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~~Reading~~ Materials for the Intensive Course on

RESEARCH FOR CASSAVA PRODUCTION 1978

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BOOK I

(The articles herein are rendered in the version as received from the authors)

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C O N T E N T S

BOOK I

CURRENT UTILIZATION AND FUTURE POTENTIAL FOR CASSAVA [1]

Barry Nestel *

The purpose of this introductory paper is to present an overview of the role that cassava plays in the world today and then to explore the future potential for this commodity. Some of the data and ideas brought out in the paper will suggest that the use of cassava as both human and animal food is likely to increase in future years. Bearing in mind the fact that chronic toxicity in humans and animals on high cassava diets is already a well recognized problem. It would appear that unless effective steps can be taken to reduce this toxicity it could become a problem of increasing significance in the future. Apart from the nutritional implications of this, it appears possible that toxicity could also play an important role economically in, perhaps, retarding the development of new markets for cassava both domestically and overseas.

PRODUCTION

Although production statistics for cassava are notoriously unreliable, the best available evidence indicates that, on a tonnage basis, annual world production is only exceeded by that of six other crops (Table 1).

Cassava is produced in more than 80 countries, but two thirds of world production takes place in only five of them (Brazil, Indonesia, Zaire, Nigeria, and India) and 90% of global production comes from 19 countries (Table 2: Fig.1).

In producing countries, production has grown steadily at about the same rate as the population increase during the past 20 years. Most of the increase in production appears to be due to an increased area under the crop since only limited changes in yield have been reported. There is, however, a wide range of variation in yields, with a global average of 9.4 tons/ha. A number of countries, especially in Africa, have average yields of less than half this figure whereas others report averages exceeding 20 tons/ha.

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1 Reprinted from Chronic Cassava Toxicity. Edited by: Barry Nestel and Reginald MacIntyre. IDRC-010e.

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Under experimental conditions, yields of more than 70 tons/ha have been taken in a 12-month period in spite of the fact that cassava has, as yet, received relatively little attention from agricultural scientists. Although there are major difficulties in bringing about yield and quality improvements in this species, the potential at least for yield improvements does appear to be considerably greater than that of many plant species that have been subjected to intensive study for many years.

TABLE 1. World production, acreage, and yield of selected crops, 1971 (source: FAO Production Yearbook 1971)

	World hectarage (million ha)	World yield (100 kg/ha)	World production (million metric tons)
Cereal grams			
Wheat	217.2	15.8	343.1
Rice (paddy)	134.9	22.8	307.4
Maize	112.9	27.3	307.8
Millet and sorghum	113.4	8.9	101.1
Barley	82.2	18.5	152.7
Oats	31.2	18.5	57.7
Rye	19.7	15.7	30.9
Root crops			
Potatoes	22.5	136.0	306.4
Sweet potatoes and yams[a]	17.0	87.0	147.7
Cassava[a]	9.8	94.0	92.2
Sugar beets	7.6	29.9	228.2
Legumes (pulses)			
Soybeans	36.2	13.3	48.3
Pigeon peas	2.9	6.8	2.0
Dry beans	22.9	5.1	11.7
Peanuts	18.8	9.8	18.5
Chick-peas	10.2	6.6	6.7
Cowpeas	3.1	3.7	1.1
Dry broad beans	4.7	11.2	5.2
Dry peas	9.0	12.2	10.9

[a] 1970 data.

Cassava is generally grown as a subsistence crop. It is particulary valued because of its drought tolerance, its ability to grow in poor soils, and its relative resistance to weeds and insect pests. These characteristics, plus the fact that it can be left in the ground without harvesting for a lengthy period of time, mean that it is a very useful crop as a security against famine. Furthermore, it is not season bound and can, therefore, be planted and harvested at any period of the year. For these reasons cassava is obviously an attractive crop for the subsistence farmer for whom risk aversion must, of necessity, be an important value objective. Indeed for such a farmer, the security of being able to harvest a crop in adverse times may be more important than the disire to harvest a higher yield, although as development brings subsistence producers into a market economy the production of marketable surpluses can be expected to assume increasing importance.

Cassava also possesses certain characteristics which make it of particular interest to the biologist and to the economist concerned with resource development in tropical areas. First and foremost of these is the fact that cassava productivity in terms of calories per unit land area per unit of time appears to be significantly higher than that of other staple food crops (de Vries et al. 1967).

Coursey and Haynes (1970) indicated that cassava can produce 250 $X 10^3$ cal/ha per day as compared to 176 $X 10^3$ for rice, 110 $X 10^3$ for wheat, 200 $X 10^3$ for maize, and 114 $X 10^3$ for sorghum. They also point out that the grain crops have been subjected to considerable research to improve their genetic potential, whereas cassava offers considerable scope for genetic improvement. Corusey and Haynes also indicate that root crops have a higher biological efficiency as food producers. They attribute this efficiency to structural engineering considerations since the edible part of tuberous roots lies beneath the ground and does not have to be supported by a stem. In fact 60-85 of the total dry weight of root crops may be edible whereas in wheat the figure is only up to 36%

TABLE 2. World production of cassava in 1970 (source: FAO Production Yearbook 1971).

	Million tons	%world. Production
Brazil	29.5	32.6
Indonesia	10.5	11.4
Zaire	10.0	10.9
Nigeria	7.3	7.9
India	5.2	5.6
		67.9
Mozambique	2.1	2.4
Uganda	2.0	2.2
Thailand	2.0	2.2
Paraguay	1.8	2.0
Burundi	1.6	1.7
Ghana	1.6	1.7
Angola	1.6	1.7
Tanzania	1.5	1.6
Madagascar	1.2	1.3
Togo	1.2	1.3
Colombia	1.2	1.3
Central African Republic	1.0	1.1
		20.4

Cameroon	0.9	1.0
Dahomey	0.7	0.8
North Vietnam	0.7	0.8
Ivory Coast	0.5	0.6
Guinea	0.5	0.6
Peru	0.5	0.6
		4.1
63 Other Countries	7.1	7.7
	92.2	100.0

In order to utilize the biological efficiency of cassava and to develop the crop, uses for it have to be found. Furthermore, it has to be produced at a price at which these uses are economic. Utilization prospects appear to vary widely between different countries. Thus the Thai farmer who grows most of the cassava which reaches the world market obtains U.S.$11-12 for the farm-dried chips from a ton of fresh cassava whereas for fresh cassava for human use, the Jamaican farmer obtains 2-4 times this price (Rankine and Houng 1971) and at certain times of year, the Colombian farmer may obtain 6-10 times the Thai price (P. Pinstrup Andersen, CIAT, personal communication). However, generally speaking the farm price seems to lie in the range of U.S. $10-15 ton of fresh root equivalent.

It is difficult to cost cassava production since the main inputs are family labour and land, and in subsistence farming areas, the land is often communally owned. Brannen (1972) reviewed some of the literature on production costs and found that the usual cost of producing cassava was about U.S. $6/ton. The major production cost was labour. For a variety of reasons, it is difficult to compare the various labour costings available, but in various surveys the man-hours used to produce a ton of cassava appeared to range from 50 to 200 and to average about 100 (Brannen 1972; Rankine and Houng 1971; Raeburn et al, 1950). Obviously the return to labour from cassava production is very low, notwithstanding the fact that Raeburn et al. found the yield per man-day from cassava production exceeded that of other tropical staples. Clarke and Haswell (1964) reported a similar finding when comparing both the output value and the labour productivity of various tropical crops in terms of FAO standard wheat equivalents.

The low return to labour relates to the fact that the opportunity cost of labour in many subsistence areas is often regarded as being close to zero, otherwise a production cost per ton of U.S. $6 would not be possible. However we may anticipate that some mechanization may be necessary in the future since, as economies develop, labour generally tends to demand a higher return, especially for an unpleasant job such as harvesting cassava (which commonly accounts for 25-30% of the total labour costs). For this reasons production costs may be expected to rise. Against this it must be taken into account that subsistence

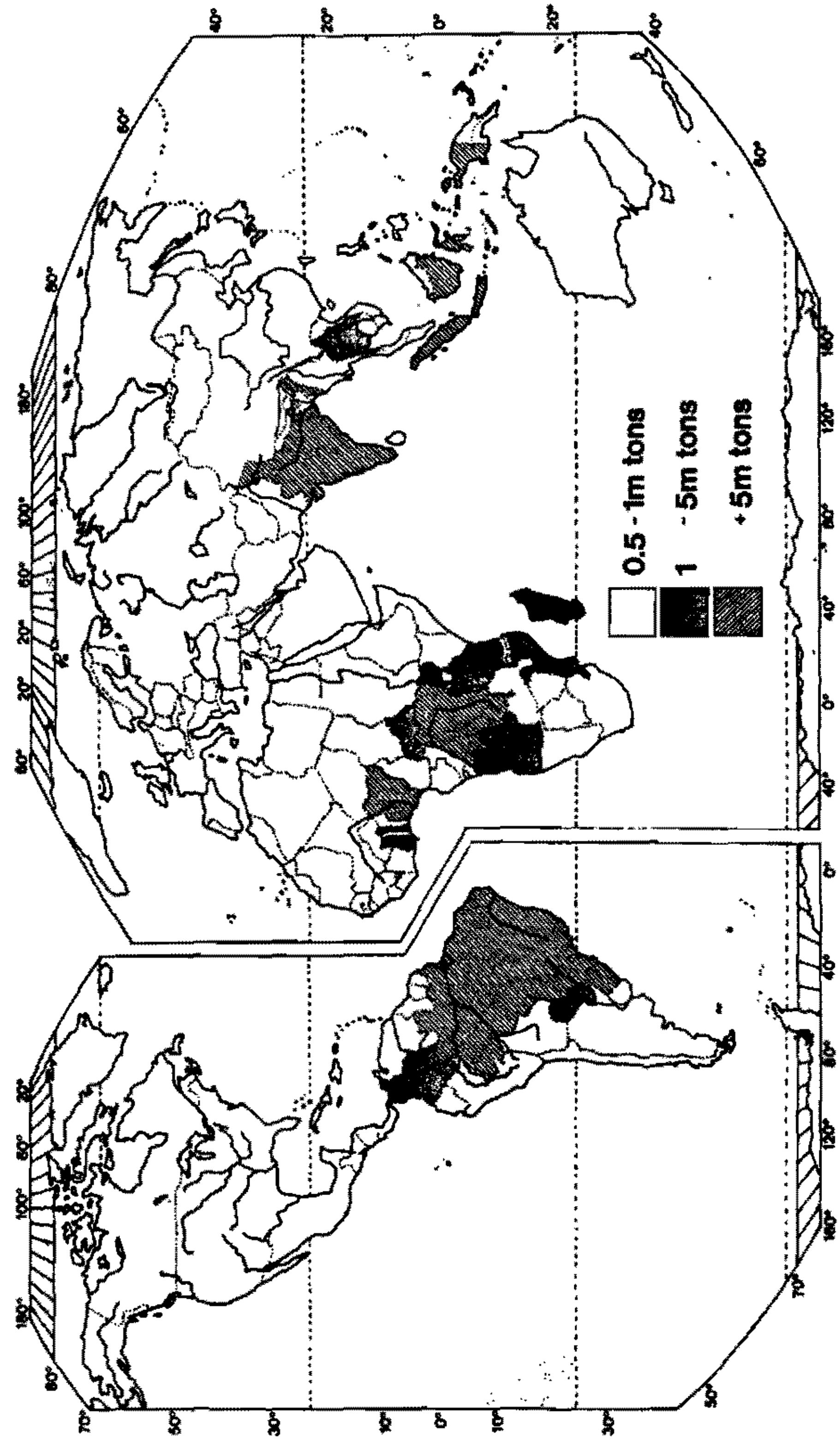

FIG. 1. World cassava production in 1970.

yields are often only about 10% of the production potential of the crop, so that there is a great deal of scope for reducing the costs of production by raising yields. This is especially true if high yield varieties can be produced that are more easily harvested (by either man or machine) but still retain adequate drought and disease tolerance. In view of the limited past resources devoted to both the breeding and the mechanization of cassava, compared with those now available, it is difficult to make any forecasts of the likely future pattern of production costs. What does appear probable is that these costs will be strongly influenced by the results of plant breeding work in terms of the achievements that are made with respect to yield and morphology (and perhaps eyanogenic glucoside content).

CONSUMPTION

The most important use of cassava is as human food (Fig.2). Consumption data are presented in Table 3 from 14 countries in which cassava is an important dietary staple. These national data may be misleading in some of the larger countries in which cassava is the primary staple in certain areas but not in others. For example, cassava is more important in the south and east of Nigeria than in the north. In a survey of southern Nigeria, Nicol (1952) found that 25-56% of the dietary calories came from cassava (as opposed to the national figure of 14% in Table 3). Bailey's (1961) surveys in Java showed 63.5% of the calorie intake (as opposed to the Indonesian national figure of 15.2%) came from cassava. Normanha (1970) reported that in Brazil in 1962-63 cassava consumption was 124 kg/person per annum at the national level. This represented an urban intake of 42 kg and 200 kg in rural areas. By comparison, it is interesting to note that the average intake of wheat (in the form of flour) in west European and North American countries is

TABLE 3. Human intake of cassava in 14 countries 1964 66 (source: FAO Food Balance Sheets 1964 66).

	Human population (million)	Cassava as % Total calorie intake	Cal/day from cassava	Cassava per year(kg)
Congo (Brazzaville)	0.84	54.8	1184	470
Zaire	15.63	58.5	1193	437
Central African Rep.	1.33	48.7	1057	354
Gabon	0.46	47.0	1027	342
Mozambique	6.96	42.6	908	304
Angola	5.15	34.5	659	220
Liberia	1.08	26.2	600	201
Togo	1.64	26.5	590	197
Dahomey	2.36	20.1	438	148

Paraguay	2.03	19.7	540	181
Ghana	8.14	18.2	380	130
Brazil	80.77	10.8	274	107
Nigeria	58.48	14.1	306	103
Indonesia	105.74	15.3	269	92
Total:	304.15	-	-	-
Weighted avg. (14 countries)		19.4	374	124

TABLE 4. Daily purchases expressed in calories, and price per 1000 calories of selected staple feeds. Kumasi and Sekondi-Takoradi, Ghana, 1955 (Johnston and Kaneda 1960).

	Kumasi		Sekondi-Takoradi	
	Purchases (cal person day)	Price (¢ 1000 cal)	Purchases (cal person day)	Price (¢ 1000 cal)
Cassava and products				
Fresh roots	243	2.68	456	2.73
Gari (meal)	46	2.94	64	3.23
Kekonte (dried roots)	212	1.63	57	2.69
Plantains	389	3.05	168	4.32
Yams	123	5.91	49	7.64
Maize and Products				
Kenkey	50	5.74	188	5.33
Dough	43	-	49	-
Rice	101	5.20	111	5.28
Cocoyams	98	3.76	15	5.02
Bread	27	11.03	47	11.70
All starchy Staples	1364	-	1260	-

50-80 kg/person per year, providing between 500 and 800 cal/day.

Wheat, of course, does tend to be the preferred energy staple in many non rice growing parts of the world but the difficulty of growing it in the tropics usually makes it an expensive item. Bearing in mind the low income normally encountered in tropical areas (where annual per capita incomes rarely exceed $200 and are often under $100), the relative cost of cassava and its products is of considerable significance. Table 4 presents data from two areas of Ghana where calorie intakes from cassava averaged around 500/day at a daily cost of under U.S. 2¢. This contrasts rather favourably in cost terms with calories derived from other staples.

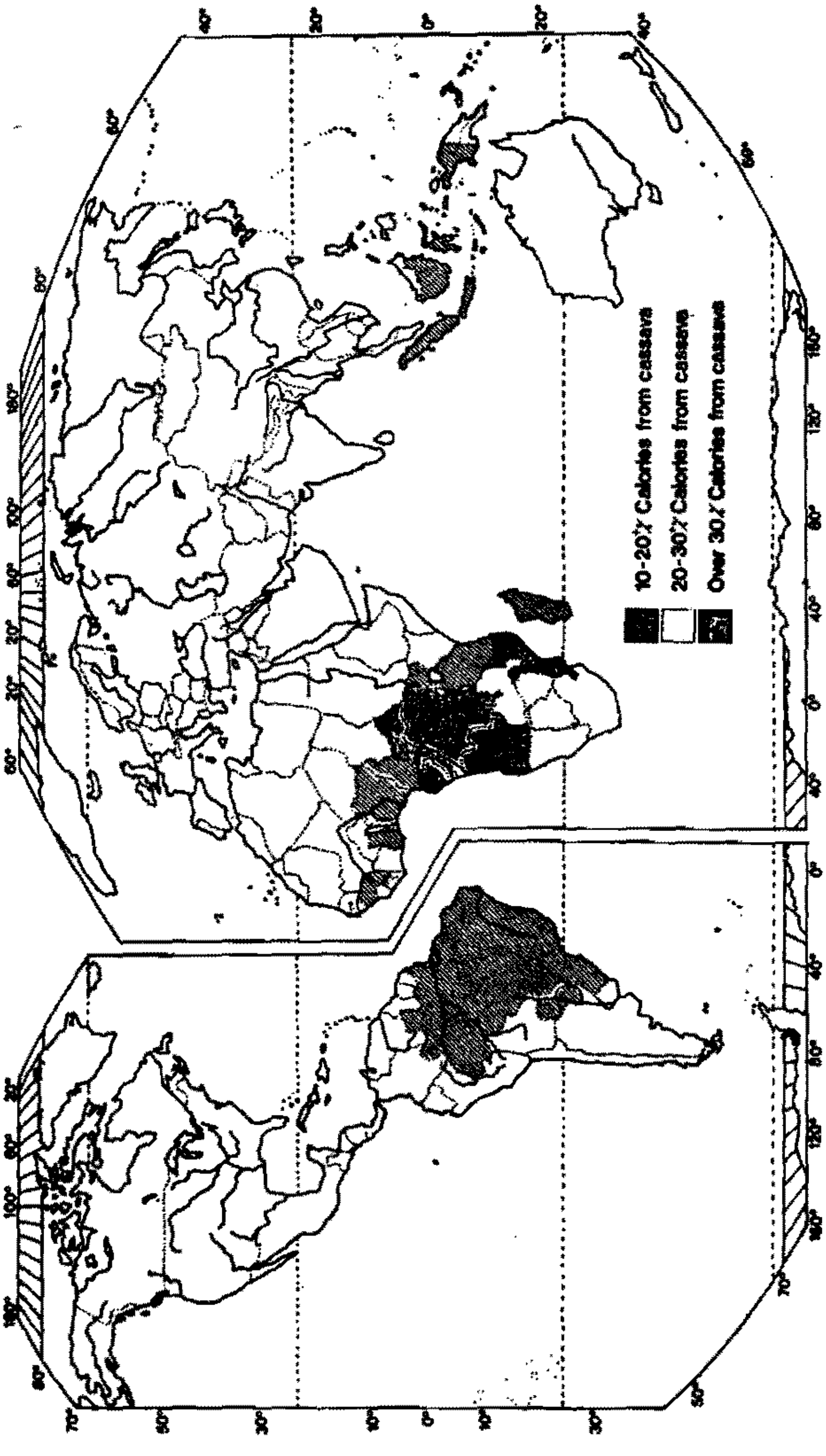

FIG. 2. Cassava consumption levels in 20 countries in 1964–66.

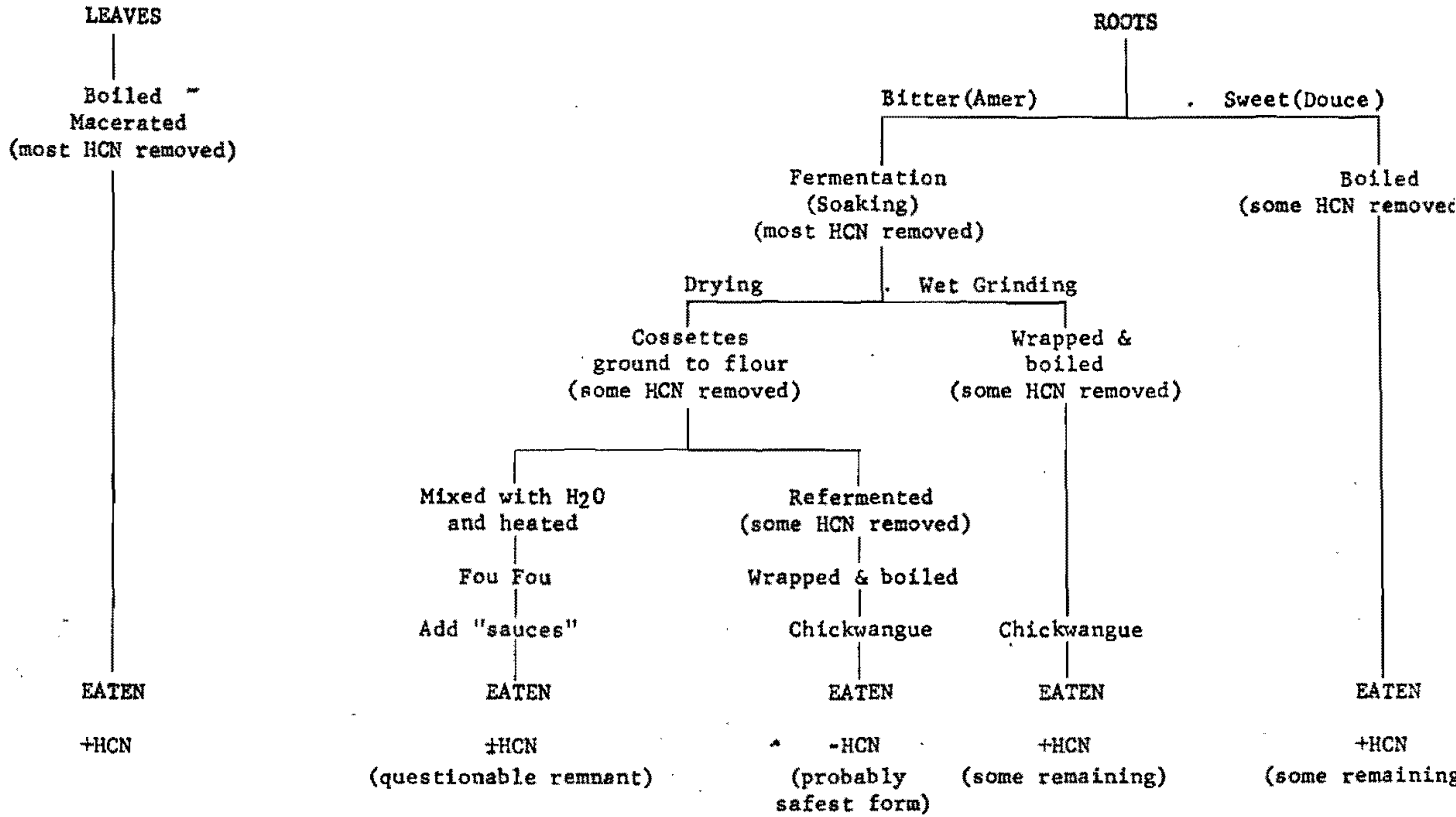

FIG. 3. Cassava use in the Kinshasa area, Zaire (source: Rogers et al. 1971).

