Performance and Dry Matter Distribution of Cassava at Different Ages and Ecological Conditions in Ivory Coast

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Abstract

The performance of three cassava varieties was studied at four harvesting periods, at 6, 9, 12 and 15 months after planting, in four locations in Ivory Coast. Important differences between locations were found concerning plant height, flowering habit, mosaic virus attack, number and diameter of storage roots, dry weight of plant parts and its distribution. Emphasis was given to dry matter distribution, adopting a model developed by Boerboom (1978). ESRP (efficiency of storage root production) and ISS (initial plant weight at which storage root production starts) were determined for the different situations. Varietal differences of ESRP and ISS values were maintained in the different locations, but ISS values were much more dependent on location than ESRP values. In fact ISS proved to be an important factor in dry matter distribution. It is recommended that for varietal selection, a combination of ISS and ESRP is preferable to use than harvest index, which is always biased by ISS.

Introduction

Studying cassava toxicity in Ivory Coast (De Bruijn, 1971), data on different plant characteristics were collected from the sample plants. Thus in an experiment in which the development of HCN content of aged storage roots was studied in four sites of Ivory Coast. Data were obtained on plant height; height of first branching due to flowering; mosaic virus attack; number, length and maximum diameter of storage roots dry weight of leaves, stems and storage roots. Additionally, harvest index was calculated

Discussion on the dry matter distribution will get special emphasis, in relation with a recent publication of Boerboom (1978) who demonstrated that, once storage in cassava roots has started, a more or less fixed part of dry matter increase is stored in the roots.

Materials and Methods

The experiment was carried out in the following locations: Adiopodoume (5.6°N, Bouake (7.6°N), Ferkessedougou (9.6°N) and Man (7.3°N). Some climatic data are given in table 1 and data on soil fertility are given in table 2. More detailed data are given in the thesis on cyanogenesis (De Bruijn, 1971).

The experiment was done with three varieties: Ta 25, 461 and Tabouca. The design was similar in the different sites. There were 15 blocks, with each block subdivided in three plots, one for each variety (split-plot). There were 25 plants in each plot, 4 plants of which were to be harvested, the rest being border plants. Planting was done at the beginning for the rainy season in June 1966, with intervals of one or two days between the different sites. The planting material originated from Adiopodoume and was completely comparable for the different sites as far as motherplants and position of cuttings on the motherplants are concerned. Length of the cuttings was 25cm and the diameter was about 23cm. Cuttings were planted at a 45° angle, at a planting distance of 1.0 x 1.5 m.

Harvesting was done at 6, 9, 12 and 15 months after planting. One plant per variety was harvested, in each of block or a total of 15 plants.

All data are expressed in current units, except those on mosaic virus attack, for which a scale from 0 to 5 was used:

1 : no symptoms at all
1 : very light attack, some spots on some leaves
2 : light attack, some spots on many leaves
3 : heavy attack but few leaf distortions
4 : heavy attack with distortion of many leaves
5 : very heavy attack with serious deformation of all leaves and heavy reduction of leaf area.

Dry matter distribution was considered adopting the model developed by Boerboom (1978), Figure 1 shows a diagram of the model. The parameters ESRP, (efficiency of the storage root production of the plant) and ISS (initial plant dry weight at which storage production starts) were calculated from the linear regression of dry weight of storage root on total plant dry weight over the four sampling periods.

Results and Discussion

Different plant characteristics. Table 3 present data, averaged over the 15 blocks, for different plant characteristics of the different harvesting periods for the three varieties in the four locations. The parameters will be dealt with one by one.

Plant height. Most striking is the very big size of the plants of all three varieties in Man, probably due to the relatively fertile soil with a high organic matter content in that location.

Plant height at flowering. The height of the first branching (forking) of the stem due to onset of flowering reflects the earlyness of flowering. Actual data on first flowering were not taken. Variety Ta 25 seems to be the first one to flower in three of the four locations. The flowering behavior at Ferkessedougou is difficult to explain. Variety Ta 25 does not flower at all and in Tabouca only one of the 15 plants was branched in each of the sampling periods. Though De Bruijn (1977) found an indication that some cassava varieties needed a day length of more than 12 hours for flowering, the present results cannot be explained by such a day length effect, as Ferkessedougou is the most northern location. Temperature interactions might have been decisive. As shown in table 1 the most important climatic differences between Ferkesesdougou and the other locations are in total radiation, average maximum temperature and potential evapotranspiration. In addition, this location has the most severe dry season.

