is obvious that environmental conditions during both the initial and late growth are crucial to root productivity. Percentage root dry matter content is high when the water stress does not exceed one period in the first 6 months. This study confirms the importance of rainfall during cassava growth, especially in the early development stage (Sriroth et al., 1999). The distribution pattern of dry matter among the different organs of cassava plant change markedly during the growth cycle, with shoot having a dominance in the first 3-5 months while storage roots become major sink for photoassimilates during the rest of the growth cycle (El-Sharkawy, 2004) (Figure 2).

It is apparent that water stress affects the root dry matter yield which is low when roots are harvested in December or March. Those two periods are preceded by two months considered like water stress periods. The root dry matter yield is highest with June planting when roots are harvested in September. Before September the two months are not water stress period. That suggests that the root dry matter yield decreases under water stress conditions. This is in agreement with Schulthess et al. (1991) who observed that the effect of drought caused the breaking of apical dominance, leading to lateral shoot formation which use reserves from roots and stems. A high percentage root dry matter in cassava is important because it is positively related to proportion *attiéké* amount (Assanvo et al., 2006). Indeed, *attiéké* is semolina finely granulated obtained starting from the cassava pulp grated, pressed, crumbled, fermented, dried, filtered and dried with fire.

Farmers customarily harvest their cassava piecemeal and later than 1 year in the field. This has been attributed to the absence of post harvest processing and storage facilities, since roots tend to deteriorate a few days after harvest. This study shows that the delay in harvesting after the physiological maturity of the crop may thus be done to take advantage of this additional yield increase. Although cassava can remain in the ground and be harvested progressively with the needs, harvest in only once in 12 months, after a September planting (small rain sea

Table 1. Yield (t ha^{-1}) of cassava storage roots at 12, 15 and 18 months after planting.

Variety	Root yield (t ha-1) of cassava roots of different varieties and harvest times grown					
	Planting time (June 06th)			Planting time (September 12th)		
	Harvest time (months)			Harvest time (months)		
	12	15	18	12	15	18
98/0581	11.95	15.0	13.15	22.0	24.37	27.36
98/2101	28.98	32.03	35.05	34.15	36.52	62.9
98/0505	30.03	33.08	19.95	34.85	37.22	31.33
98/0002	33.73	36.78	16.78	37.9	40.27	27.43
96/1632	34.9	37.95	30.9	32.25	34.62	36.41
97/3200	38.0	41.05	39.88	28.43	31.8	44.2
97/4763	40.28	43.33	42.13	40.15	43.52	62.13
97/0162	40.55	43.55	31.08	21.05	24.42	24.93
TME7	41.58	44.58	33.25	22.85	26.22	25.55
97/4769	48.83	51.83	42.38	39.75	43.12	42.4
ANADER2	51.5	54.6	65.23	17.23	20.1	16.35
98/2132	53.2	56.3	61.9	42.05	44.92	55.25
98/0510	59.23	62.33	44.38	34.63	37.5	34.63
TME419	42.83	45.88	36.1	33.0	35.87	28.38
97/4779	45.2	48.25	43.03	30.43	33.3	37.73
Mean	40.05	43.10	37.01	31.38	34.25	37.15
SE	4.9	6.1	4.2	2.1	2.6	4.3
LSD (5 %)	18.1	15.0	22.5	10.5	15.5	21.0
CV (%)	9.21	8.92	9.01	8.77	9.12	8.8
R2	69.28	68.44	69.99	71.47	70.14	72.09
Mean value	Planting time June 06th	12 MAP*	40.05b	Planting time Sep. 12th	12 MAP*	31.38c
		15 MAP*	43.10a		15 MAP*	34.25b
		18 MAP*	37.01c		18 MAP*	37.15a

Numbers within a column followed by different letters are significantly different at $p < 0.05$. (ANOVA followed by Newman-Keuls's test), SE: Standard Error, CV: Coefficient of Variation, LSD: Least significant difference, R2: Coefficient of détermination, Value for model, *: Months after planting.

son), is much more advantageous when the roots (e.g. *97/4779*) must be transformed into *attiéké*. The great dry season (December) and the great rain season (March-June) are unfavourable to produce dry matter. Indeed, the reduction of the leaf area and the stomata closing slow down the growth rate of plant during the drought periods (Lenis et al., 2006). The leaf area index most favourable for the accumulation of the dry matter ranges between 3 and 5 (Osiru, 1990). When the foliar index exceeds these values, the tubers growth rate drops, in particular in consequence of the shade. The limiting factors to the dry matter accumulation are especially stimulated when the vegetation conditions, in particular the rainfall and the sunning, are not moderated just before the harvest period.

Conclusion

This study showed that, for some varieties, cassava yields continue to increase until 15 months. Most cassava is consumed after processing; some are harvested early and eaten as snack or simply boiled. In some areas, cassava is a cash saving crop and harvested when its market price is high. Cassava needs certain moisture to be established. The late rains from September are generally enough to ensure good dry matter contents during the harvest. The most favourable time with the accumulation of dry matter is obtained during the September harvest. It is apparent that water stress does affect root dry yield, especially if this condition prevails during the two months before harvest. Also, the September planting of

Table 2. Percentage of total dry matter in the storage roots of cassava at 12, 15 and 18 months.