TABLE 5. Amino acid content/100 g food (source: FAO Amino Acid Content of Foods and Biological Data on Proteins. Nutritional Studies No. 24, Rome 1970)

Food	Moisture (g)	Nitrogen (g)	Conversion factor (W)	Protein (mg)	Lysine (mg)	Methionine (mg)	Threonine (mg)	Tryptophan (mg)	Total essential amino acids (mg)	Total amino acids (mg)
Cereal grains										
Barley	12.0	1.88	5.83	11.0	406	196	389	180	4,203	11,118
Maize	12.0	1.52	6.25	9.5	254	182	342	67	3,820	9,262
Millet	11.0	1.55	6.25	9.7	332	239	374	189	3,979	9,505
Oats	10.0	2.23	5.83	13.0	517	234	462	176	5,169	12,998
Rice (brown)	13.0	1.26	5.95	7.5	299	183	307	98	3,033	7,973
Rice (polished)	13.0	1.13	5.95	6.7	255	150	234	95	2,695	6,785
Rye	12.0	1.89	5.83	11.0	401	172	395	87	3,732	10,868
Sorghum	11.0	1.62	6.25	10.1	204	141	306	123	3,945	9,756
Wheat	12.0	2.09	5.83	12.2	374	196	382	142	4,280	12,607
Roots and tubers										
Potato	78.0	0.32	6.25	2.0	96	26	75	33	667	1,572
Sweet potatoes	70.0	0.21	6.25	1.3	45	22	50	22	414	994
Taro (Colocasia)	72.5	0.29	6.25	1.8	70	24	74	26	707	1,737
Yam (Dioscoria)	72.4	0.38	6.25	2.4	97	38	86	30	821	2,009
Cassava meal (Manihot)	13.1	0.26	6.25	1.6	67	22	43	19	404	1,184
Legumes (pulses)										
Beans (Phaseolus)	11.0	3.54	6.25	22.1	1,593	234	878	223	8,457	20,043
Beans, Broad (Vicia)	11.0	3.74	6.25	23.4	1,513	172	786	202	8,244	20,951
Chick-pea	11.0	3.22	6.25	20.1	1,376	209	756	174	7,802	19,290
Cowpeas (Vigna)	11.0	3.74	6.25	23.4	1,599	273	842	254	8,640	21,086

Table 4 also indicates that cassava is marketed in Ghana in various forms. This is a common situation in many cassava producing areas. The marketing system is often fairly complex with a large variety of cassava products being handled. Figure 3 shows the variety of forms in which cassava is consumed in one part of Zaire. The range of processed products and the number of stages in marketing both tend to depress the producers' share of the price of the product that is finally consumed.

In areas where cassava intakes are high there are sometimes problems by virtue of the low content of essential amino acids in the root (Table 5). The essential amino acid profile of cassava also indicates that it is particularly deficient in sulfur containing amino acids (Bailey 1961). The significance of this in the detoxification of cyanogenic glucosides is discussed in several papers in these proceedings.

INDUSTRIAL USE

As already noted, cassava is used to make a large number of processed products, most of which involve some form of drying and/or fermentation. One of the most important of these products is industrial starch. Cassava starch contains only 17% amylose as opposed to 22% in potato starch and 27% in corn starch and because of this it possesses unusual viscosity characteristics. The large percentage of branch chained amylopectins in cassava starch gives it great dimensional strength, which makes it in particular demand for sizing paper or fibers, to give them greater tensile strength.

TABLE 6. Imports of cassava starch and flour to Canada and the U.S.A. (Canadian imports include some sago flour (source: National Trade Data)).

	U.S.A.		Canada	
	Million lb	Million $	Million lb	Million $
1964	294	9.6	7	0.5
1965	358	12.2	10	0.6
1966	341	11.5	13	0.7
1967	304	10.7	20	1.1
1968	194	7.1	16	0.9
1969	195	6.8	15	0.8
1970	207	7.0	20	1.0
1971	182	7.1	9	0.6

Cassava starch also provides good parent material from which to hydrolize dextrins for formulating adhesives. Such adhesives made from cassava appear to have a greater flexibility and less brittleness at low humidities than dextrins derived from cereal starches. Cassava starches also possess specific characteristics that are in demand in the food industry.

At the present time the United States is the principal user of cassava starch and imports around 90,000 tons/year (Table 6).

FEED USE

Cassava has been used as a livestock feed on subsistence farms for many years, although there has been a traditional prejudice against its use in some areas because of the toxicity attributed to its cyanogenic glucoside content. However, the literature on this subject has tended to be inconclusive and controversial. Recent work by Maner (1972) and his co-workers clearly demonstrates the potential of high cassava rations. Only in the last decade has cassava assumed any significance as a component of compounded animal feeds where it is used in place of grains. This situation has arisen mainly because cassava enters the European Common Market at a highly favourable tariff rate compared to wheat, maize, and other energy components of compounded animal feeds (Tables 7 and 8).

TABLE 7. Comparison in prices of barley, maize, and manioc in EEC in September 1967 (U.S.$/ton) (source: GATT 1968 The markets for manioc).

	CIF Price	Import levies	Threshold prices or prices after levies paid	Difference: Barley	Difference: Maize
Barley	(59.65)	30.65	89.00		
Maize	(57.25)	31.03	88.28		
Manioc chips	61.60	5.52	67.12	-21.88	-21.16
Manioc pellets	64.40	5.52	69.92	-19.08	-18.36
Manioc meal	56.00	8.02	64.02	-24.98	-23.26

At present the main users of cassava are Germany, Holland, and Belgium. France has a low usage because her agriculture is still in the process of modernization, the animal feed industry is backward, and large surpluses of cereal grains exist. Italy at present still benefits from low cost maize feeds (which theoretically are not permitted under the common agricultural policy of the European Economic Community), and the

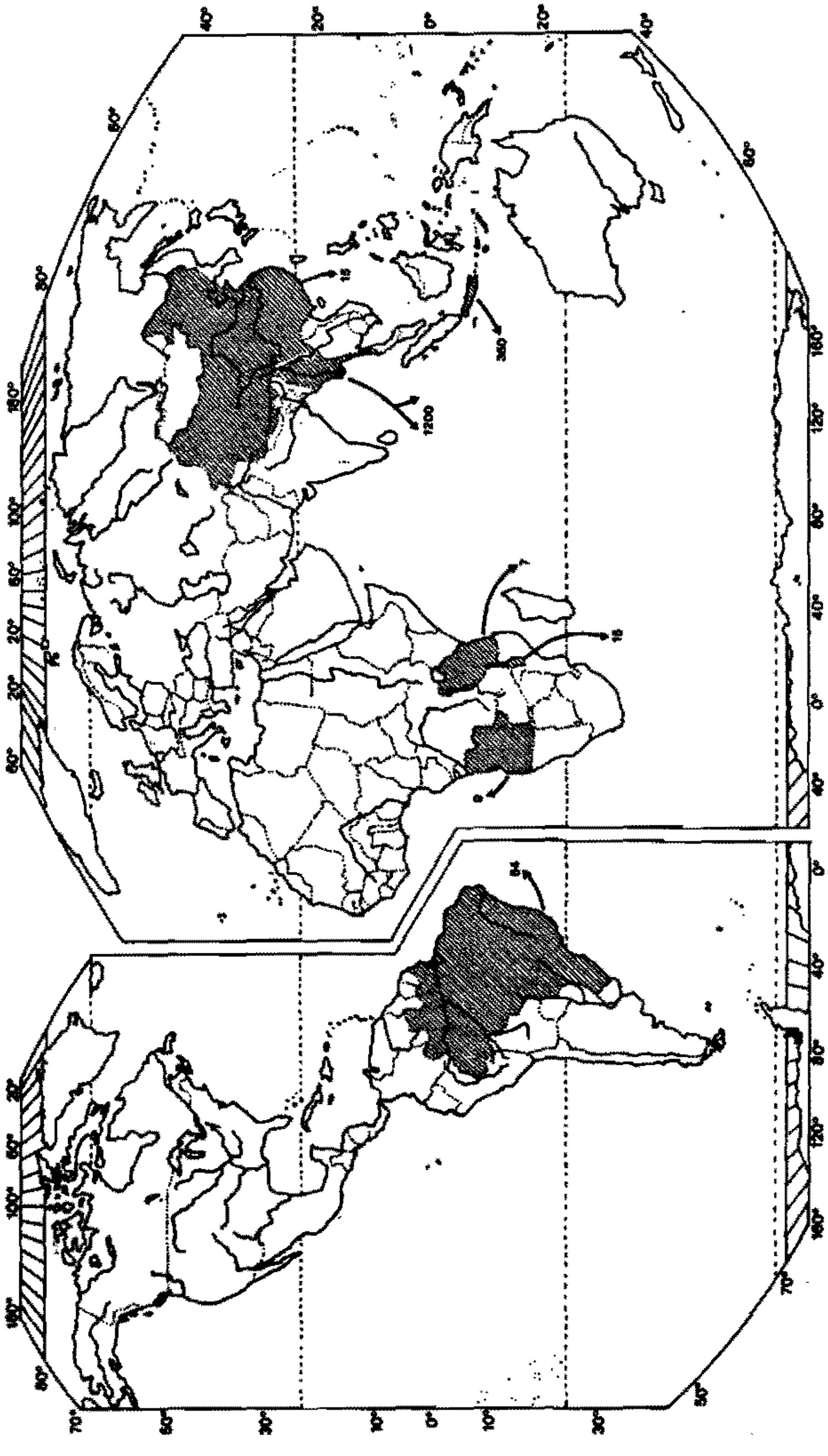

FIG. 4. World trade in cassava (in thousands of metric tons) in 1970.

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United Kingdom, Eire, and Denmark have developed their feed industries on low-cost cereals which can be bought at a lower price than cassava in the world market, but not within the framework of the EEC Common Agricultural Policy.

In the last decade the importation of cassava to the countries of the European Economic Community has more than tripled (Table 9). Between 80 and 90% of the world market is supplied by Indonesia and Thailand. The latter country is a very small consumer of cassava and produces mainly for the world market (Table 14). Brazil, China, Tanzania, Malawi, and Angola also supply the world market to a much smaller degree (Fig.4). At the present time 80-90% of the world trade in cassava for feeding purposes is absorbed by the EEC.

TABLE 8. Relationship of prices for manioc, maize, and barley on basis CIF Rotterdam resp. FOB incl. tax and levies (source: Phillips unpublished data).

	Maize	Manioc pellets	Feed barley
Average prices:			
1968 World Market Price	100.0	100.3	10[illegible].7
EEC price	177.3	126.0	174.0
1969 World Market Price	100.0	93.6	81.9
EEC price	172.3	112.1	163.8
1970 World Market Price	100.0	101.1	84.6
EEC price	148.2	114.4	148.0
Maize World Market Price = 100			

The use of cassava in compound feeds in the developing contries does not appear to have received any attention. This may seem surprising since the 1.5 million tons of cassava reaching the European mills about U.S.$75/ton has about 30% of its price made up of shipping charges from the Far East. In fact, the FOB cost at the dockside in Thailand and Indonesia appears to be less than U.S.$50/ton, a price considerably less than that at which cereals of similar energy value can be purchased for use in feed compounding in most developing countries.

While it is not possible to fully explain this situation, it would appear that the feed industry in developing countries is, to a large extent, owned and directed by multinational corporations who prefer to rely on known technology rather than to invest in the development of new technologies appropriate to the typical developing country situation (Johnson 1970). Within the EEC the size and fiercely competitive nature of the market is such that its skilled compounders appear to be prepared to utilize alternative energy sources in an innovative manner.

TABLE 9. Imports of dried cassava products into the European Economic Community 1962-70, in thousands of metric tons (source: International Trade Centre GATT).

	1962	1963	1964	1965	1966	1967	1968	1969	1970
Germany	366	387	462	520	702	NA[a]	481	548	591
Netherlands	1	5	17	76	96	NA	237	444	502
Belgium	23	72	105	100	70	NA	127	212	268
France	23	20	18	17	16	NA	NA	NA	35
Italy	0	0	0	1	0	NA	NA	NA	14
Total:	413	484	602	714	884		845	1204	1410

[a]NA, data not available.

PROSPECTS FOR THE FUTURE

Cassava has a very low income elasticity of demand. This means that when personal incomes grow people tend to spend very small parts of the increase on cassava. In fact, when their incomes increase considerably, they actually tend to shift their consumption from cassava to cereal grains. However, at the income levels encountered in cassava-eating areas, this change takes some time to occur (Fig. 5).

Because of this situation, the global food demand for cassava is likely to increase at a rate very similar to that of the human population of cassava-eating areas. In table 10, two projections for the demand

TABLE 10. Consumption demand for cassava in 1980 in thousands of tons (source: FAO 1972 unpublished data).

	1970	1980[a]	1980[b]
World	55,087	71,500	70,460
Africa	29,306	38,204	37,481
Latin America	8,492	10,838	10,651
Asia and Far East	16,422	21,318	21,154
China	734	971	1,007
Rest of World	133	169	167

[a]Demand projected on basis of past trend.

[b]Demand projected on basis of Second Development.
Decade growth model.

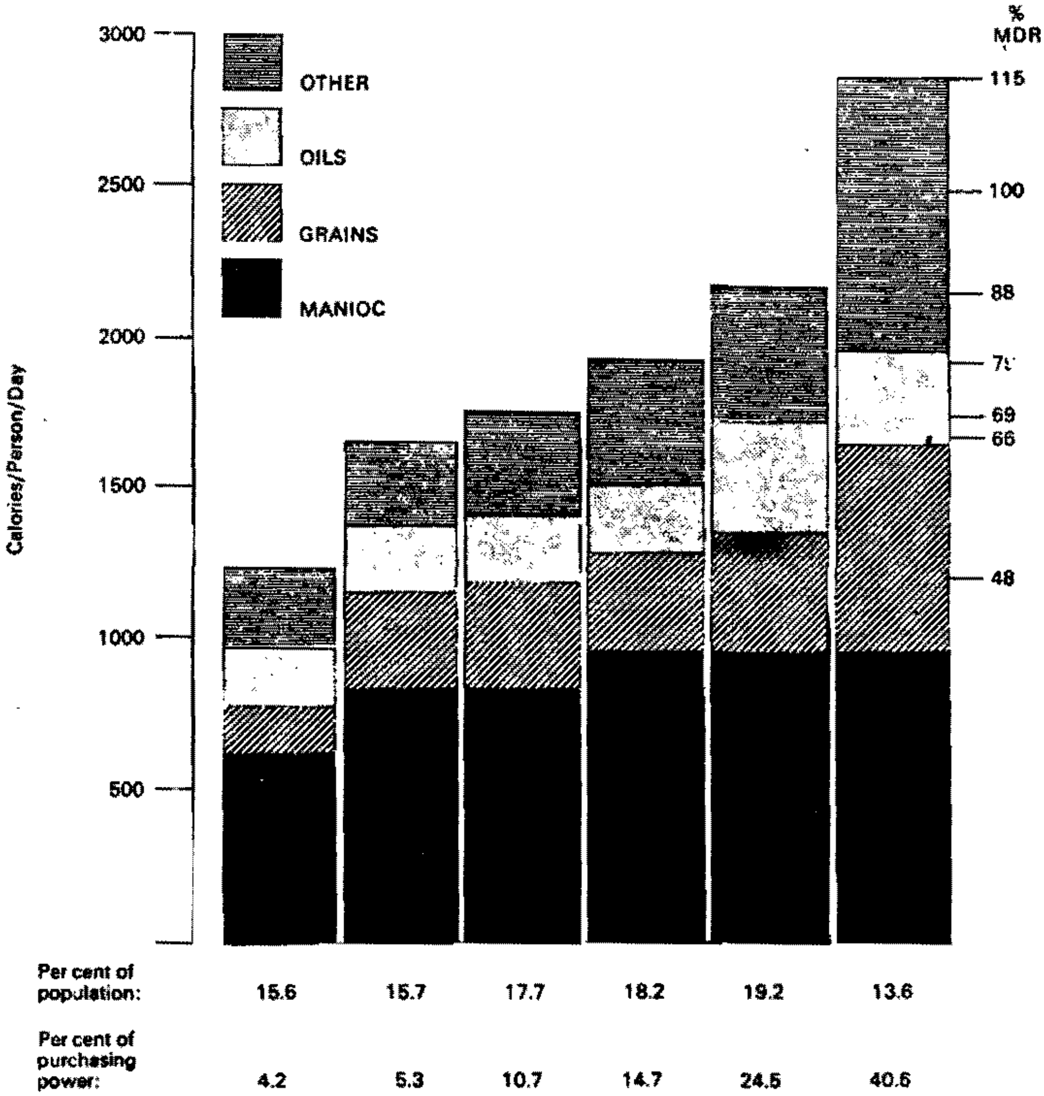

FIG. 5. Cassava consumption in relation to income levels in Zaire (source: Rogers et al. 1971).

for cassava in 1980 are shown. The first represents a continuation of the past trend in demand and the second represents a projection based on a higher income growth than in the past, namely the one targeted for 1980 in the United Nations Second Development Decade studies. The difference between the two projections is very small for the reason that has already been noted. Both projections represent a growth rate in demand of about 2.6% per annum.

If we assume that there is some reduction in population growth in cassava-eating countries by the end of this century, it would appear that the demand at that time for cassava as a food will be not far short of 100 million tons. Even if we accept that cassava represents the food of low income groups and that people will shift into cereals as and when their incomes permit, we are still likely to have twice as many food calories derived from cassava at the end of the century as are derived from cassava today. If we refer back to Table 3 we will see this means we can expect a very large number of cassava eaters in the year 2000. This suggests that the medical problems described in some of the papers presented in these Proceedings are not likely to be solved in the foreseeable future by a reduction in the use of cassava as a food.

The world starch industry is a fiercely competitive one in which cassava starch is only one of several available. The industry is dependent not only on production of starch but also on producing other products and by-products involving complex technology and marketing systems. Generally speaking, cassava processing in developing countries is carried out in a primitive fashion and the marketed product is often of poor and variable quality. In the absence of large infusions of capital the future prospects for cassava starch are questionable, particularly insofar as it competes in many respects with starches being produced in the developed countries which represent the main outlet for the starch industry.

There are some prospects for the increased use of cassava flour a partial substitute for wheat flour in composite breads in those countries where wheat flour is in limited supply. In recent years considerable progress has been made in overcoming the problems of finding: (a) appropriate additives to substitute for wheat gluten. (b) new mixing techniques to obtain improved gas retention and control of gelatinization during baking with non-wheat flours, and (c) appropriate methods of protein fortification of such flours. Because of this progress the future prospects for expanded use of cassava flour in composite breads appear promising.

During the process of flour and bread making most of the cyanogenic glucosides appear to be destroyed and from the toxicity standpoint composite breads containing cassava flour may not be of any significance. However, since this use for cassava will likely become significant (bread containing up to 50% cassava flour has already undergone successful acceptability trials), some discussion of this point is warranted.

The really attractive area for future potential use of cassava seems to be in the compound feed sector. Table 11 shows the phenomenal way in which this sector has grown in recent years within the six original members of the EEC. A similar pattern of growth in feed use is taking place in certain developing countries where incomes have reached the stage where people can afford intensively produced meat. For example, Taiwan's importation of feed grains has increased from 94,000 tons in 1964 to more than 1 million tons in 1971 and, as yet, shows no sign of levelling off.

TABLE 11. Compound feed production in the EEC from 1955 to 1970 and percentage of increase in thousands of tons (source: EEC).

	Belgium and Luxembourg	France	Germany	Italy	Netherlands	Total EEC
1955	993	1,270	1,968	380	2,900	7,511
1960	1,550	2,220	3,578	800	4,600	12,746
1965	2,527	4,544	6,594	2,600	5,625	21,290
1967	3,119	5,847	7,723	2,500	6,392	25,316
1968	3,240	5,516	7,872	3,100	6,838	26,566
1969	3,668	6,244	8,863	3,300	7,117	29,192
1970	4,282	6,475	9,727	3,633	7,851	31,968
%increase 1955-70	331	410	394	856	171	326
Yearly increase %avg 1961-65	10.3	15.5	13.0	20.3	4.1	10.8
%avg 1965-70	9.0	4.9	8.3	12.9	6.8	8.6

The projected demand for cereal grains, and their substitutes as energy sources for livestock feeds, is expected to grow globally at a rate approaching 3%/year (Table 12). Although a substantial part of this growth will take place within the developing countries, an even greater part is expected in the developed countries and in the centrally planned economies, and this would appear to represent a particularly promising opportunity for export market development in a number of tropical countries.

At present the export of cassava and its products produces about $80 million of foreign exchange for the developing countries. However, most of this money flows to only two countries, Thailand and Indonesia. It is earned by exporting around 1.5 million tons of dried cassava products which represents about 5 percent of total world fresh cassava production. These figures are relatively small in terms of the export

TABLE 12. Estimated demand for grains for feed use, in millions of tons (source: FAO 1969 Indicative World Plan).

	1962	1985
Developed countries	202	320
64 developing countries	17	48-68
Centrally planned countries (excl.China)	52	126
Total:	271	494-514

levels of some other tropical commodities (Table 13) although it would appear that a 6- to 10-fold increase in cassava exports by 1985 might easily be absorbed in the world feedstuffs market. At present price levels such an increase in exports would put cassava next to coffee and sugar as the most important agricultural export from the developing countries.

While such an increase in exportation may seem fanciful at first glance, recent computer studies of the compound feed market undertaken in Germany, England, and Canada (A. Hone, Institute of Commonwealth Studies, Oxford, personal communication) indicate that at its present price level, and assuming that the EEC Common Agricultural Policy does

TABLE 13. Exports from developing countries of selected agricultural products, 1965-67 (source: FAO 1969 Indicative World Plan)

	Millions U.S.$
Sugar	1109
Wheat and coarse grains	771
Beef and veal	321
Citrus fruits	194
Coffee	2167
Tea and mate	547
Cocoa	477
Bananas	411
Cassava chips, pellets, and starch	80 (1971 approx)

not discriminate specifically against cassava, a market demand of 4.3

million tons (almost triple the 1970 level) may be expected in the EEC by 1980. These studies also indicate that there may be some difficulty in supplying this market unless either the West African producers, who have preferential access to the EEC, or mainland China (whose production potential is not known); become significant exporters.

These projections do take into account expected increases in the demand for cassava in Italy and France (due to developments in their livestock industry) and in the three new EEC members (which will have to give up cheap imports of feed grains by 1977 to conform to the Common Agricultural Policy), but they disregard the Japanese market. Until recently Japan appears to have relied heavily on imported maize as its main source of feed energy, and indeed the Japanese feed market has played an important role in the development of the Thai and Philippine corn industries. Japanese buyers now appear to be active in the cassava market (T.P. Phillips, University of Guelph, personal communication) especially in Brazil where the growth potential is enormous. If Thailand can build up a 1.2 million ton dried cassava export in a decade it is not unreasonable to expect that Brazil (whose current production of cassava is reported to be at least eight times that of Thailand) could also become a major exporter. Other countries, such as Malaysia, are also already active in attempting to enter this export market.

TABLE 14. Utilization of cassava in selected countries, 1964-66 (source: FAO Food Balance Sheets 1964-66).

	Total production (million tons)	% consumed	%used as animal feed	% exported	% as "waste"
India	3.1	93	0	0	7
Zaire	7.2	95	0	0	5
Nigeria	7.5	80	0	0	20
Indonesia	11.1	88	2	9	10
Brazil	24.7	35[a]	39	1	20
Thailand	1.6	39	0	56	5

[a] 35 as food, 5 for non-food industrial use.

I have particularly stressed the export market potential because beef, and to a lesser extent feeds for livestock, represent the only commodities for which a really strong export growth potential appears to exist for the products of developing countries. However, if we assume that at least part of the projected demand for cassava in the developed markets is realized, it would not be unreasonable to assume a partial spin-off in the development of the use of cassava for compound feed in the developing countries themselves within the next decade. Such a development which obviates shipping costs should be of particualar interest to countries which currently import animal feeds.

If we bear in mind also that cassava is a commodity to which very limited research has been applied in the past (two major international agricultural research centres, in Colombia (CIAT) and Nigeria (IITA), are now giving priority attention to this crop), it is not unreasonable to expect that within the next few years we may see some pay-off for this research in the form of the development of production systems which will result in increased yields at lower unit costs. This in itself would be likely to increase the utilization of cassava as animal feed both in developed and developing countries.

Bearing in mind both the current role and growth potential that appear to exist for the use of cassava, a better understandig of the toxic role of its cyanogenic glucosides is both desirable and necessary. We hope that this Workshop will contribute towards such an understanding.

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AGRONOMIC POTENTIAL FOR CASSAVA PRODUCTION [1]

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CASSAVA (Manihot esculenta Crantz) is grown between 30°north and south latitudes and at altitudes below 2000 m. Yields decrease as temperature decreases with altitude above 1000 m near the equator (Cock and Rosas, unpublished). It can be grown on very infertile soils, often as the last crop in a rotation. It will produce on extremely acid soils where few other crops will yield anything. Cassava has a great advantage over most starch-producing crops in drought tolerance. The cereal crops need water during the flowering period; if not they will often yield little or nothing. Cassava, once established, has no critical period. At the onset of a drought period, it drops its leaves and remains essentially dormant; when the rains come, it draws on its root reserves to form a new leaf canopy and later fills its roots. Hence, cassava can readily be grown in areas with rather uncertain rains that may prevent planting of other crops.