Mosaic virus attack. Besides the normal differences in susceptibility to virus between varieties there are also differences between locations and between plants of different age. Adiopodoume and Man show the highest scores and Ferkessedougou and Bouake the lowest. As a general feature, it can be seen that at the age of 9 months, which coincides with end the of the dry season, virus symptoms are fewest.

Number of storage roots. The data show that the number of storage roots is slightly but significantly increasing with time. The most important increase is taking place between 12 and 15 months, coinciding with the rainy season. Up to 12 months the increase is very limited and for that period the results are in agreement with data of other authors showing that the storage root number is generally determined early in the growth cycle (Hunt *et al.*, 1977). There is also a significant effect of location and varieties. Most striking is the very low number of storage roots in Adiopodoume, as compared to the other locations. The reasons for this are not clear.

Length of storage roots. The data indicate that the length of storage roots is rather stable with time. There is also no significant difference between the varieties. As to the locations, Adiopodoume is showing highest values for all three varieties. The location effect was significant at the $P = 0.10$ level. It should be noted that in Ferkessedougou, because of the very hard soil, roots easily broke during harvest and in some cases at the last harvest period not all roots were harvested completely, thus some data are lower than they sould be.

Maximum diameter of storage roots. Significant differences were found between locations, between varieties and, self-evidently, between ages. As during carbohydrate bulking the number of storage roots only slightly increases and the length of the roots hardly shows an increase. Weight increase of the roots during growth is mainly reflected by their steady thickening. The average diameter per variety is not much different in three of the four locations, but in Adiopodoume storage roots are much thicker than elsewhere, thus compensating for the low number of roots in that location.

Dry weight of leaves. Leaf weight is different between varieties and varies with age of the plant. In most cases leaf weight is highest at the 6-month harvest and lowest at the 9-month harvest, which coincides with the end of the dry season. But in Bouake highest leaf weight is found just at the end of the dry season, which is rather surprising. The reason is not clear. In most cases, leaf weight is highest in variety 461 and lowest in Tabouca.

Dry weight of stems. The data show that the increase in weight was lowest between 9 and 12 months, which period coincides with the end of the dry season and the beginning of the rains (Table 1). But Bouake is an exception, highest increase takes place just in that period. The reasons are not clear. Highest stem weight was obtained in Man, probably because of the relatively fertile soil and high nitrogen level. Lowest stem weight was obtained at Ferkessedougou. The relatively very high insolation at Ferkessedougou a factor in which this location strongly differs from the others (Table 1) may have had a represseive effect on stem growth.

Dry weight of storage roots. The data show a rather complex picture of dry weight development in the storage roots. The dry weight build up of the varieties is not the same; there are also differences between locations. In all locations there is an important increase between 12 and 15 months, but in Bouake and Man, between 9 and 12 months. Root yield was significantly different between the varieties, but the difference between locations was only significant at the $P = 0.10$ level.

As mentioned earlier (3.1.5) some data from Ferkessedougou may be too low due to the hard soil which hampered proper harvesting.

Root dry weight will be considered further in the section on dry matter distribution (3.2)

Harvest index (HI). The data show significant differences between varieties, very low values being scored by 461. There is also a significant difference between locations; the relatively high values at Ferkessedougou are most striking, but the differences between the other locations are not very important.

The HI is increasing with age of the plant. This is a normal feature in cassava, but within the concept of the model developed by Boerboom (1978) this increase is only from mathematical origin.

Some values at Ferkessedougou may be too low due to incomplete harvesting of the roots, as explained earlier.

Dry matter distribution. The linear relationship between dry weight of storage roots and total plant dry weight over the four harvest periods was examined for all varieties in the different locations. Table 4 presents the various regression coefficients (= ESRP), with standard errors, and the intercepts of the regression lines with the x-axis (= ISS), with standard errors. The r^2 values are given as well. The data indicate a strong linear relationship between root dry weight and total dry weight, which shows that the model of Boerboom is also valid for the present data.