	Dry matter content (%) of cassava roots of differents varieties and harvest times grown					
	Planting time (June 06th)			Planting time (September 12th)		
	Harvest time (months)			Harvest time (months)		
Variety	12	15	18	12	15	18
98/0581	39.5	40.21	36.19	38.77	36.72	36.89
98/2101	35.64	36.35	34.46	34.72	32.67	33.07
98/0505	34.8	35.51	36.1	35.65	33.6	34.83
98/0002	36.52	37.23	37.58	37.62	35.57	35.67
96/1632	36.36	37.07	33.55	33.05	31.0	30.49
97/3200	32.43	33.16	33.23	35.22	33.13	31.31
97/4763	38.82	39.55	36.86	38.11	36.02	33.26
97/0162	28.14	28.87	29.41	34.94	32.85	26.26
TME7	36.64	37.37	34.68	41.38	39.29	36.44
97/4769	31.79	32.52	32.03	36.27	34.18	30.38
ANADER2	36.44	37.16	36.02	39.34	37.27	35.49
98/2132	27.49	28.21	24.91	35.72	33.65	32.6b
98/0510	35.17	35.89	33.26	37.85	35.78	32.78
TME419	38.07	38.79	37.54	39.59	37.52	33.6
97/4779	33.12	33.84	34.48	41.58	39.51	34.63
Mean	34.73	35.45	34.02	37.32	35.25	33.18
SE	1.2	1.02	0.9	0.88	0.71	0.78
LSD (5 %)	3.2	3.0	3.75	2.25	2.5	2.9
CV (%)	10.34	11.99	11.05	10.11	9.99	10.22
R2	86.12	82.17	86.67	85.87	86.8	84.32
Mean value	Planting time June 06th	12 MAP*	34.73b	Planting time Sep. 12th	12 MAP*	37.32a
		15 MAP*	35.45a		15 MAP*	35.25b
		18 MAP*	34.02b		18 MAP*	33.18c

Numbers within a column followed by different letters are significantly different at $p < 0.05$. (ANOVA followed by Newman-Keuls's test), SE: Standard Error, CV: Coefficient of Variation. LSD: Least significant difference, R^2: Coefficient of détermination, Value for model, *: Months after planting.

Table 3. Yields (t ha^{-1}) and dry matter content (%) with water stress during the different growth periods of cassava in 12 experiments.

Values of growth periods	Growth periods (From planting time to harvest time)	Fresh tubers yields (t ha-1) of cassava	Dry matter content (%) of cassava	Water stress periods (MAP)c			
				first	second	third	fourth
1	Pa June 2002-Hb June 2003	40.05	34.73	1-2	5-8	-	-
2	P June 2002-H Sep. 2003	43.1	35.45	1-2	5-8	13-14	-
3	P June 2002-H Dec. 2003	37.01	34.02	1-2	5-8	13-14	17-18
4	P Sep. 2002-H Sep. 2003	31.38	37.32	2-5	10-11	-	-

5	P Sep. 2002-H Dec. 2003	34.25	35.25	2-5	10-11	14-15	-
6	P Sep. 2002-H Mar. 2004	37.15	33.18	2-5	10-11	14-17	-
7	P June 2003-H June 2004	40.04	34.72	1-2	5-8	-	-
8	P June 2003-H Sep. 2004	43.11	35.46	1-2	5-8	13-14	-
9	P June 2003-H Dec 2004	37.02	34.03	1-2	5-8	13-14	17-18
10	P Sep. 2003-H Sep. 2004	31.37	37.33	2-5	10-11	-	-
11	P Sep. 2003-H Dec. 2004	34.26	35.25	2-5	10-11	14-15	-
12	P Sep. 2003-H Mar. 2005	37.2	33.19	2-5	10-11	14-17	-

a: Planting time; b: Harvest time; c: Months after planting.

cassava makes it possible a hasty plant to be harvested or to become ripe before cassava introduction as changing crop, or in association. This short duration of growth could constitute a solution for the regulation of access to resources factors (labour, land).Comprehension by the farmers of the various periods will make it possible to solve the problems of lack of fertile grounds, of lack labour and weakness of dry matter contents, for the tubers intended to the transformation. This is a solution to the shortage labour in villages following the rural migration and to the concerns of the industrialists, like the high dry matter rate within the cassava variety. Most investigation needs to be carried out to determine the exact role of the soil environment.

ACKNOWLEDGEMENTS

This study was financed mainly by Nestle R and D Center and the Swiss Research Co-operation (SRC). Technical support was provided by the Swiss Centre for Scientific Research (CSRS, Côte d'Ivoire) and the University of Cocody (Côte d'Ivoire). We specially thank our colleagues (P. Ilona and AGO Dixon) at International Institute of Tropical Agriculture (IITA) for sending cassava cuttings. We also thank Dr Monsan Vincent (University of Cocody) for the statistical analysis and Dr Tschannen Andres for valuable critical remarks.

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