A further attribute of cassava is that it has no determined harvest period after which it spoils. Cassava, as far as is known, grows almost indefinitely, increasing its yield with time; hence, the farmer can harvest his crop when it is convenient or when it will demand a high price rather than on a set date. This adds great flexibility to a crop program based on cassava. However, if the cassava is left too long, there may be marketing problems because of oversized roots, which are usually unacceptable, increased fibre in the roots, and a decrease in the starch content (Ghosh 1968).

The total area on which cassava is grown is about 10 million ha and yields average about 10 metric tons (t)/ha per year (FAO 1971). These yield levels are far below some of the very high figures that have been quoted (de Vries et al. 1967), suggesting that its yield potential is rarely reached in practice. At CIAT, we have obtained yields of over 50 t/ha per year on a fertile soil with minimal inputs, and on a nearby farm with rather infertile soils and no irrigation, yields of over 40 t/ha per year. These results suggest that cassava's known yield potential is 40-50 t/ha even on rather infertile soils with limited inputs and without irrigation.

In spite of its great yield potential and certain attributes that make it easy to fit into a farming system, world cassava yields at 10 t/ha

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are far below those that might be expected. The reasons for this cannot be stated categorically, but probably include: (1) poor agronomic practices; (2) por varietal selection; and (3) diseases and insects. In this paper I shall try to outline some of the more important of these.

Agronomic Practices

Cassava is reported to be agressive toward weeds and insect pests (Hendershott et al, 1972) but adequate weed control can markedly improve yields. In trials at CIAT, yields were reduced to less than 2 t/ha when no weed control was used (Doll 1974). In the same trial, plots weeded twice by hand yielded about 20% less than plots kept weed-free all the time. Hand weeding twice was considered to be sufficient by Hendershott et al, (1972).

It is also reported that cassava depletes soil, especially with respect to potassium, due to its high nutrient requirement (Dijk 1951). This is not surprising. Any crop that yields well, particularly on poor soils, will deplete the nutrient reserves in that soil. However, Birkinshaw (1926) reports up to 15 cassava crops being harvested continuously. De Geus (1967) states that to obtain high yields on poor soils, particularly lateritic soils, use of fertilizers is essential. In Latin America, farmers frequently say that excessive nitrogen actually decreases yield due to excessive top growth. In our trials using up to 300 k/ha of N, we have not observed any negative nitrogen response. Reports on favorable response to fertilizers are numerous (Blin 1905; Doop 1937; Malavolta et al. 1952, 1953; Normanha 1951; Chadha 1958; Albuquerque 1958; Jacoby 1965; Jacob and Uexkull 1966; De Geus 1967; Silva a Freire 1968; Normanha et al. 1968; Samuels 1970; Chew 1970; Kumar et al. 1971; Almeida 1971). However, due to the low value of cassava and high price of fertilizers in some regions it is not considered to be of economic interest to the farmer (Normanha 1951). The response to the different elements is extremely varied depending on soil type; however, it is obvious that yields can be increased by judicious use of fertilizers. In Colombia, less than one-quarter of the farmers use fertilizer, and those who do apply only small quantities (P. Andersen, personal communication), and it is likely that this situation does not only occur there.

The length and quality of planting material markedly influences yield. The stakes should be from the basal part of mature plants for optimum yields (Huertas 1940: Jeyaseelan 1951; Krochmal 1969; Enyi 1970), and in general, longer cuttings give higher yields (Jeyaseelan 1951; Fernando and Jaysundera 1942; Brandao 1959; Rodríguez et al. 1963). However, Loria (1962), found no significant yield differences between 40-,60-, and 80-cm stakes, suggesting that above 40 cm there is little yield increase by using longer stakes.

The results from studies on planting position -vertical, inclined, or horizontal- and planting on the flat or on ridges do not show any consistent trends. It is possible that different systems are needed for for different soil and climatic conditions. Recently, it has been reported that planting on ridges in a very wet area prevented root rots and effectively increased yield (C. Lozano, personal communication).

The results from spacing trials are also equivocal (Verteuil 1917; Fernando and Jaysundera 1942; Machado 1951; Rodríguez et al. 1966; Enyi 1972) Normanha et al. (1950) suggested that optimun plant population varied with soil conditions and more recently large variations in optimum distance have been shown for different harvesting times and different varieties (Cock, Gutierrez, and Wholey, unpublished). Large yield increases can be expected by using the optimum plant population. In our trials, yields of M Colombia 1438 decreased from about 45 t/ha at 6000 plants/ha to about 30 t/ha at 20.0000 plants/ha, whereas those of M Colombia 22 increased from about 42 t/ha to 55 t/ha over the same range (Cock, Gutierrez, and Wholey, unpublished). More work is needed in specific localities, but undoubtedly yields can be increased by planting at the optimum density.

Varietal Selection

There is ample evidence that different varieties grown under similar conditions have very different yielding ability (Galang 1931; Lambourne 1937; Arraudeau 1969; Sarmiento 1969; CIAT 1972, 1973) and that these variations are large enough to be highly important to the grower. In a recent trial at CIAT with a very low level of disease and pest incidence, yields of varieties varied from 16 to 46 t/ha per year. Thus, simple selection opens the way in some instances to very large yield increases.

Diseases and Pests

The two most important cassava diseases in the world appear to be African cassava mosaic and bacterial blight. The cassava bacterial blight (CBB) causes extremely severe losses. C. Lozano (personal communication) has shown that it can reduce yields from 47 t/ha to 25 t/ha in susceptible clones. The extent of the disease is not clearly defined. However, it is widespread in Latin America and Africa. Recently, a request for information on its control from Taiwan suggested that it may also be a problem there. The disease can survive for long periods in planting pieces from infected plantations and these can form a focus of infection in a new plantation. The disease will spread rapidly through a plantation by rain splash once a focus for infections is present. Disease-free planting material can be produce (Lozano and Wholey 1973), even from infected stocks, and from these disease-free plantations can be established to give haigher yields (CIAT 1973). Resistant lines are also available, but they have in general, low yielding ability. In time, high-yielding resistant types will be produced.

Although cassava is of Latin American origin. African cassava mosaic has not been reported in Latin America, but has been found in most areas of Africa and India. Reported losses due to this disease have been between 20 and 90% (Lozano and Booth 1974). The disease is spread by a white fly (Bemisia tabaci), as well as other species (Chant 1958), that feed on cassava. The disease may also be spread by planting infected cuttings, and as the vector is pantropic the disease is a potential menace to all cassava-producing areas. It also appears, as with cassava bacteria blight, that higher yields can be established by planting clean cuttings (Opsomer 1938; Briant and Johns 1940). Another effective method of control appears to be genetic resistance, and several highly resistant clones have been isolated (Doughty 1958; Jennings 1960; Sam Raj 1966; Beck 1971; Childs 1957).

Apart from these two diseases, there are many of lesser importance, e.g. Cercospora spp. and Oidium spp., and others of local importance, e.g. Phyllosticta spp. in the colder cassava growing areas and Coletotrichum spp. in Africa. These diseases may be of great importance in certain environmental situations, and resistant varieties should be sought. A new disease has recently been reported in Colombia that causes a superelongation of the stem. This disease, caused by a lower ascomycete, is potentially extremely dangerous as it causes severe yield losses when cassava is grown under humid climatic conditions (Lozano and Booth 1974). Fortunately, resistant varieties with reasonable agronomic characters are known to exist (C. Lozano, personal communication).

Outside Latin America, Cassava pests are not generally considered to be important. In Latin America, thrips are extremely widespread and during dry periods cause damage to the apex, reducing leaf area. Yield losses due to the pest are not known. I suspect that they may be quite severe. A large percentage of the known germ plasm has high levels of resistance to the pest and should be used where it is a problem. Thrips have also been reported in Zanzibar (Briant and Johns 1940).

Other pests are problems in specific areas. The shootfly (Silba pendula) and spidermites (recently introduced to Africa) do attack plants, but no estimates of damage are known. Highly resistant lines have not been found, but there are differences in susceptibility and less susceptible lines should be used where these pests are problematic. The hornworm (Errinys ello) occurs in sporadic severe attacks, and these can be controlled by insecticide application.

By using improved agronomic practices, selecting better varieties, and planting clean cuttings, it is certain that yields of cassava can be improved to near their known present potential. However, when introducing new varieties, great care should be taken not to introduce new diseases and insect pests, as this could largely negate the desired objective.

Future Yield Potential

It is of interest to speculate on the possible yields of cassava, in the future, under good agronomic practices with varieties that have good insect and disease resistance. Cassava, when growing its maximum rate under moderate conditions of solar radiation, will produce total dry matter at the rate of 1.2 t/ha per week. Most current cassava varieties do this for only a short part of their growth cycle when they have sufficient leaf area to intercept most of the incoming solar radiation. After about 6 mo growth, leaf area of most cassava varieties tends to decline because of increased leaf drop. However, varieties do exist that maintain a high leaf area and high growth rate during their full growth cycle. Apparently, the leaf fall is not associated with movement of carbohydrates and nutrients to the roots, suggesting that varieties can be obtained that maintain their leaf area and also fill their roots.

Varieties have also been found that distribute up to 70% of their total final harvestable dry matter to their roots. Unfortunately, these varieties do not maintain their leaf area. With a hypothetical cassava of the future, if we allow 6 wk for crop establishment and assume a total dry matter production of 1.2 t/ha per wk for 46 wk, of which 0.2 t/ha per wk is lost in leaf fall, it would be possible to obtain a variety that produced 46 t/ha per yr of total harvestable dry matter. Assuming that 70 percent of this dry matter can be distributed to the roots it appears possible to produce a variety that could yield 32 t/ha per yr of dry roots or at 65 percent moisture content a variety that would yield over 90 t/ha of fresh roots per yr.

So far at CIAT we have obtained in small plots yields of 66 t/ha per yr with a variety that had very high total harvestable dry matter production (more than 40 t/ha per yr) but a rather lower harvest index than assumed in the section above. It seems feasible to think in the future in terms of varieties with yield potential approaching 90 t/ha per yr.

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GROWTH AND DEVELOPMENT STAGES OF CASSAVA

James H. Cock *

Germination

When the cassava planting piece is planted in moist soil it looses dry weight through respiration during the first week. During the second week the axilliary buds begin to expand and a callus forms on the cut lower end of the stake.

During the third week fibrous roots from the callus and also the internodes and one, two or three of the axilliary buds elongate and produce leaves. The fibrous roots all start to store starch from the 32-38th day after planting (Lopez 1976). The starch is deposited in the xylem parenchyma.

Early growth

During the germination phase the shoots and roots are formed from the reserves in the planting piece. After about one month the new leaves produce the carbohydrate necessary for growth. The first formed leaves are small with few lobes. The size of each successive leaf increases with time and the apex produces up to four or five new leaves per week. Growth of roots occurs but there is little root thickening. At this stage almost all carbohydrate produced by the plant is used for production of new foliage. The roots do however have the capacity to expand at this stage. Tan (1977) restricted top growth by removal of apices and showed that the roots did then thicken.

In some varieties branching begins in the early growth phase. In cassava there are two distinct types of branching. First axilliary buds on the main stem develop well below the main apex and form new branches. These branches develop in the shade of the earlier formed leaves and are generally etiolated with long internodes and small leaves. In the second type of branching the main apex becomes reproductive and produces no new leaves, the axilliary apices immediately below the main apex develop into almost equally sized branches. The number of branches at each of these branch points varies from 2-6.

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Root bulking

After three to four months the plant starts forming thickened roots. In some of the more vigorous varieties the root bulking phase is delayed. Root bulking apparently starts due to a slowing down of the top growth leaving carbohydrate for root expansion. During this growth stage leaf size declines and rate of leaf formation per apex decreases. Leaf fall is also consididrable during this phase and leaf area per plant tends to decline. The roots thicken during this period but the number of thick roots does not change.

THE ADAPTABILITY OF CASSAVA

James H. Cock *

In this paper the adaptability of cassava to different climatic conditions will be reviewed. The climatic factors reviewed will be temperature, day length, radiation and rainfall.

Temperature

Most of the work reported in this section was done by Dr. Irikura whilst at CIAT on leave from TARC in Japan.

Cassava is successfully grown in zones from latitude 30°N to 30°S, at altitudes from sea level to up to 2000 m. It tolerates very hot climates but a critical point seems to exist between a daily temperature of 18-20°C below which growth is reduced and yields decline rapidly (Jones, 1959, Castro, 1964, Rogers and Appan, 1972, Cock and Rosas, 1975).

Cock and Rosas (1975) showed that at reduced temperatures (mean 16°C) germination was delayed and leaf formation rate was slow. Nine months after planting yields were very low and this was related to extremely low biomass production.

Irikura has now shown that different genotypes react differently to varying temperature conditions. Over a temperature range of 20, 24 and 28°C the variety Popayan 12 months after planting yielded 39, 15 and 9 tons per hectare respectively whilst M Col 22 yielded 9, 27 and 40 t/ha (Fig. 1). These data conclusively demonstrate that high yields of cassava can be obtained at temperature of 20°C but special genotypes may be necessary to achieve them.

Irikura also studied the physiological basis for high yields at different temperatures. In the previous section on the ideal plant type a LAI optimun of 3 was suggested for root bulking under CIAT conditions. The same optimun LAI for root bulking was found at all three temperatures for the four varieties used (Fig. 2). These results suggest that although the same phenotype may yield well at different temperatures, different genotypes are required when temperature is below 21 or 22°C.

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Photoperiodic response of cassava

In green studies Bolhuis (1966) and Mogilnen et al showed reduced root number and hence total root weight when plants were exposed to long days. In a field trial at CIAT with 15 hr. days throughout the growth cycle the proportion of total dry weight in the roots was reduced whilst total dry wight was unchanged (Cock & Rosas 1975, Fig. 3). Later work has shown that long days during the first three months after planting reduce yields of roots in some varieties (Fig. 4) but at later stages no reduction is observed.

These data suggest that to maximize yields in areas with long days either photoperiod insensitive varieties should be used or planting should be done during the short day period of the year.

Radiation

In general, crop growth rates increase as solar radiation increases, shading was used to decrease radiation receipt of a cassava crop and crop growth rate was markedly decreased (Fig. 5). However, not only did shading decrease the crop growth rate but also the proportion of dry matter distributed to the roots. Of the newly formed dry matter of cassava under 50% shade during the period 5-10 months after planting only 40% was found in the roots as opposed to 58% in control plants. Shading increased stem elongation and internode weight and little excess carbohydrate was available for root expansion. Shading also decreased leaf life in cassava (CIAT, 1973) resulting in lower leaf area indices. Hence, low radiation levels have very deleterious effects on cassava growth; they reduce crop growth rate due to decreased leaf area index whilst low radiation per se decreases crop growth rates and also lowers the proportion of total assimilate moving to the roots.

The critical times when low radiation may have its most serious effects on yield have not yet been studied.

Water requirements

There are few data on the water requirements of cassava, critical periods when water is essential or the response to irrigation. Our experience with cassava, unfortunately not yet supported by data, suggest that it requires moist soil for germination and establishment. After the first two months of growth, if a drought occurrs,the cassava plant virtually stops growing, that is, no new leaves are formed. The leaves on the plant when the drought occurrs fall and the plant becomes essentially dormant while other crops like corn, beans, and rice, die; with the onset of the rains the plant utilizes carbohydrate reserves in the stems and roots to produce new leaves (Cours 1952). These observations suggest that cassava is an extremely useful crop in areas of uncertain rainfall.

In low rainfall areas cassava responds to irrigation (Smith, 1968, Dos Reis Campos, 1974, Muthukrishman, 1973). In two of these three reports, yield was shown to decrease when irrigation was applied more frequently than once a week. We speculate that too frequent irrigation may lead to eccessive top growth and reduced yields with many of the existing cultivars and hence cassava may be well adapted to low rainfall areas and soils with low water holding capacity. Conversely, cassava like most other crops will not tolerate excess water and yields can be seriously reduced by poor drainage on heavy soils.

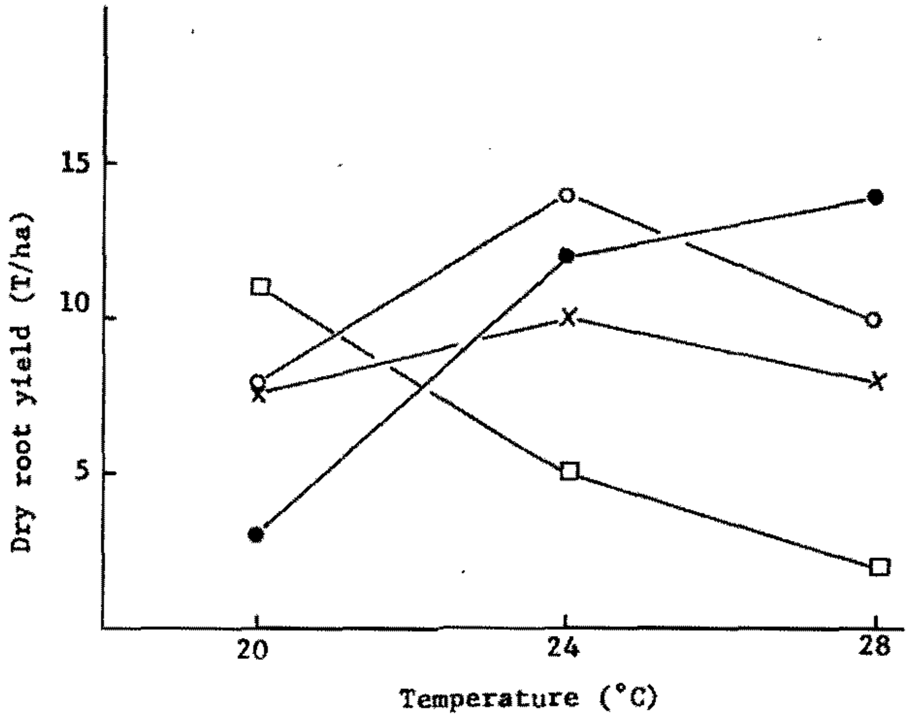

Figure 1. Dry root yield twelve months after planting of four cassava limes at 20, 24 and 28°C

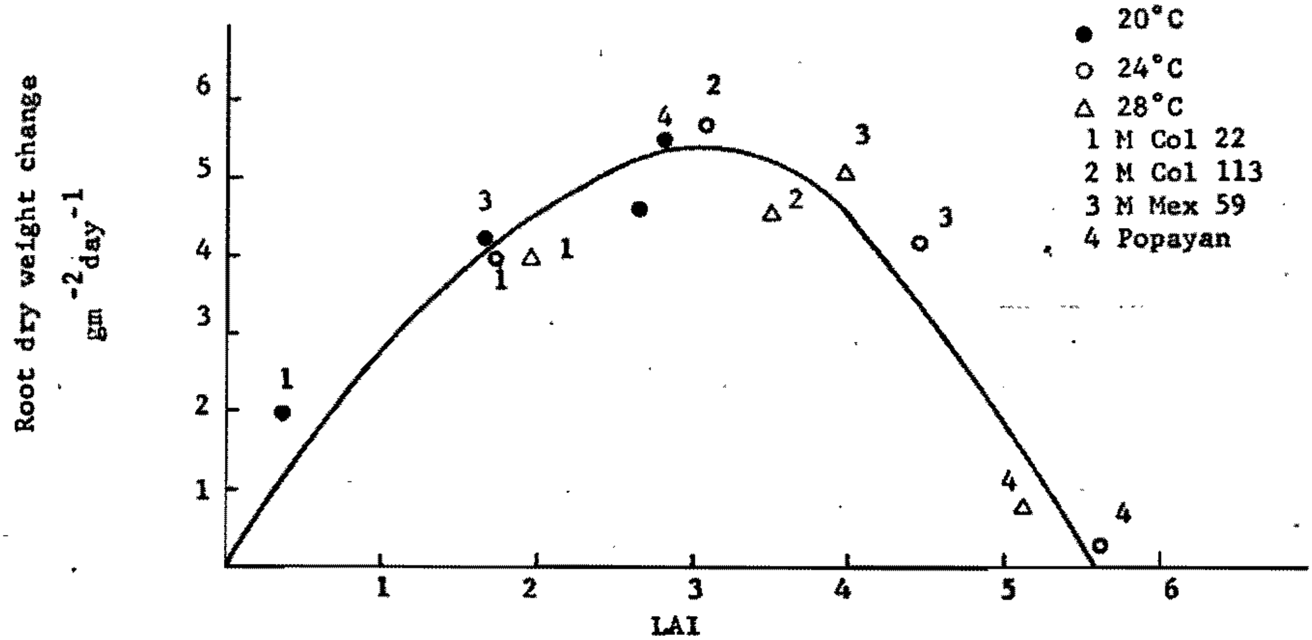

Fig. 2 Root dry weight increase as related to mean LAI from 8 - 16 months after planting.

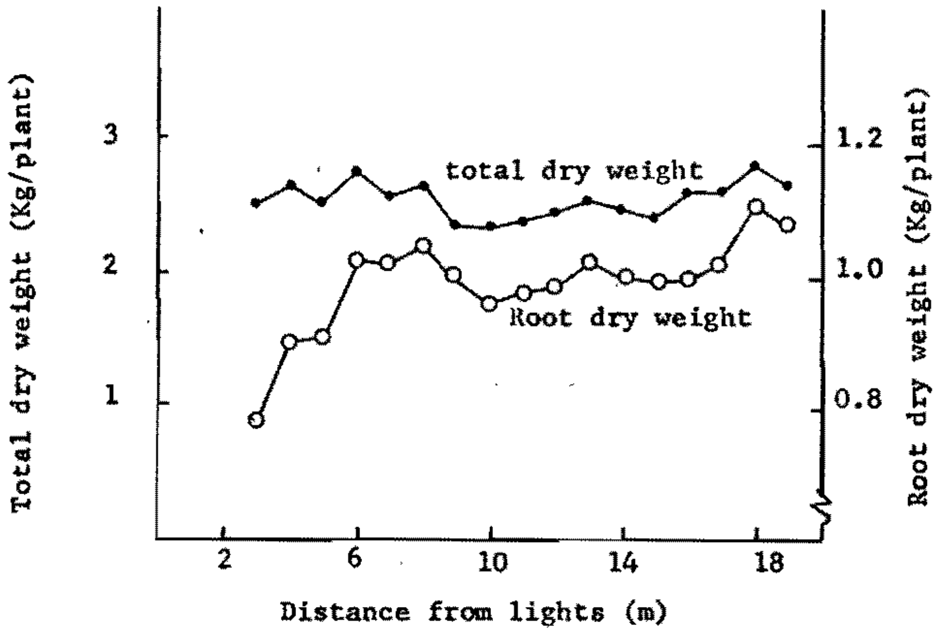

Fig. 3 Total dry weight per plant and root dry weight per plant as influenced by long days (means of 12 varieties harvested 9 months after planting.

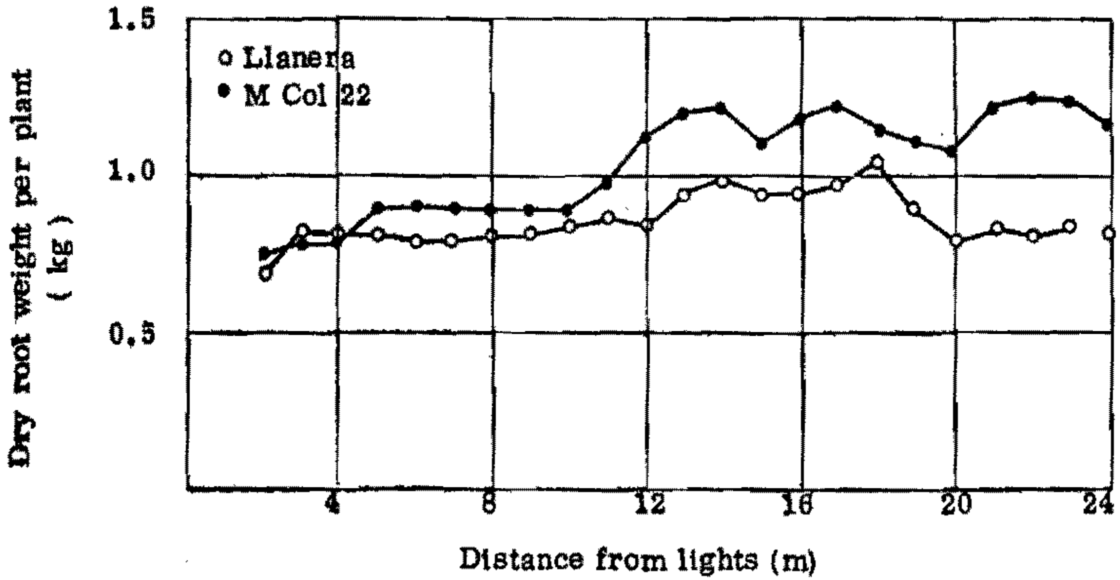

Fig. 4 . Effect of long days during the first three months after planting on the yield.