For two varieties in Ferkessedougou the ISS values are negative. This is impossible in practice. In these cases the regression coefficients (ESRP) are rather low, even lower than the corresponding harvest index, which is also impossible in practice. The reason could be that the regression line is not really a linear one or that the error variance is too high. But more likely, the negative values are due to incomplete harvesting of the storage roots which has occurred during the last harvest period, as mentioned before (3.1.5) Thus there is reason to assume that the ESRP values in these cases are underestimated. The ISS values should of course be positive. Though their true value is not to estimate there is a strong indication that the ISS values must be rather low because of the relatively high harvest index which was found at the early harvest periods (table 3). The harvest index at early harvesting cannot be high if the ISS value is high, as is demonstrated in Gif. 2. Moreover ISS of the third variety (Tabouca) is also low in that locations.

In Table 5 the ESRP and ISS values have been grouped together. The data indicate that the ESRP is rather stable in the different lcoations. Differences between varieties are more pronounced. Tabouca has the highest and 461 the lowest ESRP in all locations.

Though ESRP values are rather uniform in the different locations, the ISS values are not. Bulking in storage roots appears to start very early in Ferkessedougou and very late in Man. But also the varieties behave differently. Ta 25 starts tuberization earliest and Tabouca latest.

Thus, the data indicate that regarding ESRP there is not much difference between locations, but a pronounced difference between varieties. ISS is varying both between locations and between varieties. We have tried to test the statistical significance of the indications. For this the actual data were compared to models based on different restrictive assumptions, as indicated in table 6. For the models 2 to 5 the error variance was compared to the error variance of model 1 and the F-value calculated. A low F-value would mean that the assumptions of the model are acceptable and a high value means that the assumptions should be rejected.

From this approach the following indications can be obtained:

- ESRP does not vary significantly between locations (Model 2)
- There is no interaction between varieties and locations for ISS (Model 2a)
- ESRP is different for the different varieties (Model 3)
- ISS is different for the different locations (combination model 2 and model 4)
- ESRP is different for the different varieties (combination model 2 and model 5)
- From the co-variance analysis in model 5 it was found that ISS is also different for the different varieties.

In fact, most of these indications are in agreement with earlier mentioned visual evidence obtained from Table 5. Nevertheless, one restriction to the followed statistical approach should be mentioned. In fact, it appeared that the error variance of the linear regression between root weight and total plant weight was high and variable, thus hardly allowing a combined analysis for the data. The reason for this is not quite clear. Especially Man and Bouake which showed high error variances, but in these locations dry matter production was higher than in the other two locations.

The data we obtained on ISS indicate that this parameter is an important factor in cassava dry matter distribution as it is very dependent on both variety and ecological conditions. The rather stable varietal differences in the locations indicate that ISS is under genetic control, thus could be used as a selection trait. As to the ecological conditions it is difficult to distill from the present data which factors are contributing to the variation. Total radiation may have an influence.

The data indicate that as a selection criterium a combination of ISS and ESRP is preferable to harvest index. HI is always biased and in fact it is dependent on ISS and ESRP. This is clearly illustrated in figure 2, which shows ISS, ESRP and development of HI as a function of total plant weight increase, taking variety Tabouca as an example. HI is calculated from ISS and ESRP using the formula:

$$HI = ESRP\ \left(1 - \frac{ISS}{x}\right)$$

where x represents total plant weight. In case ISS has a low value, HI very rapidly increases and soon approaches the horizontal line corresponding with the ESRP value. Thus, the lower ISS, the lower the deviation of HI from ESRP.

It should be noted however, that also our ISS and ESRP values are biased because the total dry matter data we used do not include the weight of fallen leaves. If these would have been included ESRP values would become lower, and ISS values higher in most cases. But we did not collect these data. Nevertheless, the model works even without inclusion of dropped leaves. This could be an indication that, at least after the onset of tuberization, there is a linear relationship between increase of leaf dry weight and increase of the real total dry weight. This sould be checked.

Conclusion

Apart from some interesting differences between locations in plant performance, such as plant size and root number, the main results concern the dry matter distribution. The pattern of dry matter distribution in our experiment is in agreement with the model of Boerboom (1978), and confirms the importance of the contribution of that study.

Our results indicate that ESRP values are rather stable at the different locations and the differences between the three varieties are maintained in the different locations. The results clearly show the importance of the moment of onset of tuberization, (ISS) a factor which is not only dependent on variety but also varies largely with ecological conditions.