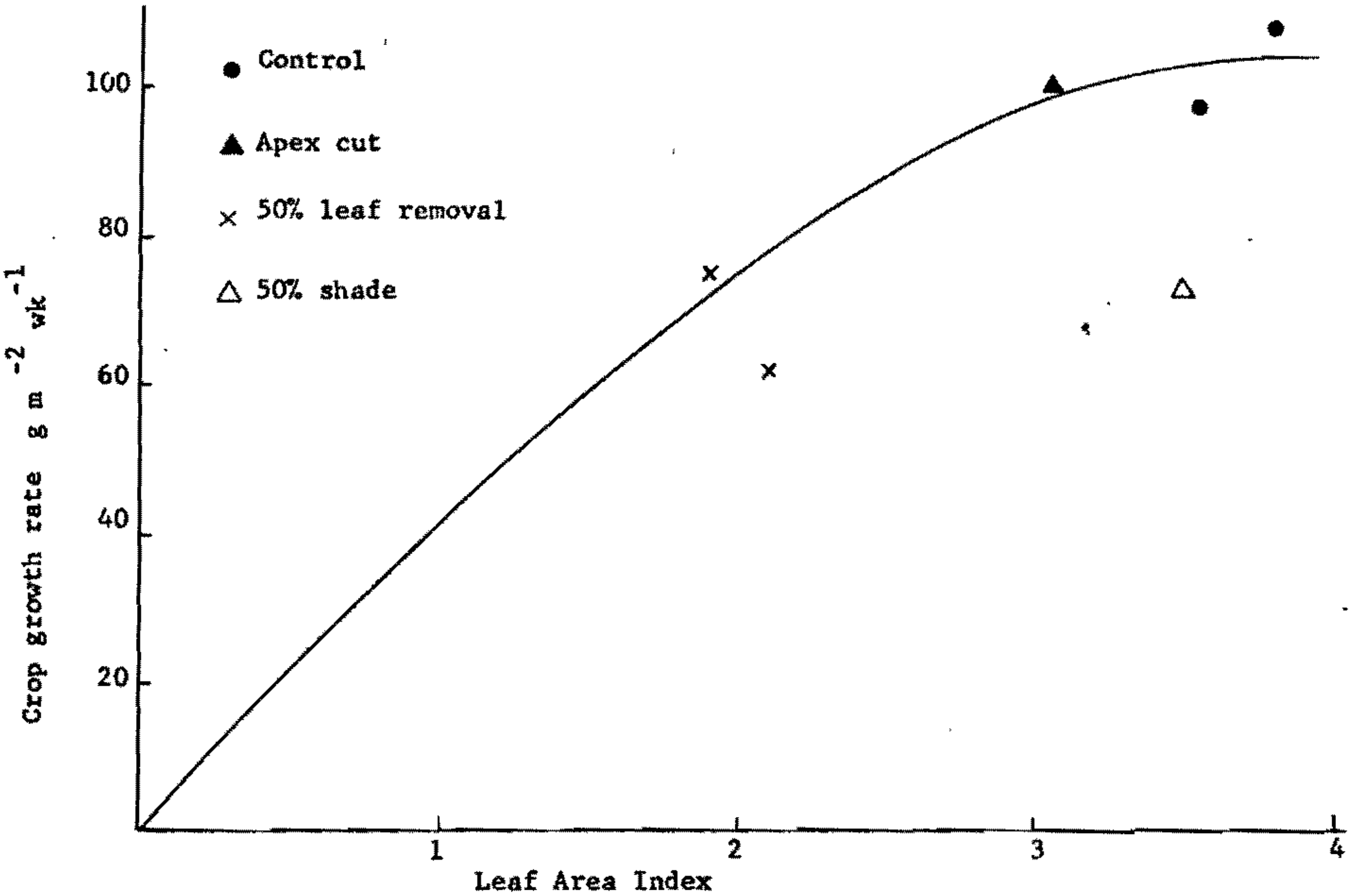

Fig. 5 - Crop gorwth rate (corrected for leaf fall cut apices and roots) as a function of leaf area index. M Col 1413, 3-5 months after planting.

THE IDEAL CASSAVA PLANT

James H. Cock*

The production of any crop depends on the total dry matter production and the proportion of that dry matter deposited in the useful parts of the plant. In this paper I shall discuss factors involved in increasing dry matter production and the balance between total production and a good distribution of dry matter to the roots.

Dry matter production and distribution

Leaf area index and growth. Crop growth rate in most crops increases as LAI increases up to a certain level, above this level crop growth rate may stay constant or decline. The crop growth rate in one trial reached a level of about 110 gm^{-2} wk^{-1} at LAI of four (Fig. 1). The decrease in crop growth rate above LAI 4 may be due to very short leaf life at high LAI's with a resultant high proportion of very young expanding leaves which have low photosynthetic rates (Tan & Cock unpublished data). This maximum level is similar to that found in other CIAT trials (Fig. 1, CIAT 1972).

Root growth for M Col 113 rate has a marked optimum at a LAI of 3-3.5 (Fig. 2). With three varieties the same tendency for an optimum LAI for root growth was observed (Fig. 3). An hypothesis to explain this marked optimum leaf area index is shown schematically in Figure 4. Crop growth rate increases with leaf area index but at higher levels of LAI the marginal increase of CGR with LAI is small, and becomes less than the material required to form and maintain the extra LAI. Hence as LAI increases above the optimum less, material is available for root growth.

The crop growth rate does not vary much as a function of leaf area index in different varieties. Crop growth rate increases with LAI giving values of about 110 mg^{-2} wk^{-1} at LAI of 4 (Fig. 5). The differences between two varieties with very different leaf angle were small, M Colombia 1148 consistently being 10% greater in crop growth rate at any given LAI than M Colombia 12. Model data used to predict crop growth rate of maize suggest that below LAI 2 horizontal leaves are advantageous and above 3 vertical leaves give greater crop growth rates (Duncan et al 1967) and hence these differences are probably not due to differences in leaf angle. Furthermore differences due to leaf angle are undoubtedly small in comparison with the differences due to LAI and when dealing with a crop in the present state of development of cassava the differences are too small to be of importance. Hence the

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leaf area index is of paramount importance in determining crop growth rate. Up to the present only minor differences between varieties have been found.

Root growth and its relation to leaf and stem growth

In order to understand the growth of cassava it is necessary to know if the root sink capacity limits root expansion or even total growth and also if the sink draw by the roots affect the development of the aerial plant parts.

When thick root number of M Col 22 was reduced three months after planting no significant effects on any plant character were observed (Fig. 6) except that root number was reduced from 12.5 to 9.1 and weight per root increased, so that total root yield was not significantly effected. In another trial with CMC 84 root number was reduced by clipping and once again no effect was observed on top growth (Fig. 7). However, when root number was greatly reduced from 10.2 to 3.9 per plant both root dry weight and total weight were reduced. Nevertheless when root number was reduced to 8.1 the reduction in both root dry weight and total dry weight were small (Fig. 7).

Girdling or ringbarking of plants cuts the phloem and hence prevents transport of carbohydrates from the tops to the roots. This method can be used to isolate the leaf source from the root sink. M Colombia 22 and CMC 84 were ringbarked at the stem base to eliminate of the sink effect of the roots on the tops. No significant variety per treatment interaction was observed on any character measured 2 months later and so only treatment means are presented. There was no significant treatment effect on leaf area per leaf or per plant. Stem weight increase was greater in ringbarked plants but the stem plus root weight change was similar in treated and untreated plants (Table 1). In another girdling trial the treatment had no effect on rate of leaf production per apex nor leaf size (Table 2).

When M Colombia 22 was shaded for two months during the root filling period top growth was not reduced significantly but root growth was reduced by 35% (Table 3). Leaf size was not reduced but leaf production rate was reduced by 5 - 15%.

These data suggest that leaf and stem growth has preference over root growth; the roots accept the carbohydrate produced in excess of the potential needs of the top. When root number is greater than 9 per plant (at 10.000 plants/ha) root sink capacity neither limits root growth nor total dry matter production. If root number is very limited then the limited sink capacity may either limit total dry matter production or the stem may accept more carbohydrate in the internodes. Extra available carbohydrate does not change the pattern of leaf area development.

Development of LAI

The previous sections emphasis the importance of leaf area index and the lack of overiding sink limitations as yield determining factors and hence a description of the development of LAI is essential to define the process of yield formation.

Leaf size. The leaf area index is a function of individual leaf size, rate of leaf formation per apex, number of apices per unit area and leaf life. In CMC 84 plots planted and harvested at different times there was a tendency for leaf size to increase until four months after planting and then decrease (Fig. 8). Similar trends were found in other varieties, both with profuse branching (M Col 1607) and without branches (M Col 72 and M Col 1120) suggesting that the same trend occurrs in both branching and non branching types (Fig. 9). The more profuse branching type in this trial showed a slightly greater decline after six months and further trials are needed to define the interaction between the decline in leaf size and branching habit. However, when branch number was artificially reduced by 75% in M Col 113 five months after planting leaf size was only increased by 10% ten months after planting.

Leaf life. When cassava leaves are placed in darkness they abscise and fall within a ten day period (Rosas, Cock and Sandoval, 1976). In order to test the effects of partial shade various treatments were imposed on leaves 10 and 30 days after formation. The leaves did not show any tendency to fall more rapidly until light was reduced by 75% and then the effects were small. With shading up to about 85% the leaf life was markedly reduced; however, the reduction was not such that the leaves fell within 10 days of applying the treatment as in the case of complete shading (Fig. 10). The exact mode in which shading reduces leaf life is not clear but the data do suggest that (1) under complete shade leaf life is ten days from the time after which complete shade occurrs and (2) levels of shade up to 75% have very little effect on leaf life.

Five lines were planted as spaced plants and leaf life was measured through the greater part of their life cycle. CMC 9 had a consistently greater leaf life than the other varieties (Fig. 12). It is unlikely that these differences are due to different shading effects because CMC 84 has about the same vigour as CMC 9, but showed much shorter leaf life. Furthermore there was no trend for leaf life to change with time as would be expected when LAI reached maximum. Recently the variety M Col 72 has been shown to have a leaf life of up to 125 days (CIAT, 1976). In another trial it was found that girdling or ringbarking the plant to prevent the roots draining carbohydrates and minerals from the stems had no effect on leaf life (Rosas, Cock, and Sandoval, 1976). Hence leaf life is independent of root expansion but is dependent on variety and shading.

Leaf formation rate. The rate of leaf formation per unit land area depends on (1) the rate of leaf formation per apex (2) the number of apices per plant and (3) the number of plants per unit area.

The rate of leaf formation per apex of two varieties M Colombia 113 and M Colombia 22 showed a trend to decrease with time (Fig.13,14) and little difference was noted between the varieties. Further trials with five varieties grown as spaced plants (Fig. 15) showed the same trends and little varietal variation. (Data for three varieties is presented, the other two were always between the extreme values and are not shown). Furthermore the actual rates in the two trials grown at different times were remarkably similar for plants of the same age.

Plant population. The number of plants per unit area depends on the planting density and germination. In general germination is near 100 percent and hence number of plants per hectare is nearly equal to plant population.

Branching habit. The number of apices per plant is determined by the branching. There are two classes of branching in cassava. (See previous paper in this series).

The time at which this branching occurrs is a varietal character the variety M Col 1120 has never been observed to produce reproductive branches, M Col 72 occassionally branches after 10 or 11 months, M Mex 11 starts branching after about 5 months while types such as CMC 9 will start branching less than two months after planting and will continue branching six or seven times before they are one year old. Tan (1977) has shown that branching occurrs at the time interval between branch points is constant for example if the first two branches are at 4 & 6 months then the plant will branch at 8, 10, 12, etc.

Suker or side shoots start growth in the shade of the upper leaves and are normally etiolated with small leaves. When these side shoots were removed at high plant populations yields were increased, at low population, when total yield was lower in a non vigorous variety, yield was slightly greater when side branches were present (CIAT, 1975). It does however appear that in order to obtain maximun yield varieties that do not produce side branches are necessary.

DISCUSSION

In order to obtain high yields of cassava roots it appears necessary to maintain a leaf area index of three for as long as possible. During the first three months leaf size increases and leaf formation rate decreases while few leaves fall. The net effect of this is to increase the total leaf area index. In non-branching types leaf size and leaf formation rate decrease and leaves start to fall in large quantities, causing a decrease in LAI from 4-6 months onwards. The only viable manner to prevent this decrease in LAI from this time appears to be via branching at about 6 months. This increases the number of active apices and hence the leaf area formation.

Furthermore maintenance of leaf area index can be obtained with less energy wasted in new leaf formation by maintaining a longer leaf life.

A simulation model has been used to define the ideal plant type (Cock, Franklin, Sandoval and Juri _in press_) and suggests that the ideal plant type has:

1. Maximum leaf size of 500 cm^2.
2. Three point branching at 20 or 30 weeks after planting.
3. Leaf life without shading of 15 weeks.
4. Light nodes.
5. More than ten roots per plant.

TABLE I. EFFECT OF RINGBARKING AT THE STEM BASE ON GROWTH OF CASSAVA. (MEAN OF TWO VARIETIES).

	Root dry weight change (gm^{-2})	Stem dry weight change (gm^{-2})	Stem + root weight change * (gm^{-2})
Control	456	162	618
Treated	60	580	640

* Leaves not included.

TABLE II. EFFECTS OF GIRDLING ON LEAF PRODUCTION RATE AND LEAF SIZE.

	Leaves formed per apex	Mean leaf size (cm^{-2})
Control	11	72
Girdled	12	68

TABLE III. EFFECTS OF SHADING FOR TWO MONTHS DURING ROOT FILLING PERIOD ON M COL 22

	Root dry weight increase gm^{-2}	Stem dry weight increase gm^{-2}	New nodes per plant	New nodes per apex	Final leaf size (cm^2)
Control	303.5	76.6	29.6	18.9	130
Shaded	196.6	70.2	27.7	16.1	146
% reduction due to shading	35	8	6	15	-12

TABLE IV. EFFECT OF REDUCTION OF APEX NUMBER AT 5 MONTHS ON PLANT CHARACTERS OF M COL 113 AT 10 MONTHS.

Reduction in apex number (%)	Fresh root yield (t/ha)	Dry root yield (t/ha)	Dry stem weight (t/ha)	Harvest index (%)	Final LAI
0	33.6	11.3	12.5	44	4.86
25	38.5	13.3	12.7	47	4.44
50	39.7	13.6	12.0	49	4.28
75	40.3	14.0	11.8	49	4.92
Significant Differences	**	**	NS	**	NS

** P= 0.01

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FIG. 1 Crop growth rate of M Colombia 113 as a function of leaf area index compared with (o) data from M Col 1148 in two different experiments

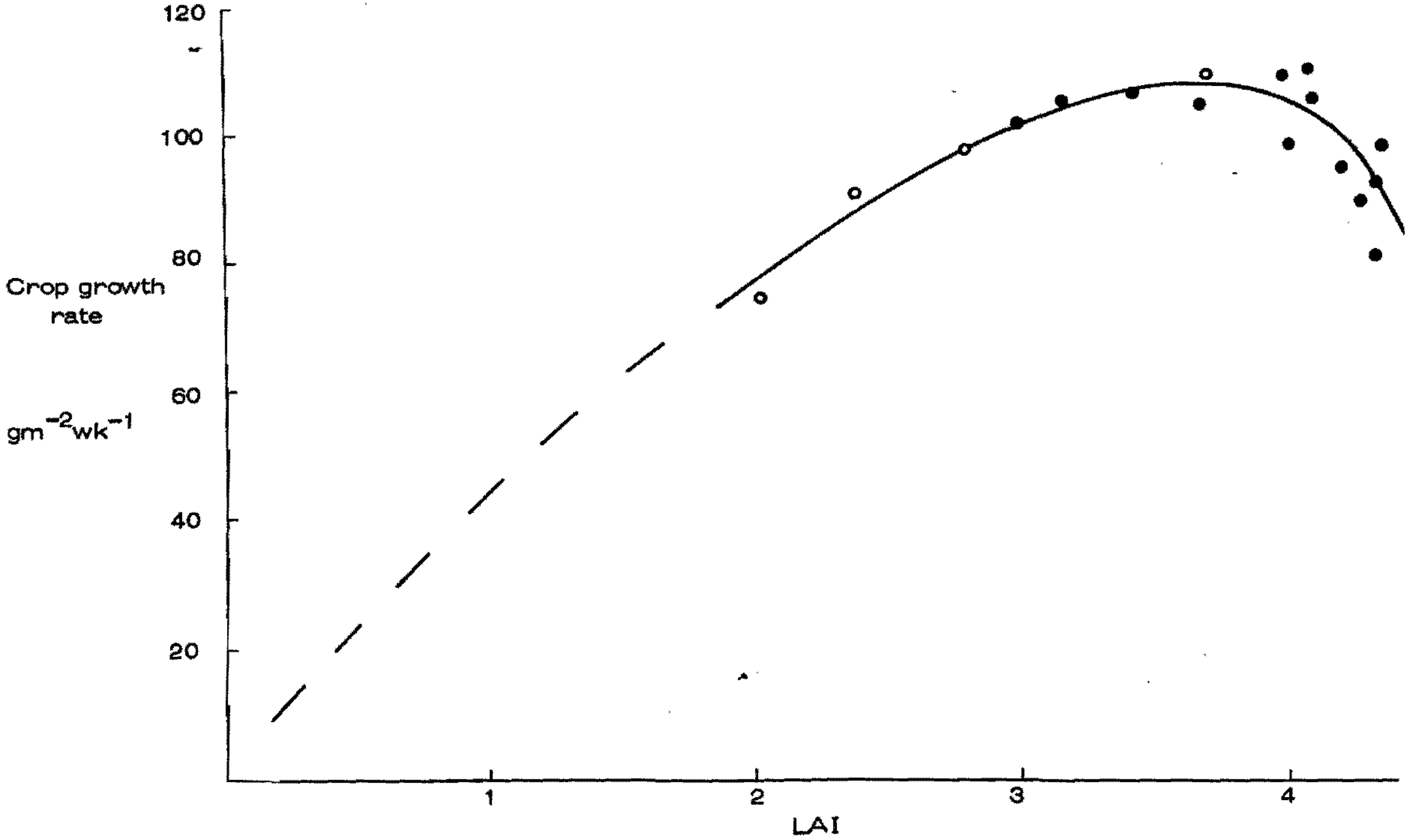


Fig. 2 Root weight increase as a function of LAI
in M Colombia 113

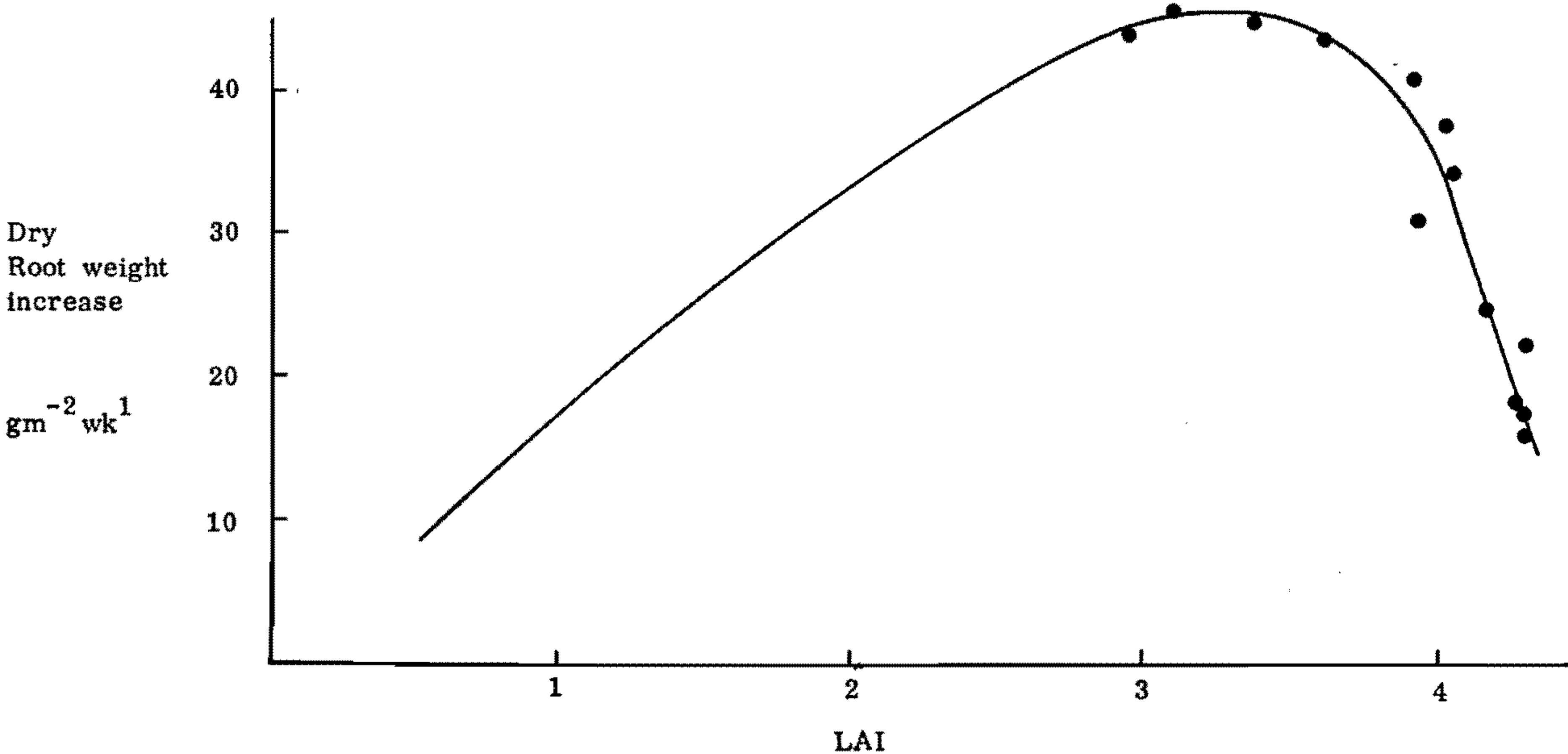


FIG. 3 Changes in root dry weight as related to mean leaf area index 4–6 and 6–9 months after planting