Finally, considering our results, the desirability put forward by Boerboom (1978) of using ISS and ESRP as selection traits rather than the biased harvest index, should be supported. Both ISS and ESRP can be determined rather early during growth and once they are known HI can easily be claculated if desired.

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Table 1. Climatic data from Adiopodoume´(A), Bouaké(B), Ferkéssedougou (F) and Man (M). Average annual values of 10 years (1959-1968) (I). For rainfall and insolation, in addition, totals over experimental period (II). (De Bruijn, 1971)

	A	B	F	M
I. Annual averages (10 years)				
Average temperature (°C)	26.6	25.6	26.9	25.0
Average maximum temperature	29.3	30.3	33.3	30.3
Average minimum temperature	23.3	20.9	20.5	19.6
Total rainfal (mm)	2179	1152	1350	1714
Total insolation (hours)	2086	1855	2751	1914
Relative humidity (%)	85	75	68	80
Potential evapotranspiration (mm)	1320	1478	1847	1502
II. Totals during experiment (16 months)				
Rainfall (mm)	2627	1821	1990	2912
Isolation (hours)	2423	2338	3542	1928

Table 2. Chemical properties of the soil (0-20 cm) of the experimental field in the four regions (average over 5 sampling periods (De Bruijn, 1971)

	Adiopodoumé	Bouaké	Ferkéssédougou	Man
Organic matter (%)	1.70	2.63	2.04	3.99
Carbon (%)	0.98	1.52	1.18	2.31
Nitrogen (%)	0.08	0.10	0.08	0.18
C/N	12.9	15.1	15.9	12.6
P_2O_5 total (%)	0.050	0.042	0.038	0.059
Absorption complex (meq %)				
Ca	1.01	1.76	2.32	4.35
Mg	0.46	0.95	1.40	0.91
K	0.03	0.17	0.20	0.14
Na	0.03	0.03	0.02	0.02
CEC	4.90	9.78	6.73	11.89
pH (H_2O)	5.4	5.2	6.2	5.4

Table 3. Data for different plant characteristics in Adiopodoumé (A), Bouake (B), Ferkessedougou (F), and Man (M) at 6, 9, 12 and 15 months after planting for varieties Ta 25, 461 and Tabouca

	6	9	12	15	Av.	6	9	12	15	Av.	6	9	12	15	Av.
PLANT HEIGHT (cm)															
A	162	196	215	231	201	204	260	270	253	247	204	291	291	308	274
B	189	188	230	261	217	221	225	257	273	244	230	240	280	295	261
F	151	189	248	288	219	187	208	240	252	222	164	217	275	297	238
M	267	280	310	327	296	309	337	328	345	330	343	369	385	398	374
Av.	192	213	251	277		230	258	274	281		235	279	308	325	

Statistical significance †) L** V** A** AL** AV**

	6	9	12	15	Av.	6	9	12	15	Av.	6	9	12	15	Av.
PLANT HEIGHT AT FIRST BRANCHING (cm)															
A	43	54	52	55	51	131	123	132	130	129	137	124	152	157	143
B	73	65	66	68	68	151	133	127	141	138	154	150	177	163	161
F	–	–	–	–	–	133	120	129	109	123	145+	140+	125+	105+	129+
M	172	132	146	149	150	259	226	220	224	232	291	292	245	269	274
Av.	96	84	88	91		169	151	152	151		194	189	191	196	

\+ only one of the 15 plants

	6	9	12	15	Av.	6	9	12	15	Av.	6	9	12	15	Av.
MOSAIC VIRUS ATTACK (scale 0-5)															
A	2.2	1.1	1.4	1.6	1.6	2.2	1.3	1.7	2.1	1.8	2.7	2.6	2.8	2.7	2.7
B	1.4	1.2	1.3	1.1	1.3	1.7	1.2	1.7	0.9	1.2	2.5	1.7	2.4	2.5	2.3
F	1.1	0.6	0.9	0.9	0.9	2.4	0.6	1.2	1.2	1.4	1.8	1.4	1.9	2.5	1.9
M	2.0	0.9	1.3	1.7	1.5	2.4	1.0	1.6	1.7	1.8	2.9	1.7	2.5	2.4	2.4
Av.	1.7	1.0	1.2	1.3		2.2	1.0	1.6	1.5		2.5	1.9	2.4	2.5	