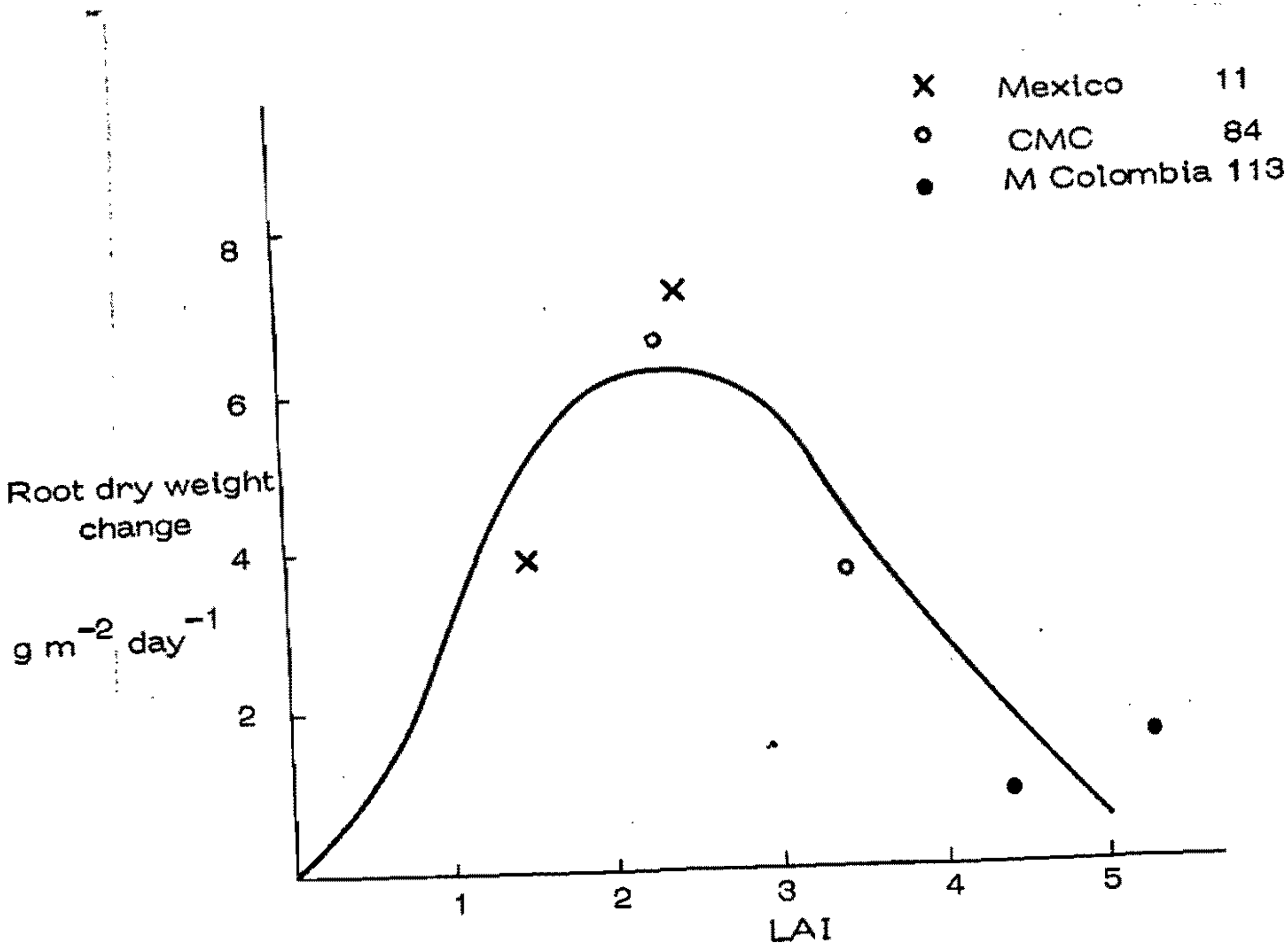


FIG. 4 Schematic representation of relationship between leaf area Index, crop growth rate, dry matter used in leaf area formation and root growth

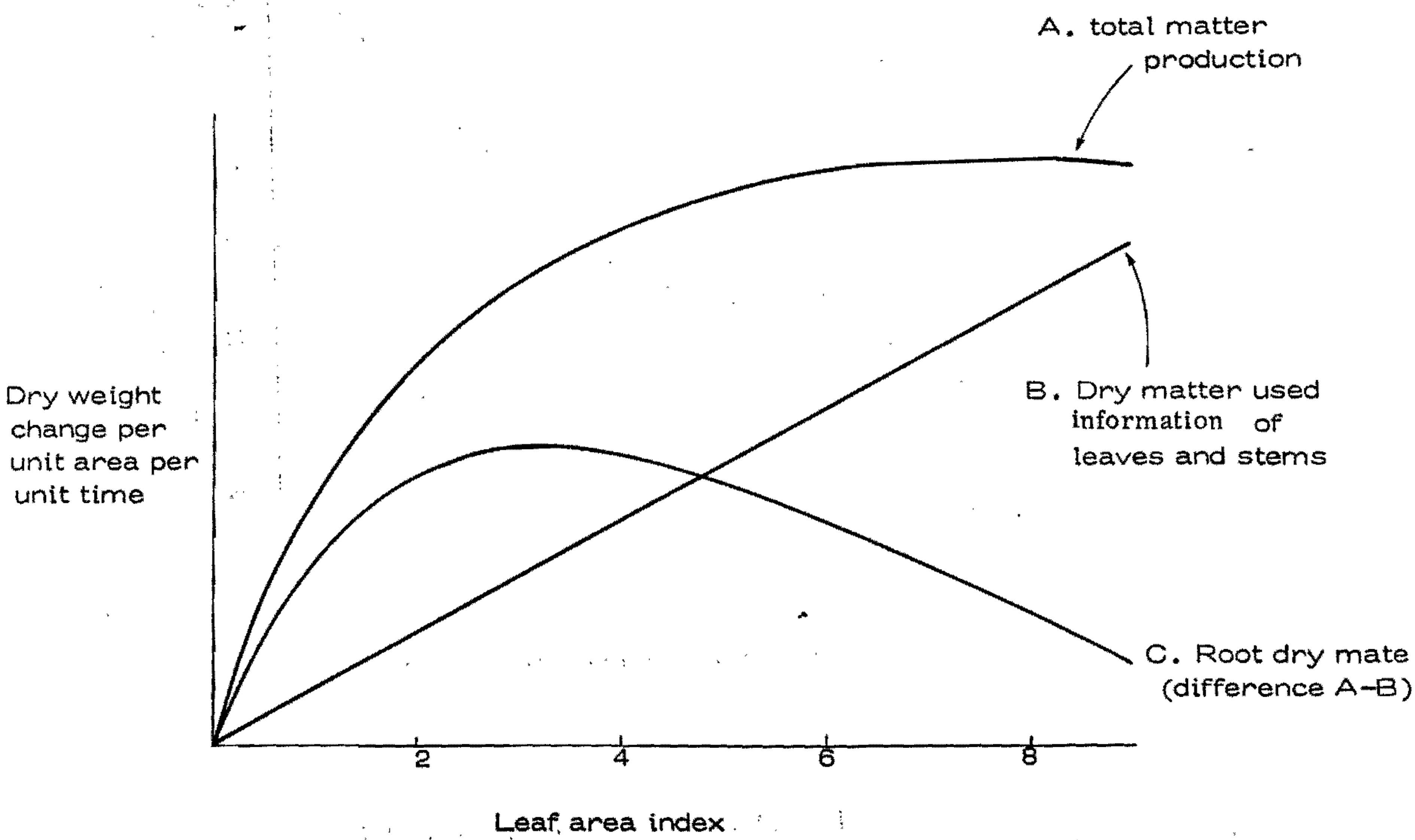


FIG. 5 Crop growth rate as a function of leaf area index M Col 1148 (●) and M Col 12(o)

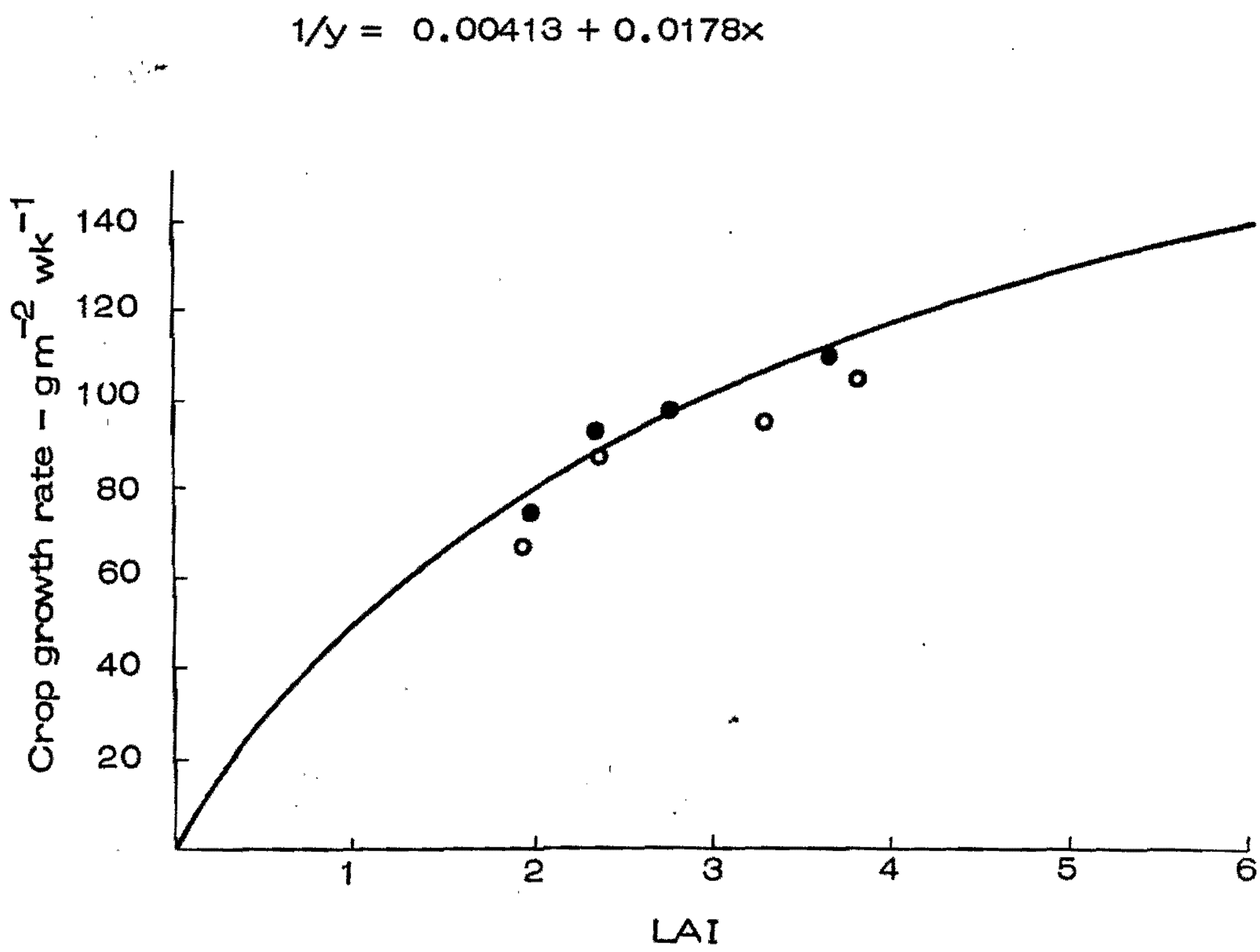
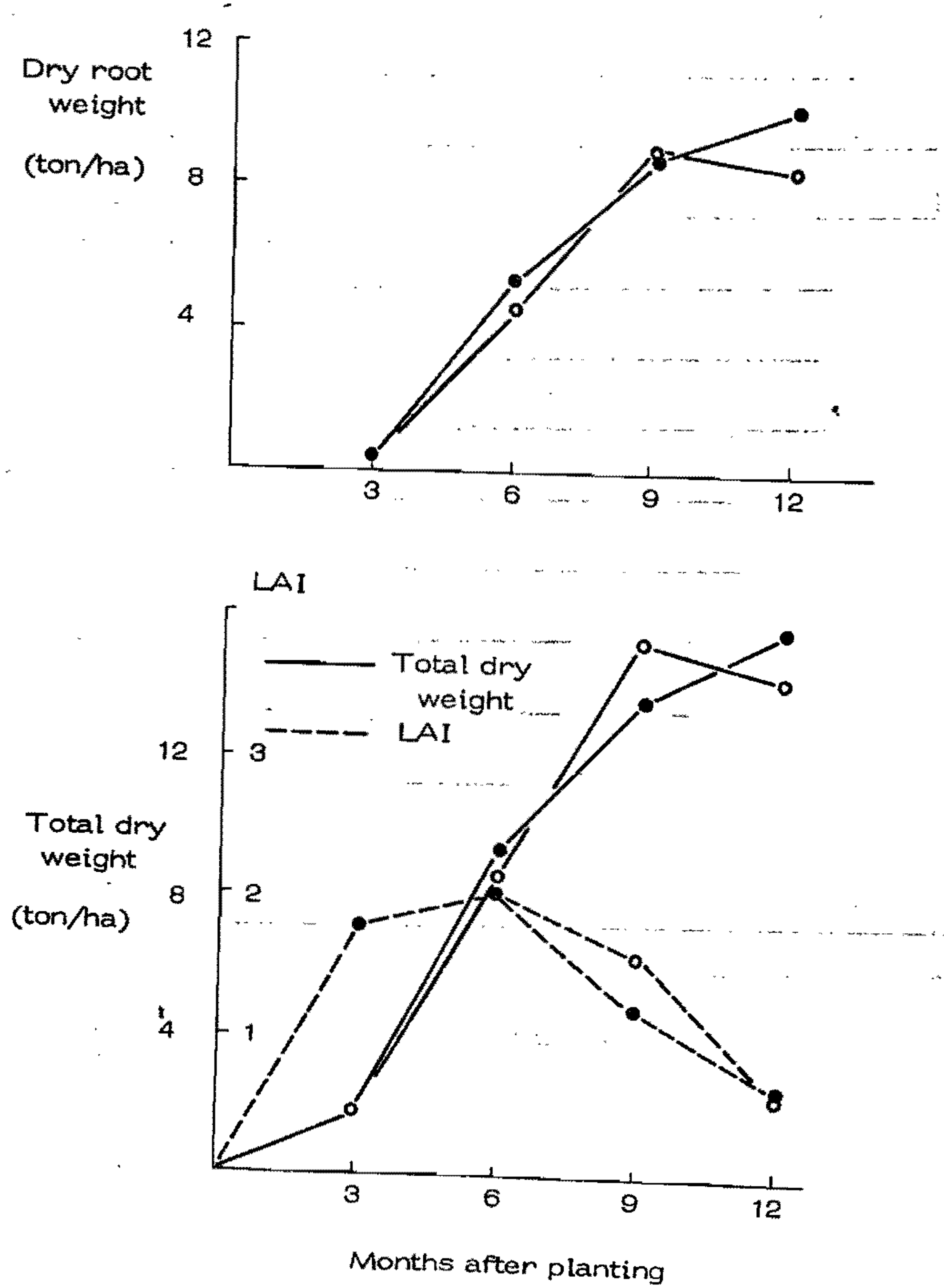


FIG. 6 Change in root yield, leaf area index and total dry matter of M Colombia 22 with normal (.) and reduced (o) thickened root number



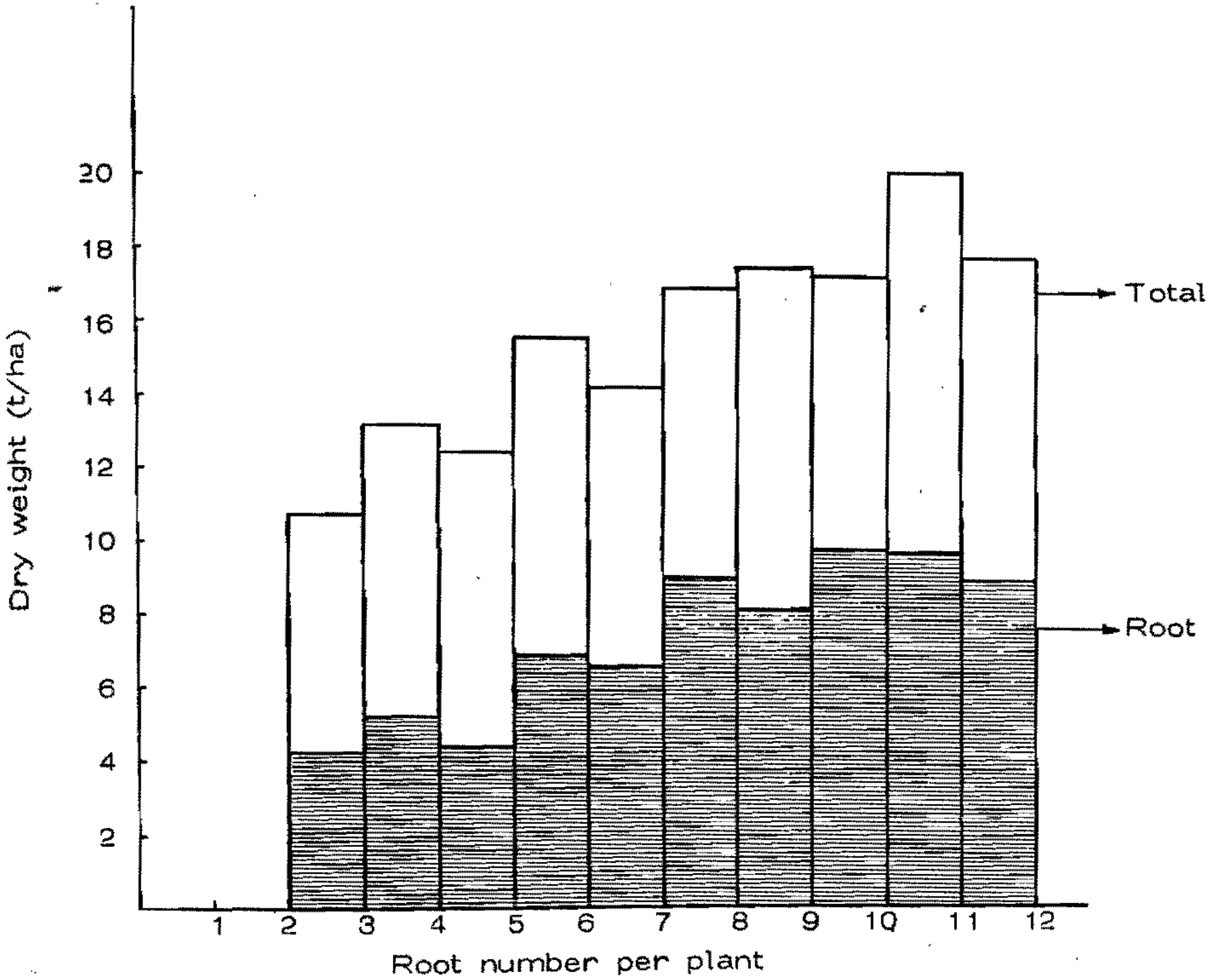


FIG.7. Total and root dry weight as related to root number per plant. Means of all plots that fall in each range are presented. Root number was artificially reduced by clipping at 6 or 12 weeks. Variety CMC 84, harvest 8-1/2 months after planting.

FIG: 8. Leaf size of M Col 1513 as a function of time

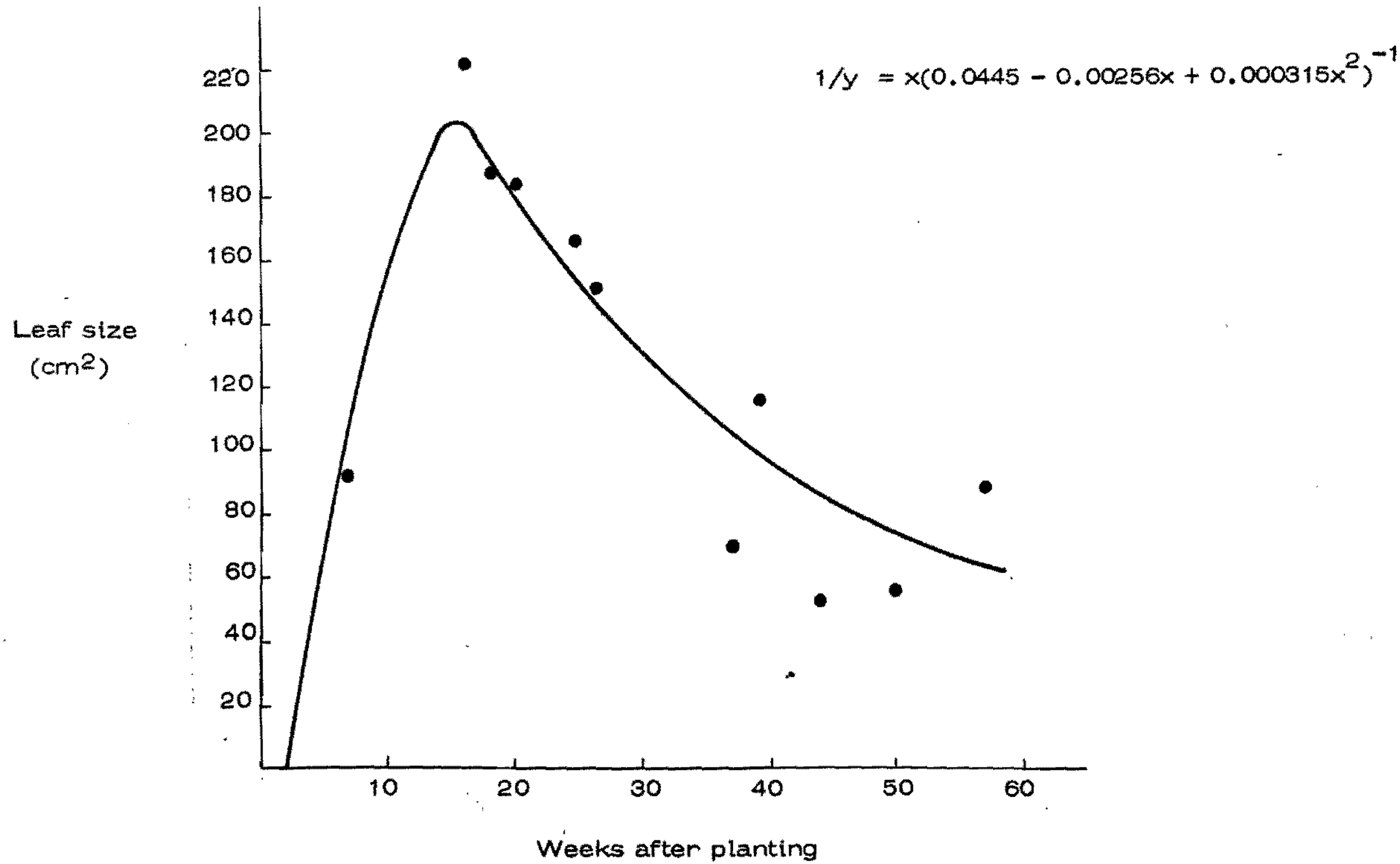


FIG. 9. Leaf size of three varieties

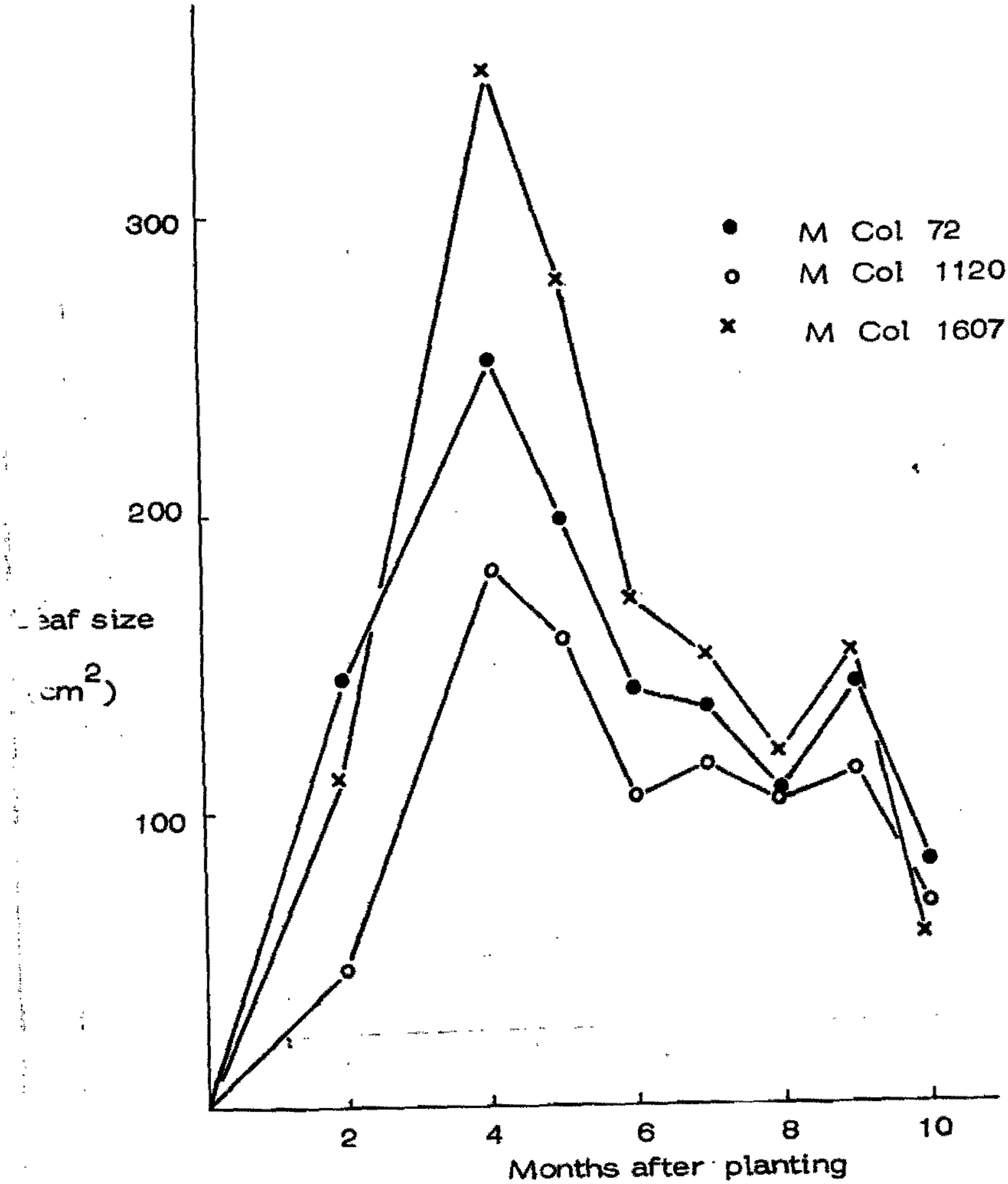


FIG. 10. Comparison between field data and assumption (dotted line) of shading effect used in model