L** C** A** AL: ns AV: ns

Table 3 (continued)

NUMBER OF STORAGE ROOTS

A	4.3	5.2	5.1	4.5	4.7	2.7	4.0	3.0	5.5	3.8	4.0	4.4	3.7	4.3	4.1
B	7.0	8.5	8.1	8.7	8.1	6.1	5.6	6.5	6.2	6.1	7.0	6.1	6.7	8.1	7.0
F	9.3	8.4	9.1	9.3	9.0	8.1	7.6	7.1	9.5	8.1	7.8	7.0	7.2	9.1	7.8
M	9.9	8.6	10.8	10.4	9.9	6.5	8.2	9.8	9.7	8.6	7.2	8.8	9.6	8.1	8.4
Av.	7.6	7.7	8.3	8.2		5.9	6.4	6.6	7.7		6.5	6.6	6.8	7.4	
					L**		V**		A**	AL: ns			AV: ns		

†) For statistical significance: L = Locations; V = Varieties; A = Age at harvest; AL and AV corresponding interactions. Sign. levels: *: P = 0.05 **: P = 0.01 ns: not significant at P = 0.05

LENGHT OF STORAGE ROOTS(cm)

A	32	32	28	36	32	30	29	35	29	31	27	25	30	28	28
B	30	28	30	32	30	25	23	23	24	24	24	26	27	27	26
F	25	26	27	24	26	29	25	29	25	27	21	21	22	23	22
M	25	26	25	27	26	21	18	22	25	22	26	24	23	29	26
Av.	28	28	28	30		26	24	27	26		25	24	26	27	
					L: ns		V: ns		A: ns		AL: ns		AV: ns		

MAXIMUM DIAMETER OF STORAGE ROOTS (mm)

A	45	57	70	82	64	33	41	57	55	47	36	47	62	65	53
B	35	39	51	58	46	28	30	37	44	35	29	38	46	51	41
F	40	46	52	57	49	30	33	35	39	34	33	37	43	51	41
M	35	41	48	56	45	31	31	37	48	37	34	35	49	58	44
Av.	39	46	55	63		31	34	42	47		33	39	50	56	
					L**		V**		A**		AL**		AV*		

table 3 (continued)

DRY WEIGHT OF LEAVES (g/plant)

A	162	74	98	98	108	222	150	192	187	188	155	76	76	75	96
B	84	172	139	128	131	137	170	191	92	148	83	126	72	58	85
F	116	68	93	136	104	140	106	175	189	152	78	57	57	62	64
M	219	52	99	127	124	283	116	214	177	198	201	67	111	79	115
Av	146	92	107	122		196	136	193	161		129	82	79	69	

L:ns V** A** AL** AV**

DRY WEIGHT OF STEMS (g/plant)

A	375	910	771	1030	772	504	1008	1023	1454	997	506	780	887	1039	803
B	524	613	1135	1417	922	608	734	1227	1408	994	592	775	1003	1156	882
F	349	346	498	746	485	459	547	708	832	637	311	376	468	662	454
M	748	1211	1185	1597	1185	840	1354	1560	1929	1421	974	1427	1396	1536	1333
Av.	499	770	897	1198		603	911	1130	1406		596	840	939	1098	

L** V** A** AL** AV*

DRY WEIGHT OF STORAGE ROOTS (g/plant)

A	517	1185	975	1454	1033	222	553	692	1116	646	454	772	1019	1315	890
B	645	777	1369	2242	1258	379	329	716	1033	614	458	549	1125	1705	959
F	864	977	1166	1430	1109	874	654	625	933	697	478	601	781	1372	808
M	699	970	1142	1921	1183	385	445	911	1681	856	587	837	1517	2194	1284
Av.	681	977	1163	1762		390	495	736	1191		494	690	1111	1647	

L: na V** A** AL** AV: ns

HARVEST INDEX (storage root weight/total plant weight) x 100

A	49	55	53	56	53	23	32	36	40	33	41	48	51	54	49
B	51	50	52	59	53	34	27	34	41	34	40	38	51	58	47
F	65	70	66	62	66	49	50	41	48	47	55	58	60	65	60
M	42	43	47	53	46	26	23	34	44	32	33	36	50	58	44
Av.	52	55	55	58		33	33	36	43		42	45	53	59	

L** V** A** AL** AV**

Table 4. ESRP values and ISS values with standard errors, for the three varieties in the four locations, over four sampling periods

Location	Variety	ESRP	ISS	r^2
Adiopodoumé	Ta 25	0.611 ± 0.014	223 ± 42	1.00
	461	0.497 ± 0.021	532 ± 64	1.00
	Tabouca	0.658 ± 0.011	435 ± 24	1.00
Bouaké	Ta 25	0.629 ± 0.044	312 ± 167	0.99
	461	0.466 ± 0.070	438 ± 253	0.96
	Tabouca	0.719 ± 0.054	592 ± 122	0.99
Ferkéssédougou	Ta 25	0.543 ± 0.058	-345 ± 247	0.98
	461	0.444 ± 0.114	- 84 ± 550	0.88
	Tabouca	0.727 ± 0.011	215 ± 19	1.00
Man	Ta 25	0.628 ± 0.031	609 ± 103	1.00
	461	0.590 ± 0.063	1025 ± 198	0.98
	Tabouca	0.811 ± 0.072	1149 ± 170	0.99

Table 5. Efficiency of storage root production (ESRP) values and initial plant weight (g) at which storage root production starts (ISS) for the 3 cultivars and the 4 locations

	ESRP Values					ISS Values				
Varieties	Locations					Locations				
	A	B	F	M	Av.	A	B	F	M	Av.
Ta 25	0.611	0.629	0.543	0.628	0.603	223	312	-345	609	200
461	0.497	0.466	0.444	0.590	0.499	532	438	-84	1025	478
Tabouca	0.658	0.719	0.727	0.811	0.729	435	592	215	1149	598
Average	0.589	0.605	0.571	0.676		397	447	-71	928	

Table 6. Testing of different assumptions concerning ESRP and ISS by comparing the actual situation (model 1) with a number of restrictive models

	Assumptions	Calculated F-value	Conclusion
Model 1	No assumptions (actual situation)	–	–
Model 2	ESRP uniform for locations	$F^{9}_{24} = 1.09$	Model acceptable
Model 2A	As 2, but no interaction between varieties and locations assumed for ISS	$F^{15}_{24} = 1.19$	Model acceptable
Model 3	ESRP uniform for varieties	$F^{8}_{24} = 4.57^{**}$	Model rejected
Model 4	ESRP and ISS uniform for locations	$F^{18}_{24} = 11.93^{**}$	Model rejected
Model 5	ESRP uniform for varieties and locations	$F^{11}_{24} = 3.84^{**}$	Model rejected

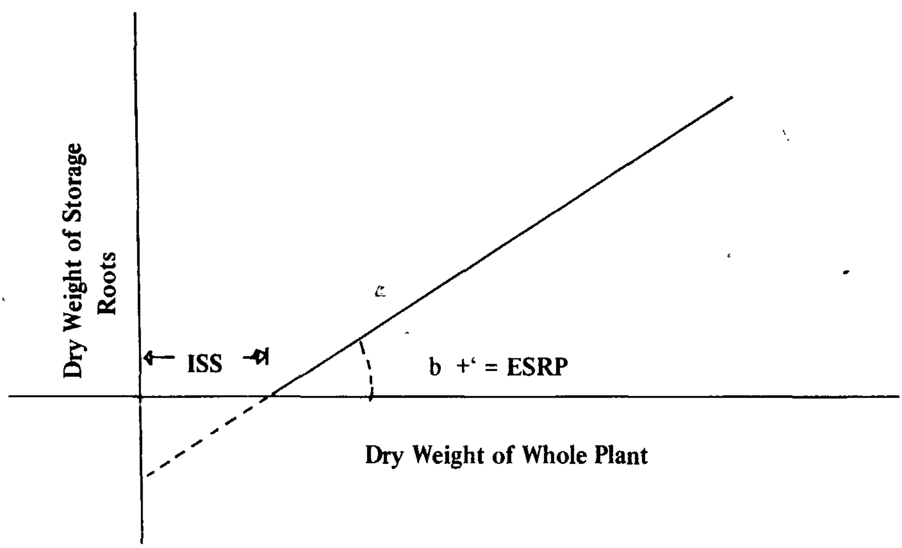

Figure 1. Model of the relationship between dry weight of whole plant (x) and dry weight of storage roots (y), being a linear regression. The regression coefficient b indicates the efficiency of storage root production (ESRP). ISS = initial plant weight at which storage root production starts. After Boerboom (1978).