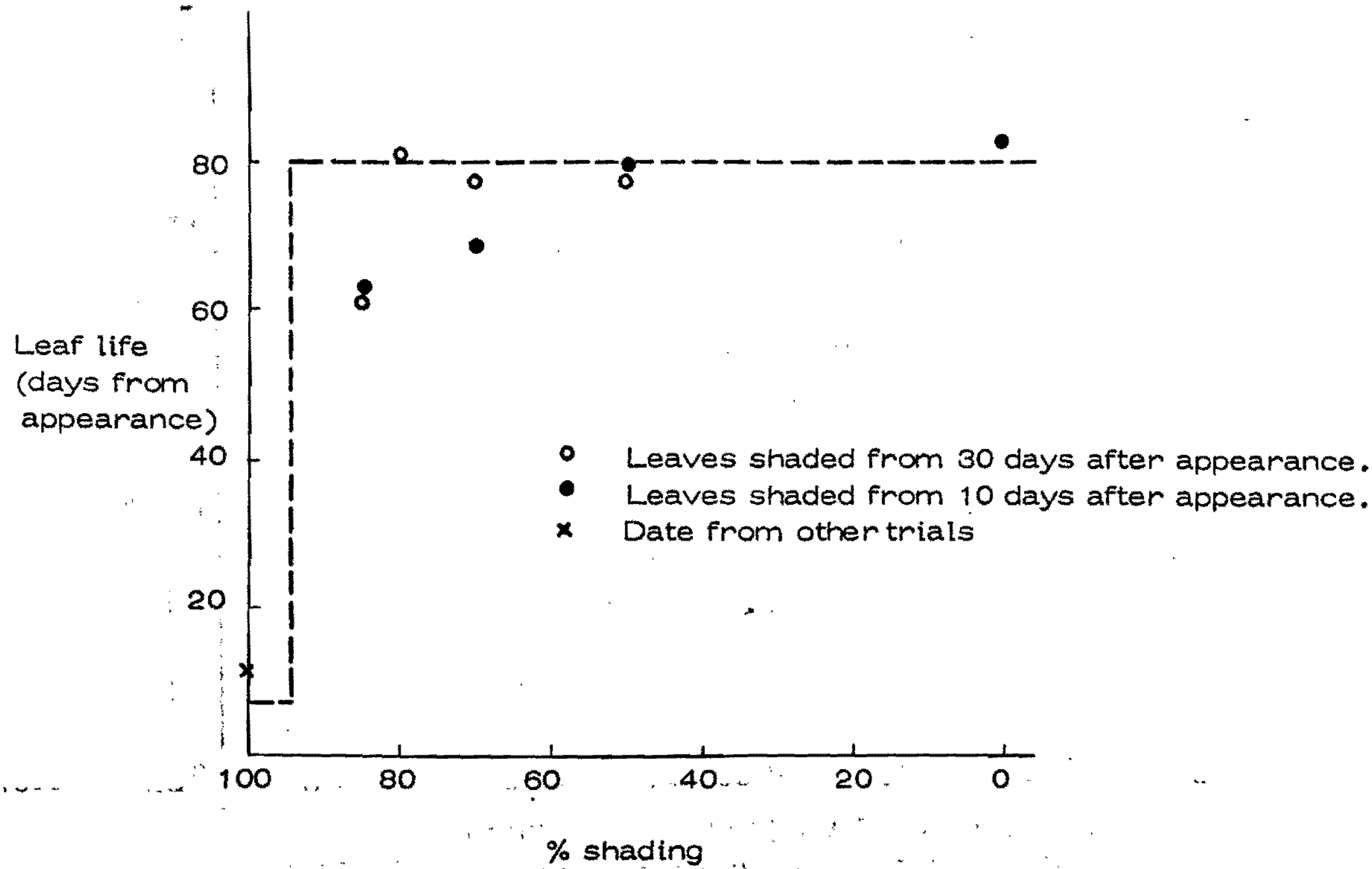


Fig. 11. Leaf life as a function of mean leaf area index during the six weeks after leaf formation.

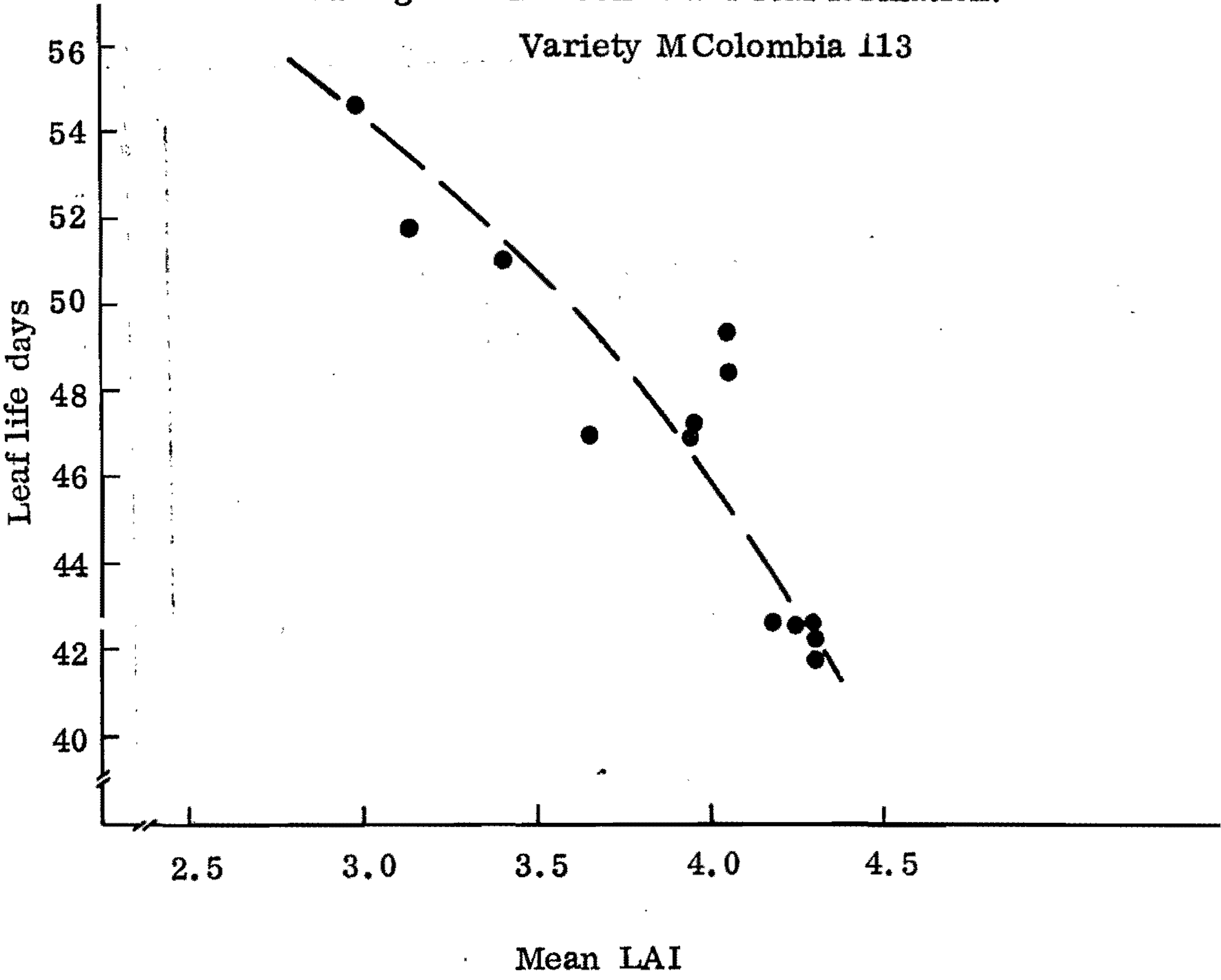
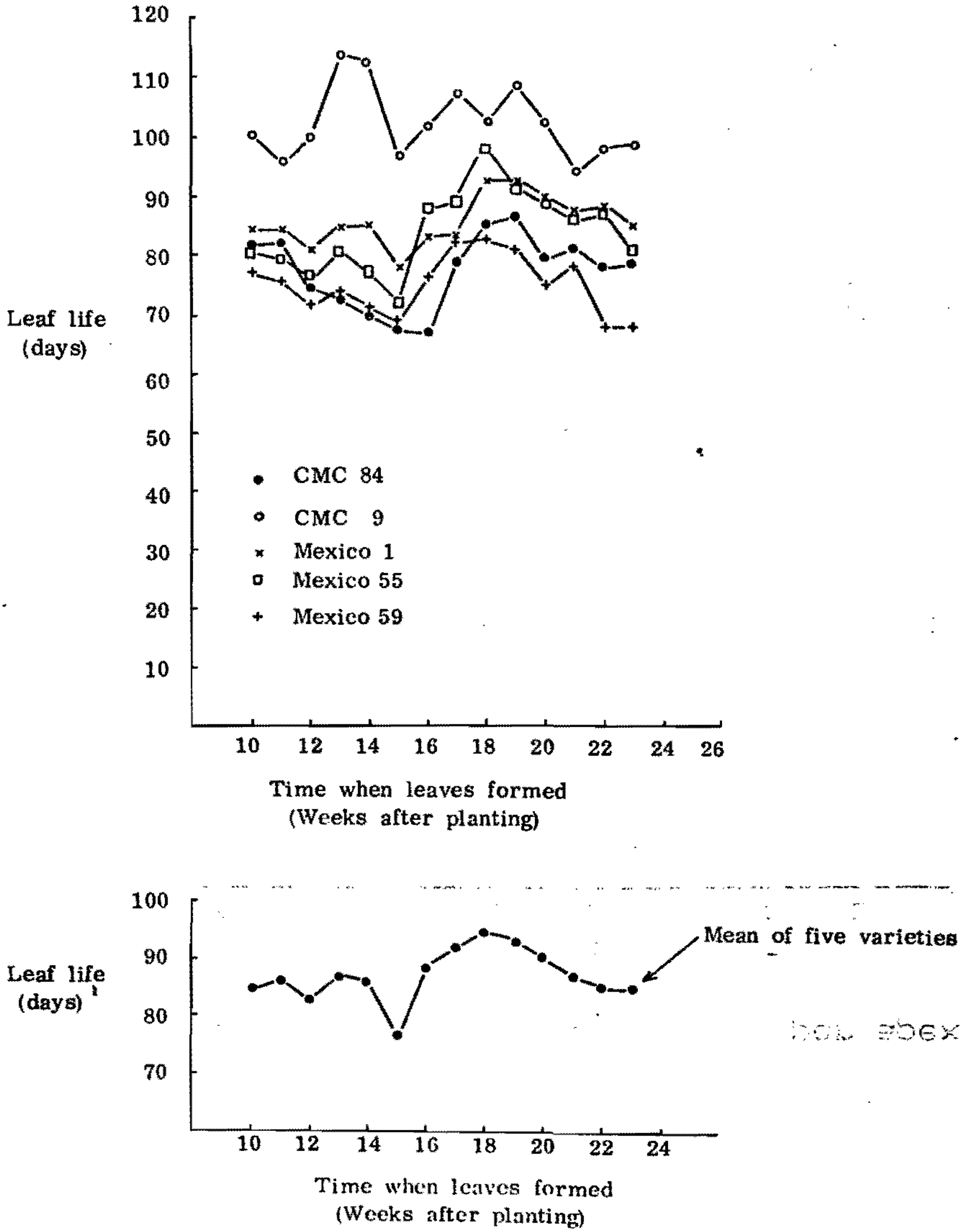


Fig. 12 LEAF LIFE OF FIVE VARIETIES AS A FUNCTION OF TIME AFTER PLANTING (SPACED PLANTS)



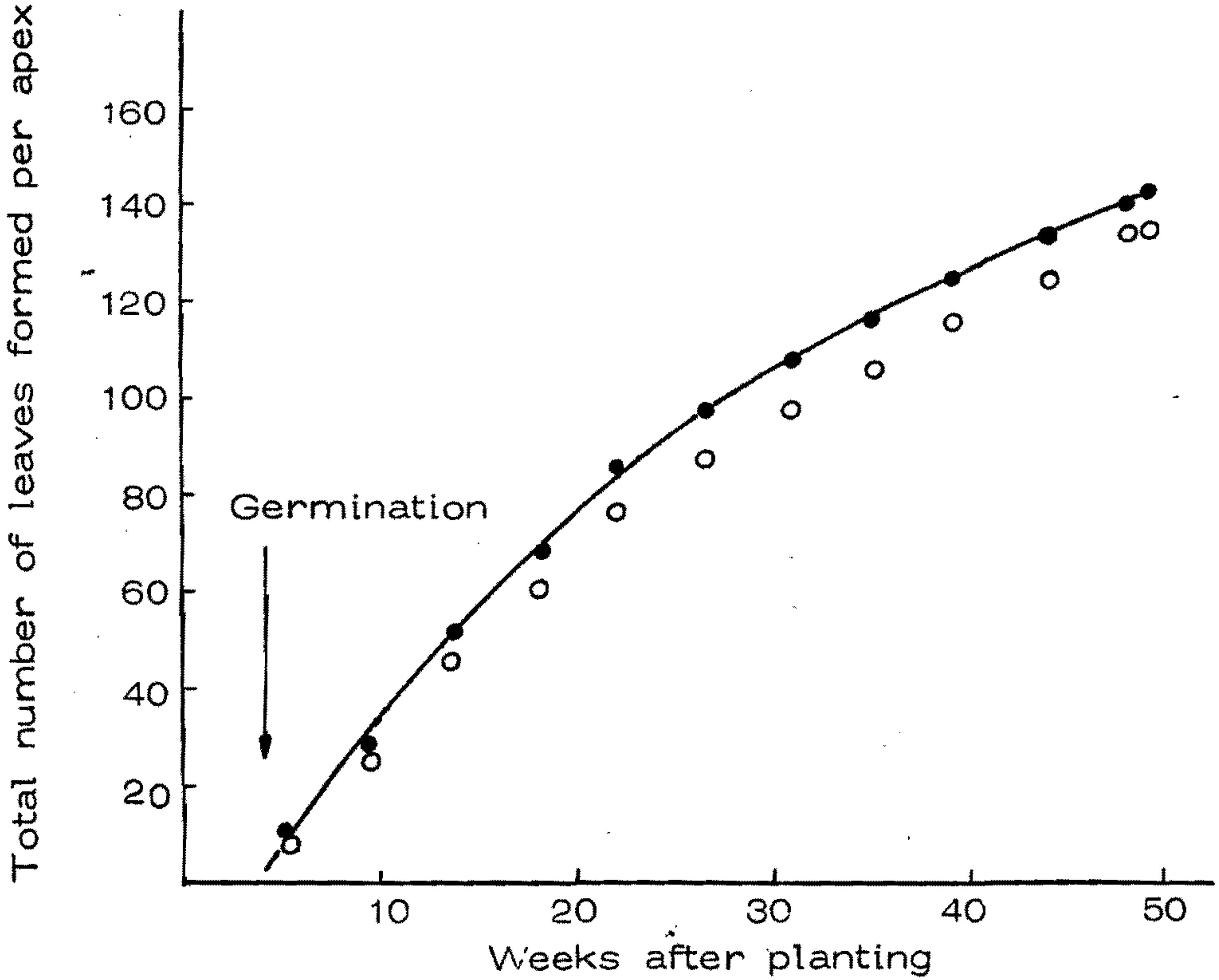


Fig. 13. Total number of leaves formed per apex in M Col 113 (•) and M Col 22 (o).

FIG. 14 Estimated rate of leaf appearance per apex

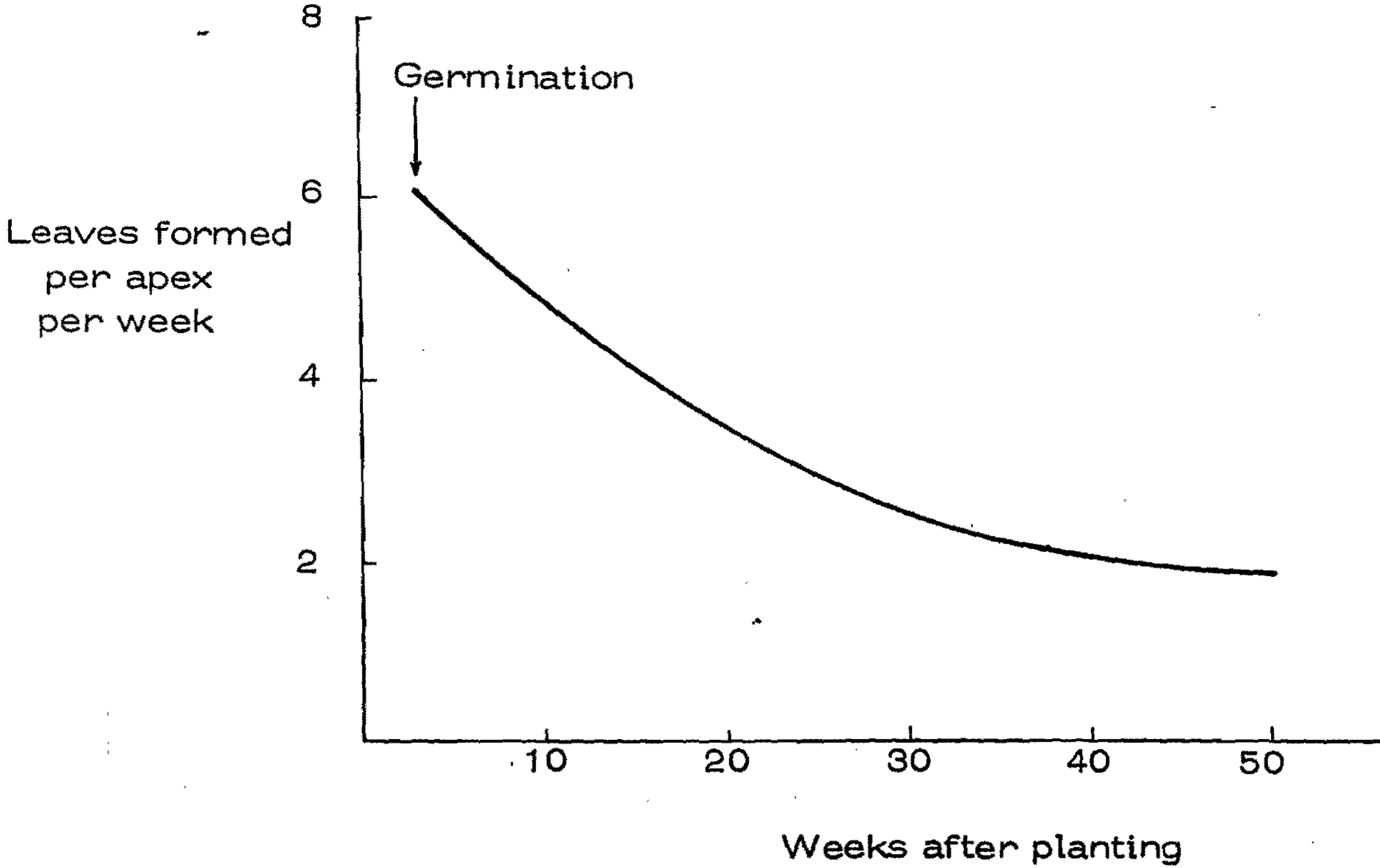
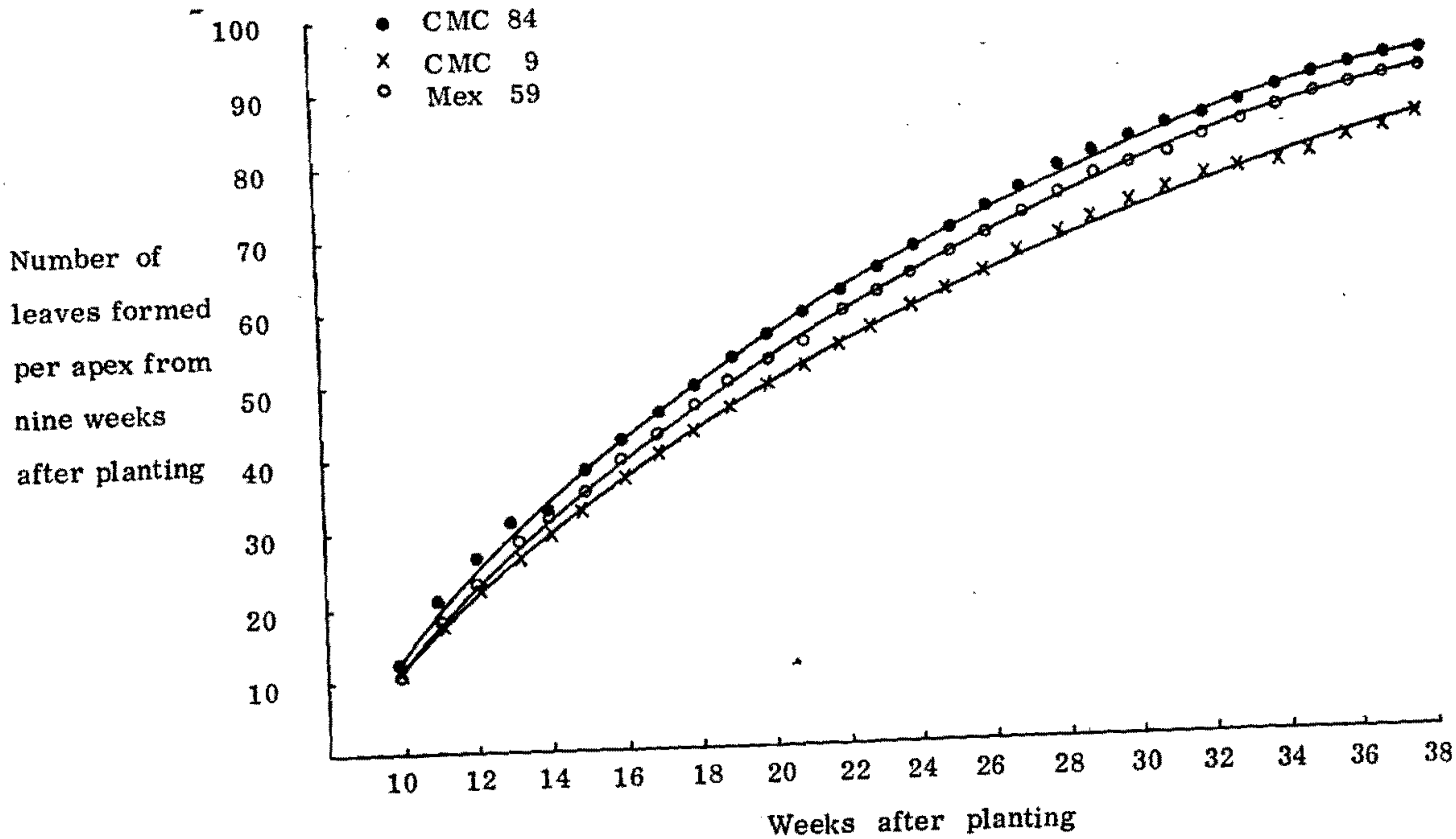


Fig. 15 TOTAL NUMBER OF LEAVES PRODUCED PER APEX FROM NINE WEEKS AFTER PLANTING. SPACED PLANTS.