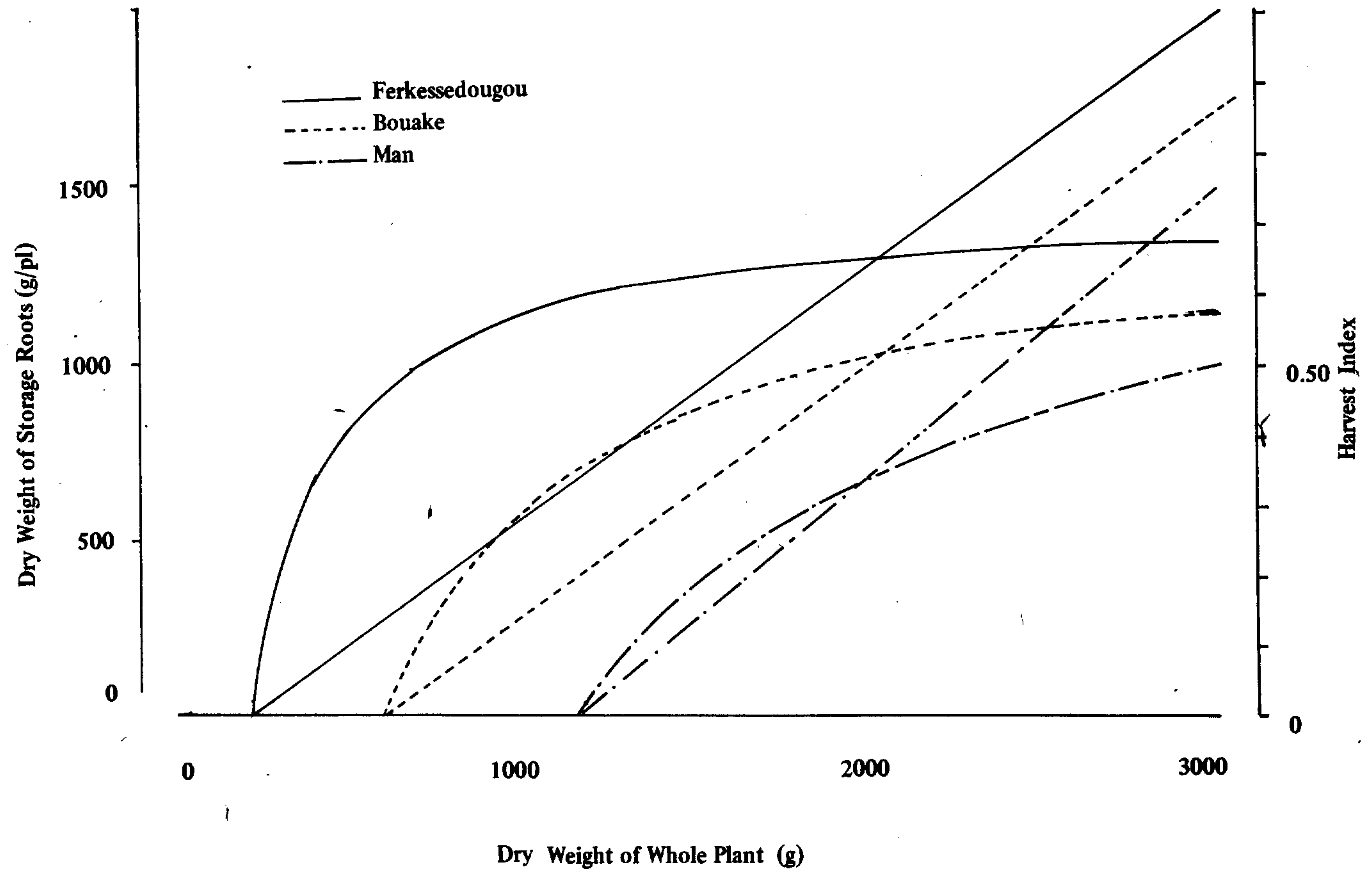

Figure 2. Regression lines of root dry weight on total dry weight and development of corresponding harvest index (curved lines), of variety Tabouca in Ferkessedougou, Bouake and Man. (Adiopodoume has been left out because the lines almost overlap those of Bouake).