CASSAVA "SEED": QUALITY, SANITARY CONDITIONS AND STORAGE *

J.C. Lozano
J.C. Toro
A. Castro
A.C. Bellotti**

ABSTRACT

Quality cassava seed production depends on several factors, including the type of material used, sanitary conditions and storage. The quality of the seed per se is determined by the age of the stem used, The number of nodes per cutting, the thickness of the cutting, varietal differences in germination, and the extent of mechanical damage that the cutting may suffer when it is being prepared, transported and planted.

Seed quality is reduced by the presence of systemic, localized or soil borne pathogens or by the attack of mites and insects that may be found on the surface of the stem cutting, within the stem, and/or in the soil.

Storage generally reduces germination of cuttings as a result of dehydration or attack by pathogens and other pests during the storage period.

To avoid problems involved with cassava planting material, cuttings should be selected carefully from good-quality stems, they should be disease and pest free and treated with eradicant as well as protectant fungicides, insecticides and/or acaricides. This tratment makes it p possible to store cuttings for periods of more than 30 days.

Cassava(Manihot esculenta Grantz) is a vegetatively propagated perennial shrub. The swollen roots accumulate carbohydrate (25). Since the plant does not mature physiologically, the roots are harvested from 7 to 24 months of age, depending on the ecological conditions, on the demand for the product, and on the variety used. It should thus

* Throughout the text the term "seed" is used to refer to the asexual form of propagation; i.e., vegetatively.

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be considered as a crop with a long growing cycle.

In any vegetatively propagated crop good propagating material is necessary for high yields; in cassava, losses in germination reduce yield drastically. Unfortunately, this aspect is underestimated by the majority of farmers. In most cassava plantations, the plant population is lower than the number of cuttings planted originally, there is no uniformity in plant vigor from one plant to another, production per plant varies considerably, and root rots are generally found at harvesting. Although edaphic and climatic factors may account for some losses the use of high quality, sanitary cuttings will generally reduce the relative frequency and intensity of losses.

In addition, systemic pathogens (viruses or viruslike organisms, mycoplasma, bacteria and fungi) as well as mites and insects that attack the cassava stem, are diseminated through the use of infected propagating material (1, 14, 15, 19, 20), and are commonly introduced into plantations, regions, continents or countries where they did not previously exist.

For these reasons it is of the utmost importance that cassava growers always use good seed in order to obtain uniformity in their establishment, vigor and production, to reduce root rots, an to prevent the introduction of pests not found in the area. Good cassava seed is produced from quality cuttings, under sanitary conditions, and with proper storage.

QUALITY OF THE CASSAVA SEED

The quality of cassava seed depends on age, thickness, number of nodes per cutting, and size. Although there have been no conclusive findings in this respect, repeated observations indicate that control of these factors is essential for the germination of vigorous plants capable of producing a good number of commercial roots.

Age of the cutting.

There is no definite standard for the age of a stem cutting. Never theless, it is well known that although cuttings from green stems (slightly lignified) will germinate, they are extremely susceptible to attack by soil borne pathogens as well as by sucking insects. Besides, immature herbaceous (green) stem cuttings cannot be stored for a long period of time since they have a high water content and tend to dehydrate rapidly. Also, since they are succulent, many microorganisms (bacteria and fungi) attack them, causing severe rot a short time after planting (11, 27).

When cuttings are taken from plants more than 18 months old, the stem is well lignified and sclerotized, containing only a small amount of food reserves for the shoots that germinate from the buds. For this reason, germinating buds have reduced viability, present delayed germination, and/or produce shoots of little vigor. These older stems may also have suffered a greater number of lesions caused by localized pathogens or insects. It is also more difficult to prepare the cuttings from older, woody stems.

It is recommended that seed be taken from plants ranging from 8 to 18 months of age. The younger the plant, the more lignified should be the part of the stem selected for the cutting. One practical way of knowing whether a stem is sufficiently mature is to determine the relationship between the diameter of the pith and the stem cutting in a transversal cut. If the diameter of the pith is equal to or less than 50 percent of the diameter of the stem, it is sufficiently mature to be used for planting (27).

Number of nodes per cutting.

Each stem node has a germinating bud; theoretically, one plant can be obtained from each node. Nevertheless, it has been found that cuttings with one to three nodes have a lower percentage of germination under field conditions (27). These cuttings are very short and therefore more susceptible to rapid dehydration. Also, pathogens can invade the whole cutting in a relatively short time. Finally, cuttings with a few germinating buds have a greater probability of losing the viability of all their buds during their preparation, transportation and planting. Long cuttings with more than ten nodes theoretically have a better chance of conserving their viability because of the greater number of germinating buds. Nevertheless, when long cuttings are used, much more propagating material per unit of surface area is required, and there is also a greater possibility that this material will be affected by localized pathogens and insects.

Based on these data, the stem suttings used should have from 5 to 7 nodes and a minimum lenght of 20 cm.

Thickness of cuttings

Although any part of the cassava stem can be used for propagating material in a commercial operation, shoots from thin cuttings are weak and produce only a few swollen roots, which are small in weight. It is therefore recommended that the thickness of the stems used for cuttings should not be less than one half the diameter of the thickest part of the stem of the particular variety being used.

Variety

Great varietal differences exist as regards the germinating capacity of cuttings. These differences are accentuated when the cuttings are stored: the longer the period of storage, the greater the differences (Sanay and Lozano, personal information). Therefore, varieties with a higher germinating capacity should be used. The germinating capacity of any given variety can be determined easily by evaluating the percentage of germination among cuttings from different varieties after a short storage period; i.e., 15 days.

Mechanical damage

The epidermis and buds of cuttings sugger bruiser,friction, and machete wounds during their preparation, transportation, storage and planting. Each wound is a new site of entry for microorganisms that cause rot during storage or after planting. It is very important that all precautions be taken to avoid rough handling when cutting and transporting the stems or branches that have been selected for propagating material. The cut should be made on a resiliant surface that will soften the blow of the machete, or a mounted saw should be used, holding the stem with both hands while it is being cut. The cut should be made at a right angle in order to obtain perimetral and uniform rooting (9, 27).

SANITARY CONDITION OF THE SEED

The stem of the cassava plant is attacked by various pathogens that induce internal or external rot and/or cortical or epidermal cankers. Other pathogens invade the woody stem tissue systematically without leaving any visible symptoms (viruses, mycoplasma, cassava bacterial blight). The cassava stem is also attacked by insects and mites that are localized on the epidermis or within the stem.

Pathogenic aspects related to cassava seed

Based on their localization and presence on the stem, the pathogens attacking cassava can be grouped as follows:

1. Systemic pathogens

Are vascular viruses and mycoplasma (10, 14), *Xanthomonas manihotis* (19), and cortical or epidermal (*Sphaceloma manihoticola*) (5, 13), causal agents that invade the host systemically without leaving any visible signs in the mature portion of the stem. For this reason a high percentage of the plants coming from diseased cuttings are diseaded; these plants may constitute the source of primary inoculum in the new plantation. It is by this means that systemic pathogens are disseminated from different regions, countries and/or continents (20).

To prevent the presence of these pathogens it is essential to use healthy seed. For example, African mosaic appears to be caused by a polyhedral virus (2, 24) not found in the Americas or Asia (except for India). However, its vector (the Whitefly *Bemisia* spp.) has been reported in Latin America (1). For this reason it is vital to prevent the introduction of propagating material from Africa and India. In places where the disease is found, its incidence has been lowered through the selection of apparently healthy plants from diseased fields (2). Resistant varieties exist (22), but their seed may bear the causal agent, thus constituting the source of inoculum for plantations where susceptible varieties are used.

It was recently shown that apparently healthy plants can be produced by cultivating plant meristem taken from plants infected with African mosaic (12). Nevertheless, since there is still no method that detects the presence of the causal agent in the host, the system does not provide a margin of absolute safety.

The American viruses (common mosaic and leaf vein mosaic) and mycroplasma (witches'broom) appear to be transmitted in cassava only by mechanical means and in relatively low percentages (10, 14). There, fore, the percentage of infection from these diseases is limited (10). Disease-free plants are always available for selecting seed for planting, and the disease can be eradicated with a high degree of efficiency by roguing (10, 14).

It has been shown that healthy plants can be obtained from plants affected with cassava bacterial blight by taking shoots (5 to 10 cm) from cuttings from diseased plants (17. 18), using the method of rooting in sterilized water (26). The plants obtained by this method constitute the foundation for producing certified disease free seed (18). The foundation stock can be multiplied by traditional methods or by using the rapid propagation method developed by Cock et al. (8). The disease free material can then be used to plant lots where cassava has not been planted before or where the pathogen has been eradicated by a six month rotation (16,17). This seed can be distributed without risk to other regions where the disease does not exist.

The causal agent of superelongation (S. manihoticola) can also be introduced into a plantation, geographic area, country or continent by using cuttings taken from infected plantations (4, 5, 6, 13). For this reason, only cuttings from healthy, disease free plantations should be used. Nevertheless, it has been found that treating cuttings with fungicides such as Difolatan and Orthocide (4000 ppm a.i.), the pathogens can be eliminated from the cuttins (7). Therefore, one of these fungicides should be used to treat the cuttings that are taken from areas where the disease is endemic.

2. Lozalized pathogens

Are nonsystemic pathogens (causal agents of bacterial stem rot, anthracnose, concentric rings leaf spot, some basidiomycetes, etc.), that only invade a part of the stem. These pathogens generally leave cankers of light brown to black necrotic areas on the epidermis of the stem. Otherpathogens such as the causal agent of bacterial stem rot also invade the pith region, which turns reddish yellow to dark brown in color.

This group of pathogens enters the stem through wounds produced mechanically or by insects or by invading the leaf petioles, penetrating them directly or through the stomata. Others enter directly into the stem, rapidly invading the green portion. The degree of invasion decreases as the stem becomes lignified (15).

Any part of the stem that is healthy and that does not show any signs of attack from localized pathogens can be used for planting material. When selecting seed, all parts that are affected by these pathogens i.e., cankers, blackish epidermal areas or reddish pith areas- should be destroyed. It is also advisable to disinfest or handsaws that are used to cut stems, cleaning them with commercial preparations of formaldehyde at 5 percent to prevent mechanical transmission of the disease through infested tools.

3. Soilborne pathogens

That commonly attack some other host such as forest trees (Fomes lignosus, Rosellinia necatrix, Armillaria mellea), perennial crops such as coffee, bananas and plantains (Fusarium spp. Rosellinia spp., etc.), and herbaceous crops with short growing cycles such as cotton and beans (Rhizoctonia spp., Sclerotiumrolfsii, Whetzelinia (Sclerotinia) sclerotiorum, Phytophthora spp., Pythium app.) often also attack cassava. Attack by these pathogens occurs once the cuttings have been planted, beginning at the ends of the cutting, entering through the epidermal wounds or at the base of the shoots and/or in the rootlets.

The best way to prevent cuttings and seedling from attack by these pathogens is to diminish soil infestation by rotating cassava with nonsusceptible crops such as Gramineae and by using certain cultural practices such as good drainage and planting on ridges (3, 23, 27). In addition, it has been shown that treating the cuttings with disinfestants, desinfectants and seed protectants is highly advantageous. Treating cuttings with certain fungicides or mixtures of these has the following advantages: (1) a disinfestant effect, (2) protectant action, (3) longer storage time, and (4) accelerated germination, rooting and growth. Among the fungicides and mixtures that can be recommended are Orthocide + Bavistin, Daconil + Manzate, Dithane M 45 + Manzate, Demosan 65, Brassicol 75, Vitrigram and Agallol (2000 ppm. a.i. in mixtures; 4000 ppm a.i. when used alone). Mixtures usually provide a broader protective spectrum. The cost of the treatment is relatively low (see table) since only one preparation is required for treating a large number of cutting. Therefore, it is recommended that this treatment be done as a matter of routine immediately after the propagating material has been prepared. Results suggest that once cuttings have been treated, yields will increase more than 25 percent and the material will store for one month without losing its germinating capacity (Sany and Lozano, personal information). If superelongation is found in the region, Difolatan or Orthocide should be used. In addition, as discussed below, an insecticide such as malathion, tamaron or basudin should be used to control insects found on the surface of the cutting.

Entomological aspects of the cassava seed

There are mites and insects that attack the cassava stem, reducing the production and the quality of the propagating material that comes from affected plants.

Soilborne insects are also found and attack after planting causing wounds or boring holes through which soilborne pathogens can enter. They may also destroy the epidermis and/or buds of the cuttings completely. Other insects cut the roots and/or shoots shortly after their emergence. Mites and insects attacking cassava can be classified as follow:

1. Mites and insects located on the stem surface

Mites generally attack leaves and green parts of the plant. When they migrate, they are found on the stem surface of the infected plants, where they attack the germinating buds. Through infested material, they can be carried to other geographical areas and continents. For example, *Monocychellus tanajoa* was introduced to Africa on infested cuttings (1,20). The scale insects (*Aonidomytilus albus*, *Saissetia miranda*, etc) and the mealybug (*Phenacoccus gossypii*) are also disseminated in this manner. These insects can reduce the germination of infested cuttings up to 70 percent, depending upon the degree of infestation. The eggs and larvae of other insects such as thrips. (*Frankliniella williamsi*, *Corynothrips stenopterus*, *Caliothrips masculinus*), mealybugs (*P. gossypii*), lace bugs (*Vatiga* spp.) and others can also adhere to the surface of stems and are spread when the infested cuttings are transported from one place to another.

In order to prevent mite and insect infestations on cuttings, acoricides and insecticides such as malathion E.C. (100-300 ppm), tamaron (200 ppm) or basudin (200 ppm) should be used. These products can be applied by dipping the cuttings in the product for 5 minutes; the product can be mixed with the fungicides that are recommended as protectants, disinfestants and/or disinfectants (see table).

2. Insects found within the stem

The insects that are found in the cassava stem are generally stemborers (various species of Coleoptera, Lepidoptera and Hymenoptera). Larvae of these and other insects such as the fruit fly (*Anastrepha* spp.) and the surface or subterranean cutworms that feed on the stem (*Agrotis ipsilo*, *Prodenia eridania*) are often carried unknowingly from one place to another. The tunnels and galeries they make in the stem are another means of access for microorganisms that cause stem rot. To avoid using cuttings that have wounds or that are infested with insects, a careful selection should be made of the stems beforehand. Any part of the stem that has external or internal lesions caused by insects should be discarded and burned.

3. Insects found in the soil

Some insects that attack cassava cuttings after planting are gound in the soil. They usually destroy the cortex of the cuttings and make tunnels, which favor microbial rots. Losses in germination and/or sudden death of the seedlings result. The most common soil insects are white grubs (Coleoptera belonging to the families Scarabaeidae or Cerambycidae), termites (*Coptoterms* spp.) and cutworms (*Agrotis* spp.).

To prevent the attack of these insects, aldrin should be incorporated in the soil (1.5 Kg a.i./ha) or carbofuran (0.9 g a.i./plant) should be placed immediately under the cutting. In the case of termites (Coptotermes spp.), the use of a residual insecticide such as aldrin, dieldrin or chlordane should be used. Toxic baits (i.e., 10 kg sawdust, 8 to 10 liters water, 500 g sugar or molasses, and 100 g trichlorphon for 1/2 to 1 ha) also give excellent results (1.21).

STORAGE OF CUTTINGS

Farmers usually store cuttings while they prepare the land for planting or until the rainy season begings. While the cuttings are being stored whether already cut or in long pieces of stem-buds usually germinate, pathogens and insects contaminate the material, and the material dehydrates. Longer storage periods favor more severe damage. The material may dry out, with signs of visible rotting and cankers on the cortex or, immediately after the cuttings are made, they may lose their germinating capacity. The final result of storage is a reduction in plant population per unit of surface area, which becomes more severe as the period of storage increases.

It has been found that more than 90 percent germination can be obtained after one month of storage when 20 or 80 cm cuttings or stem pieces are treated before storage with the protectang fungicides recommended previously (see section on soil pathogens).

An additional treatment before planting (with the same fungicides) favors germination even more. These treatments can be made with the insecticide applied for controlling the insects that are comoonly found on the cuttings. To prevent dehydration of the cuttings during storage, long pieces of stem, preferable 50 to 80 cm, should be used. When prepating the cuttings, the 10 cm at each end of the stored stem should be discarded.

The storage area should be well shaded and offer high, but not excessive, relative humidity (about 80%), and moderate temperatures (20-23°C). Planting should be right after a rain or after the lot has been sprinkled, since high soil temperatures inhibit germination. The termal inactivation point of cuttings is low.

Although it is not known whether there is varietal resistance to factors that damage cuttings during storage (dehydration, attack by pests, and rapid germination of the buds), highly significant varietal differences have been found (Sanay and Lozano, personal information). Consequently, varieties that have a high germinating capacity should be used.

CONCLUSIONS

It is necessary to plant good cassava seed in order to obtain high yields. In order to obtain good seed, the following points should be considered:

1. Goog quality seed come from a variety with good germinating capacity. The part of the stem selected for the cutting should be of correct maturity (between 8 and 18 months old), have 5 to 7 nodes, measure at least 20 cm in length, and have a thickness of more than one half the maximum thickness of the stem of the variety planted.

2. Care should be taken to prevent mechanical damage to the cuttings during their preparation, transportation and planting. The cuts should be even and transverse.

3. Propagating material should not be introduced from Africa or Asia.

4. Propagating material should not be introduced from regions where there is cassava bacterial blight or superelongation. When these diseases are present in a region, sources of planting material should be taken only from those plantations that remain disease free during the rainy season. If there is no such material available, material free of bacterial blight should be produced (18) and the cuttings treated with fungicides that will eradicate the causal agent of superelongation (Difolatán and Orthocide).

5. Cuttings should not be taken from plants that present symptoms of virosis or mycoplasma, All such plants should be rogued and burned.

6. All cuttings should be checked carefully and any piece of stem that shows signs of localized pathogens (Localized epidermal cankers or pith rotting and insect damage (galeries or tunnels, epidermal wounds) should be destroyed.

7. Cuttings should be treated with fungicides and insecticides as soon as they are cut from the plant and before storage. Storage should be reduced to a minimum, preferably no longer than 30 days.

8. Cuttings should not be planted in soil infested with insects (white grubs, termites, cutworms) without applying insecticides around the cuttings or in the soil.

9. Planting should be done when the soil has a good moisture level and not during the dry season. Good agricultural practices should be used, preparing the soil well before planting.

10. If upon harvesting, there is a lack of uniformity in production and

more than 5 percent root rot, cassava should be rotated with Gramineae for a period of no less than six months.

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COSTS OF TREATING CASSAVA CUTTINGS WITH CERTAIN PESTICIDES AND ZINC SULFATE

Product	Price/kg (Col.pesos)*	G/ha	Cost/ha* (col.pesos)	Aggregate cost/ha (Col. pesos)	Aggregate cost (US $)
Dithane M-45	48,5	333,0	16,0	16	0,43
Manzane 80	45,0	187,5	8,0	24	0,65
Vitigran	61,0	300,0	18,0	42	1,15
Malathion E.C.	86,0	750,0	65,0	107	2,93
Zinc sulfate **	20,0	6.000,0	120,0	222	6,21

* Work of 0,5 man-days

** Use only when there is a deficiency of zinc.

LAND PREPARATION

Alfonso Diaz D. *

Introduction

By land preparation we understand the mechanic manipulation of the soil, which means turning, loosening, leveling, cultivating and packing the material. The purpose of these manipulations is to provide favorable conditions necessary for plant growth. Exact rules, to be followed at land preparation cannot be given because the response of the soil to land preparation methods will be different under apparently similar conditions.

Land preparation is an escencial operation, it is required by every crop, and it is also the most important operation. Proper weather, quality and the cost of land preparation influence following cultural practices as well as yields and other costs.

The objectives and the means used to achieve them will vary according to weather, temperature, water, land labor, soil, machinery available, topography, land tenure, etc. No method is correct by itself under every condition nor it is incorrect under all conditions as well. Decisions about land preparation at each cropping season must be made, and the operation executed before planting. To select the method it is necessary to have a knowledge about the land, as well as some principles which may serve as a guide.

Objectives

The main objectives in land preparation are :

a. To obtain a good seed bed: i.e. create favorable conditions for the establishment of the desired plant population. Such conditions will depend on: controlled moisture, air, nutrients and favorable temperature conditions for germination and rooting of the plant.

b. To increase the organic matter content of the soil by the incorporation of plant residues.

c. To estimulate microbial activity and liberate nutrients from the soil.

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d. To allow air circulation in the ground.

e. To destroy weeds, insects, as well as larvae and eggs.

f. To favour growth of the plants which can be obtained by :

1. Incorporation and dilution of fertilizers and other materials for a slow release of nutrients.

2. Increasing the volume and decreasing the density of the soil to allow a higher water retention capacity and a better root penetration.

3. Improving the utilization of the nutrients retained by coloids.

4. Increasing water absorption by the roots and controlling water movement beyond root zone influence.

LAND PREPARATION OPERATIONS

Land preparation operations can be classified in primary and secondary. Primary labors are those performed with tools like disk plows, mold board, chisel plows, blades, subsoilers, rotay plows. Secondary operations are done with disk cultivators, spike tooth harrow, flexible tooth harrow, roller harrow, etc. Preparation of a soil includes the following steps :

Clearing of the land

This includes elimination of all types of vegetation like trees, tree stumps,chopping of weeds and branches, root chopping and clearing of rocks and stones. In new areas this can be an expensive, slow and big task.The "bulldozer" is the most frequently used machine for this job. The ordinary blade used to carry soil is substitute by special implements.

In preparing lands covered with grasses or crop residues, clearing is performed with implements which chop the grass or residues allowing burning or incorporation according to prevailing conditions. This is done with choppers or rotary plows.

Plowing

Different types of equipment are used for this labor. Disk plows and mold boards are common; but the use of other implements such as subsoilers, rotary plows and chisel plows is becoming wide spread.

Plowing consists of cutting and turning over the upper layer of the soil. Plowing depth depends on the soil itself, loose soils require little depth. Other factors conditioning plowing depth are the type and development of the rootsystems of the crops to be planted, the seed or vegetative portions planted, the formation of hard-pans in the soil, the capacity of the available equipment, the soil moisture conditions, etc. In general, the plowing depth varies between 15 and 60 cm.

Plows are classified in :

a. Mold boards

These will cut the soil with the mold and turn it with the board. Several types of mold boards exist whose uses depend on the type of soil.

b. Disk plows

These were designed to decrease the traction force necessary for the mold board; the rotation of the discs decreases friction of the discs.

c. Rotary plow

This implement is composed by a rotator connected to the tractor's power take, on top of which, certain number of specially designed blades, are inserted. These type of plows are particulary usefull for horticulture and for the habilitation of pastures because of its uniform job at chopping and incorporating crop residues, besides decreasing soil compactation caused by excessive machinery traffic.

d. Chisel plows

These plows are composed of a set of rigid or flexible blades set up like cultivator blades, which penetrate hard layers beneath normal depth of plowing.

e. Subsoiler plows

This is a very specialized piece of equipment for breaking hardpans at depths of 45 to 90 cm. Composed by a sharp cutting end in a rigid bar, with variable depth. A torpedo can be coupled to the implement, thus forming drainage conducts. Its main function is to improve internal drainage of the soil and to allow a better distribution and a deeper development of the roots.

Cultivation

This labor includes breaking soil chunks, thus providing a better seed bed.[1]

Several types of cultivators exist:

a. Spike tooth cultivators

Used to break soil chunks into fine material.

b. Flexible tooth harrow
The same use as the above implement.

c. Disk cultivators
Together with the plow, they are considered the farm's most usefull tool. Several types exist which differ greately in size, weight, number of disks and diameter of the disks. The biggest ones are called rotary plows and are very usefull in land recuperation and may even substitute the plow in light soils. The smallest ones are called finishers and are used to prepare the final seed bed.

d. Rotary hoe
Commonly called "diablo", used to brake the soil crust formed by rain action or irrigation in fine textured soils, facilitating seed germination. It also gives a good weed control during the early stages of development when weeds are begining to emerge. It is composed by star-shapped teeth, coupled to a pulling bar, which rotate as the implement is pulled by the tractor.

Leveling

This operation is fundamental for an efficient use of the soil. It consists of changing the natural slopes of the land accordingly with a topographical study, leaving the soil in all directions or with one or two slopes. Sometimes will be necessary to lebel the surface only in which case natural slopes remain untouched.

LAND PREPARATION SYSTEMS

Conventional systems

Consists of combining the primary and secondary tillage practices normally used in seed-bed preparation.

Minimum tillage system

Generally, only secondary tillage practices are used at a minimum possible intensity.

No-tillage planting system

Planting is done directly on an un-prepared seed-bed.

Reduced tillage method

Consists of using primary tillage practices in combination with special planting systems in order to reduce or eliminate secondary tillage practices.

LAND PREPARATION FOR CASSAVA CROP

In heavy texture soils, were danger of root rot exists, cassava must be planted on ridges accordingly with experimental results obtained at CIAT Cassava Program.

To plant cassava on ridges, land can be prepared in several ways as :

1. Conventional tillage, by plowing, disking and furrowing with furrower blades spaced so the ridges are spaced 1 m.

2. Plowing with a chisel, finishing with a rototiller followed by the furrower or ridger.

3. Furrowing the field at 1.50 m distance followed by a rototiller with a bedder attached behind.

4. Preparing the land to obtain loose soil followed by a sugarcane furrower, which makes ridges spaced 1.50 m.

In general, we can say that land preparation must seek to produce a ridge or bed which allows a better development of plants and roots, limiting losses due to root rots caused by excess moisture, especially in heavy soils. In light soils, land preparation must be such that requires a minimum energy expenditure followed by planting in the flat. CIAT reports that planting in ridges also makes harvesting easier, even though yields obtained at the Caicedonia area have been somewhat lower, 28.4 ton/ha, when cassava was planted on ridges, and 32.2 ton/ha when it was planted in the flat; results from some plots were : 1070 kg/man/day harvested in seven hours with cassava planted on ridges and 869 kg/man/day when planted in the flat.

The time required for each of the different types of land preparation for cassava is presented in the following table :

1. Steep ridge with 1 m distance between centers

LABOR	No. OF PASSES	Time/plot (hours) (2.300 m^2)
Disk plow	1	1.0
Flexible tooth harrow	2	0.4
Disk cultivator	3	0.6
Furrower	1	1.0
Total time/plot		3.0
Total labors	7	

2. High ridge with 1.50 m between centers

LABOR	No. OF PASSES	Time/plot (hours) (2.300 m^2)
Disk plow	1	1.00
Flexible tooth harrow	1	0.20
Ridge shaper	2	2.45
Total time/plot		3.65
Total labors	4	

3. Wide bed. 1.80 m between furrows

LABOR	No. OF PASSES	Time/plot (hours) (2.300 m^2)
Disk plow	1	1.0
Flexible tooth harrow	1	0.2
Bed shaper	3	2.4
Total time/plot		3.6
Total labors	5	

4. Planting in flat

LABOR	No. OF PASSES	Time/plot (hours) (2.300 m^2)
Disk plow	1	1.0
Flexible tooth harrow	2	0.4
Disk cultivator	3	0.6
Total time/plot		2.0
Total labors	6	

METHODS	PREPARATION TIME/PLOT (HOURS) (2,300 m^2)	TRACTOR (HRS) PER HA
1.	3.00	12.60
2.	3.65	15.33
3.	3.60	15.12
4.	2.00	8.40

A RAPID PROPAGATION SYSTEM FOR CASSAVA [1]

J.H. Cock *
D. Wholey **
J.C. Lozano ***

Cassava, like most vegetative propagated crops, has a slow rate of propagation. A mature cassava plant will give about 10 to 30 normal sized (25 cm) stakes after one year; thus the propagation rate is only 10 to 30 times per year. This rate can further be increased to about 100 times per year by using two-node cuttings, but considerable care is required to obtain good results with this system.

These rates of propagation are not sufficiently rapid to give large short-term increases in planting material from new varieties or to supply disease-free stock for commercial planting. A simple rapid propagation method that requires minimum facilities to function was developed by inducing stake sprouting and shoot rooting. This method can provide approximately 36,000 cuttings per year from only one mature plant. This is not the only system that can be used: for example, rooting under mist or in peat pots in humid chambers has been successful. However this system is the easiest to use to date.

Materials

Propagation frames. A level, well-drained site (1.20 x 5 m) should be chosen and delimited by a wall of hollow concrete blocks (0.4 x 0.15 x 0.10 m). The blocks should be placed with the holes in a vertical plane, sealing the holes at the bottom with concrete to form water reservoirs. Crushed stone (about 5 cm) is placed to a depth of 10 cm in the area enclosed by the blocks. The frame is then filled with a soil that drains well. Both sand and lateritic soil brought to pH 6.0 gave good results. A roof made from wood or aluminium covered with polyethylene is placed over the centre of the holes on the blocks (Fig. 1).

1 The initial work on propagation was the research for D. Wholey's PhD thesis; later J.C. Lozano rooted plantlets in water under laboratory conditions and then J.H. Cock put the system together.

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Rooting area. A table covered with a transparent propagation roof frame over it to prevent rainwater splash is used. The propagation frame must be highter than 1.50 m to prevent high temperatures inside resulting from sunshine.

Containers. Samll 25-ml glass flasks, 2 cm in diameter, are used (Fig.2).Old medicine vials are a cheap and effective container.

General sundries. Razor blades and a caldron to boil water, sodium or potassium hypochlorite for tool sterilization, and a soil sterilant (methyl bromide, Terraclor, Brassicol, etc.) are needed.

Methodology

Shoot production. Incorporate fertilizer in the seedling beds if soil has low fertility. Sterilize the soil using a soil fumigant or chemical sterilant according to the manufacturers' instructions. Many of these are highly toxic, thus great care should be taken in their use.

From a mature plant (eight months or older), cut two node cuttings from the woody mature part of the stem, using a saw. Plant these cuttings horizontally, 1 cm below the soil surface (Fig.3). Moisten soil to field capacity and maintain at this level by watering daily. Fill the water reservoirs in the concrete blocks with water and place the roof on the concrete blocks.

About three weeks after planting, a considerable number of shoots form (Fig. 1); with a razor blade sterilized in 1 percent sodium or potassium hypochlorite, cut shoots of 8 cm or more just below a node, leaving a 1-cm stub on the parent cutting. Shoots will continue to be formed (Fig. 4); these should be harvested at three- to four-day intervals, once they reach the appropriate length (8 cm).

Sterilize the glass flasks by placing them in boiling water for at least half an hour. Boil more water for half an hour, allow to cool and then fill flasks to 5 cm.

Clean latex that has oozed from the cut end of choots by washing them in a container filled with boiled water. This water should be changed at regular intervals. Place shoots in flask (1 shoot/flask is best) and leave them inside the rooting area.

During the first week many leaves may wilt and fall. After one to two weeks, shoots will form roots (Fig. 5). When the first roots

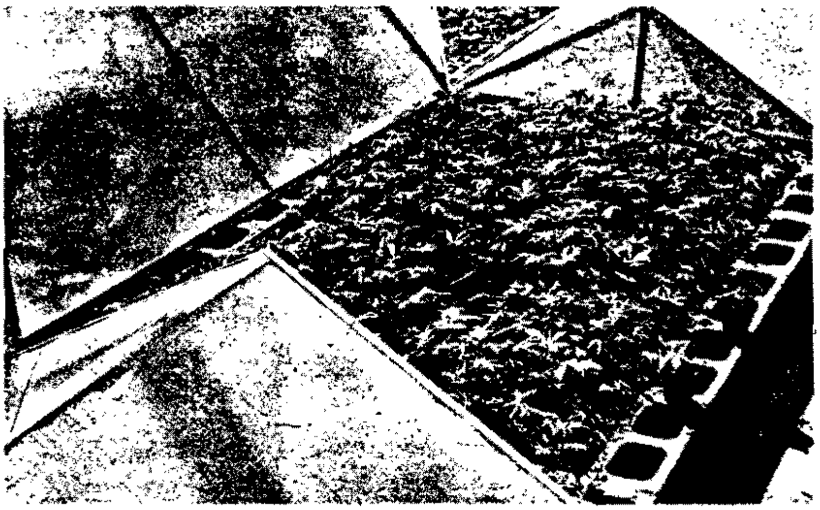

Figure 1. The propagation frame showing many shoots ready for cutting.

Figure 2. Shots rooted in water. These plants have passed the stage when they should be planted.

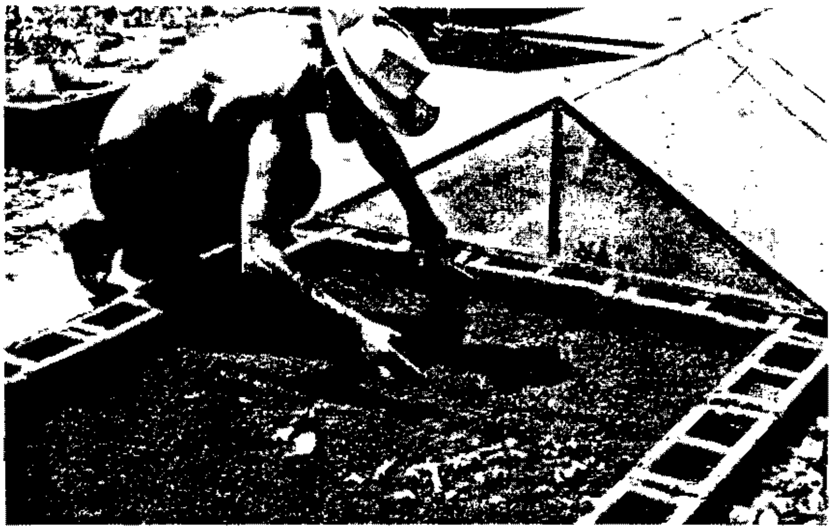

Figure 3. Planting two-node cuttings in the propagation frame.

Figure 4. Two-node cuttings after repeated removal of young shoots show the capacity to produce up to nine shoots per node planted.

1

Figure 5. Rooted shoot ready for planting.

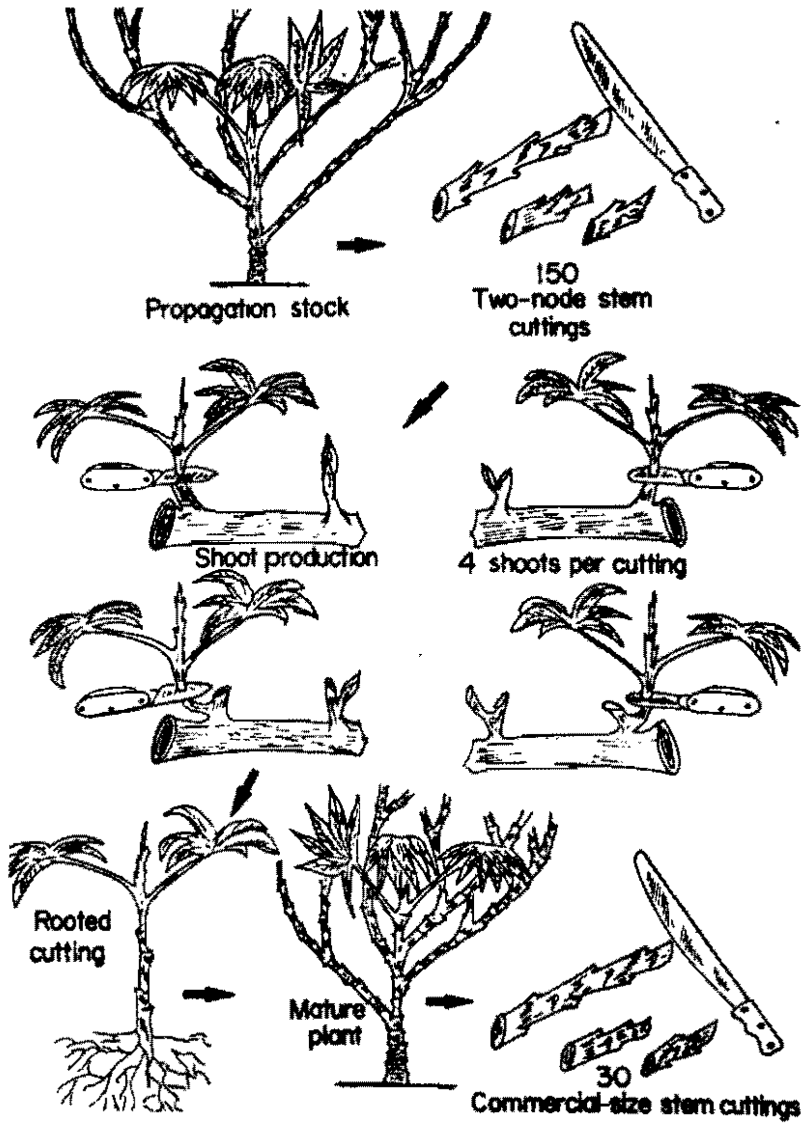

Figure 6. The rapid propagation system.

appear, transplant directly to the field, taking care not to damage the roots. The depth of planting should be such that the plants are buried to the base of the lowest leaf (5 cm approximately). Plants should be well watered for the first ten days.

Discussion

The method depends on the growth of new shoots from the cut base of the first shoot (Fig. 6). It was found that up to nine shoots can be produced from one nodal unit; it is reasonable to expect a production of eight shoots per two-node cutting during the four months after planting.

Starting from a mature plant with 30 normal cuttings, the rate of normal methods can be compared with the rapid system.

Normal System	Rapid System
One mature plant	One mature plant
30 mature plants or (30 x 30)= 900 normal planting pieces after one year.	150 two-node cuttings after four months (150 x 8)= 1,200 plants that give (30 x 1,200)= 36,000 normal planting pieces after one year.

In many parts of the world cassava bacterial blight (CBB) is a severe disease, causing yield losses of up to 50 percent. The disease spreads rapidly through diseased propagating material, reducing establishment and yield and increasing the incidence of root rot. With this propagation method, healthy material can readily be produced and CBB-free "seed" stock built up.

Thus the system can also provide rapid build-up of planting material free of cassava bacterial blight.*

If planting material is to be taken from a CBB-infected plantation, the following recommendations are suggested:

1. Select those apparently healthy plants inside the plantation. They can be identified because of absence of defoliation, dieback, leaf

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* See CIAT Annual Reports 1973, 1974 and Cassava Bacterial Blight (CIAT Series EE-8).

spot and blight, and exudation of gum along the green stem portions.

2. Take the most lignified (mature) portion of stems and cut them, sterilizing tools in between cuts with 5 percent solution of commercial formalin.

3. Plant this material in isolated propagation frames, avoiding spray watering. After sprouting, select only those shoots that are healthy. These must be harvested before 20 days after planting because CBB is able to infect young shoots systemically from diseased cuttings.

4. Observe shoot-rooting material daily and eliminate any suspicious or CBB-infected shoots. After shoot harvesting, burn initial planting material and sterilize frames and covers with a soil sterilant (Downfume, formalin, etc.) before replanting.

Plantlets obtained by this method constitute the foundation block of CBB-free material. These must be planted in an isolated field free of previous CBB infection or in a field that has had no cassava or volunteer cassava plants for at least six months. Plants obtained are sources of clean material for further propagation six to ten months after planting.

Generally, it is recommended to use only CBB-free planting material for propagation since contamination could occur easily if care is not taken.

If a plantation is CBB-infected, clean material must not be planted immediately after harvesting. The elimination of CBB from the soil may be possible through a fallow or crop rotation, releasing the land from cassava for at least six months. All infected cassava residues should be destroyed by burning. It is also recommended that large areas be maintained between clean and infected plantations because of danger from infection through wind-borne rain, soil splash, insects, irrigation, drainage water, and any other mechanical and accidental means of CBB dissemination.

SELECTION AND PREPARATION OF CASSAVA PLANTING MATERIAL

Julio César Toro M. *
Abelardo Castro M. **
Ernesto Celis A. ***

Cassava stem cuttings are used as propagation material or "seed".

The farmer obtains his cuttings from the basal, middle or upper part of the plant depending on his tradition, beliefs or experience. Size and style of cut of the cuttings will vary according to the availability of plant material.

Field Research Data is varied and even contradictory in some cases. This may be explained by the fact that, in many cases, the enviromental conditions as well as the plant material used are different. Field trials are being conducted at CIAT to provide an answer to this question.

I. Selection of Stakes

A. Age of the Plant

Tender cuttings will encounter more problems in the field than mature ones, especially if soil moisture is deficient. On the other hand, as stems grow old, i.e. 18 months, the axillary buds will sprout, thus impairing the plant material for use in commercial propagation. Reference is made here to age of the stem and not of the plant since age of the stem will depend on its relative position within the plant. For example: A very tender plant, i.e. three months old, only a very small portion of the basal part of the stem could be used safely as planting material under field conditions. However, as the plant grows older and the stem accumulates reserves, upper portions of the stem could be utilized as propagation material. A mature plant (12 months old, under CIAT conditions) like MCol 673, will provide good planting material from its basal, mid and even its apical portion.

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Literature is controversial as to recommendations related to optimum age and part of the plant from which cuttings should be obtained for propagation material. According to Fairlie (6) germination, number of shoots and yield are independent of a basal, mid or apical origin of the cutting. Delgado (5) and Jeyaseelan (7) obtained the best results with cuttings from the woody (basal) section. Costa (4) recommends as best propagating material the mid portion of the plant.

B. Diameter of the Pith.

A practical key to determine if the cutting is mature enough to resist adverse conditions can be obtained by performing a cross-sectional cut on the stake. The diameter of the central pith should occupy 50 percent or less of the total diameter of the cutting. These conditions may be found in any part of the plant, depending on its age. If we consider the same cultivar from the previous example, with only 7 months of age instead of 12, growing under the same conditions, we would find that in cuttings from the apical portion the diameter of the pith is more than 50 percent of the diameter of the whole stem, limiting the use of this material in commercial plantings. If the plants available for seed material are too old (two years) probably only the material from their mid and upper third would be adecuate, because the basal portion of the stem would be too thick and woody which makes cutting, transportation and planting more difficult. Depending on the cultivar, it is also possible to find deteriorated or "germinated" axillary buds.

C. Crop Protection.

Plantations affected by disease which can be transmitted by the stakes, such as virus and bacterial blight, which affect productivity, should not be used as a source of seed. Certain cortical fungi, such as those causing superelongation and others affecting woody tissue such as Diplodia sp. Glomerella sp., etc. are also transmitted by infected stakes. In either case, even apparently healthy plants should be eliminated from an infected plantation. If a stem is affected by an insect, the stem or at least the affected portion should be eliminated. (Lozano et al, 8).

D. Viability of the Stake.

A cross-section cut stake will show a latex flow in the cortex zone. This latex is characteristic of the Euphorbiaceae family. The presence of latex determines the stakes potential for sprouting. Latex content is related to the moisture content of the stake.

According to CIAT (1), a 10 percent, moisture loss in the cut stake results in a 10 percent loss in germination but, if loss of moisture is 20 percent, germination losses will increase to 50 percent. A total loss will occur when moisture is reduced to 60 percent. A stem cutting exposed to solar radiation will rapidly loose its germination ability and the amount of latex will gradually decrease. If latex appears immediately after cutting or within three seconds, it can be assumed that the stake has sufficient moisture, and consequently good germination potential. If latex takes more than three seconds to show, the stake should not be used for planting if better quality material is available. The shorter the stem the more rapid will be the loss of sprouting potential and the apical ends will be affected first. Because transportation and handling may damage the axillary buds, stakes with less than three healthy buds should be discarded.

II. Preparation of stakes

A. Size.

A cassava plant may be obtained from a very small cutting, with only one bud, but the possibilities of germination under field conditions are scarce especially when the soil is deficient. The early development would be affected if planting is done in poor soils because nutritional reserves would not be enough in a small cutting for initial growth stages. Also the smaller, the unburied portion of the stake, the tougher will be the competition with weeds. The advantages of using very long stakes, i.e. 60 cm long, would be higher initial height of the plant and a faster overshading of the soil increasing the ability to compete with weeds. Economic aspects as well as practical considerations about handling of the stakes normally affect the size of the propagation material. The lenght of the stakes generally used by farmers is 15-25 cms. Recommendations of some research workers are within this range and could be applied unless a field trial done under local conditions, including production costs, indicates a more convenient size. Field trials are being conducted at CIAT to answer these questions. Silva (10) found a positive correlation between size of stake and root yield. He recommends stakes at least 30 cm long. Chan (3) found no differences in yield using stakes 8, 15 and 23 cm. long. Rosas (9) used stakes 10, 20 and 30 cm. and found the highest yields were produced by 10 cm. long stakes. CIAT (2) in three different locations obtained the best results with 40 cm. long stakes.

B. Cutting of Stakes.

Once the plant material is free of insects and disease, it is ready to be cut with a sharp instrument, normally a machete. The cut should be performed uniformly, without ripping the cortex or splitting the wood. When a knife or a machete are used, the piece of stem is held with one hand, one small blow with the machete followed by a 180° turn of the stem and a second is needed to finish the cut. Using a single blow of the machete will produce good cuts at first while it is still sharpened and the operator is not yet tired. After one half hour the cuts will start to be defectus.

When the cassava stems are placed against a hard surface for cuttings,

great damage is caused to the stake; it is preferable to hold them freely in the air for the cutting operation.

*The use of stationary benches with power saw to cut large amount of stakes is very common in Brazils large cassava plantations, intended to produce alcohol. A very simple device is also attached to the unit for continuous cleaning or sterilization of the saw to avoid any possible contamination by any undetected mechanically transmitted disease.

C. Treatment.

The cut material can be treated immediately before planting to prevent the attack of soil born fungi which could impair germination and diminish stake vigor. **At present time a mixture of 3 fungicides and an insecticide (Table 1) is recommended. Some of the products can be changed later according to better findings of the pathology group.

TABLE 1. STAKE TREATMENT RECOMMENDATION MIXTURE

Product	Grams/ Litre H_2O	Grams/ ha	Accumulated cost/ha US$*
Dithane M-45	2.22	333.	0.43
Manzate 80	1.25	188	0.65
Vitigran	200	300	1.15
Malation W.P.**	500	750	2.93
Zinc Sulphate***	40.00	6.000	6.21

The solution could be prepared in a 200 lt. container, using only 150 lt. to allow the full immersion of the sack cloth containing the stakes without spilling the liquid. Aproximately 30 lt. of the solution are enough for 10000 stakes, depending on the type of sack cloth used. Immersion of the stakes should last 5 minutes, when no zinc sulphate is used. When this last product which is a fertilizer is used, stakes must be immersed during 15 minutes.

For ease of handling it is advisable to place the material in fique or cabuya sacks[1] with a not too thick needle point in such a quantity that allows soft treatment of the stakes and easy handling of the bags. Once immersion is over, the excess of liquid is allowed to drain out of the bags and the stakes will be ready for planting.

* Using 0.5 man-day

** When using concetrated emulsion use 1cc per liter of H_2O

*** To be used only in Zinc deficient soils.

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PLANTING METHODS AND CARE AT EARLY GROWTH STAGE OF CASSAVA

Julio César Toro M. *
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Ernesto Celis A. ***

Whichever the planting method used, it must be emphasized that good permination of the stakes, requires sufficient soil moisture and good soil preparation.

Planting methods

Several planting methods are used depending on climate, soil and preferences of the farmer. Basically there are four methods :

A. On Flat Level

Planting is done in the field either by hand or by planting machine after conventional tillage labors have been made. This method is much used in light or sandy soils which do not present problems due to excess moisture that may cause rottenness. Studies carried out by CIAT at the Oriental Plains of Colombia, showed that level planting is advantageous when done during the dry season.

B. On Ridges

Stakes are planted on the crest of a ridge, made with a moldboard plow or ridger. These furrows may be high and steep or with a flat crest. This system is recommended for areas with high precipitation where soils are heavy or drainage is poor. The furrows in between the ridges provide a good surface drainage decreasing the occurrence of root rotting. At the Oriental Plains of Colombia, levee planting is favorable when done during the rainy season.

The levee method facilitates the use of furrow irrigation by making water handling easier. Finally, on very heavy soils, levee planting makes harvest easier and the same will be true for any type of soil if harvest is done under dry conditions.

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C. Bedding

Under this system, developed at CIAT, stakes are planted on a trapeze shaped bed. The beds are built by attaching a special Large Hinge behind a rototiller. Height and width of the beds are variable depending on the equipment used and on the type of soil.

Ridge and bed planting systems are used preferably on medium to heavy soils where problems due to excess moisture in the soil are expected. With these three methods, planting may be manual or mechanized.

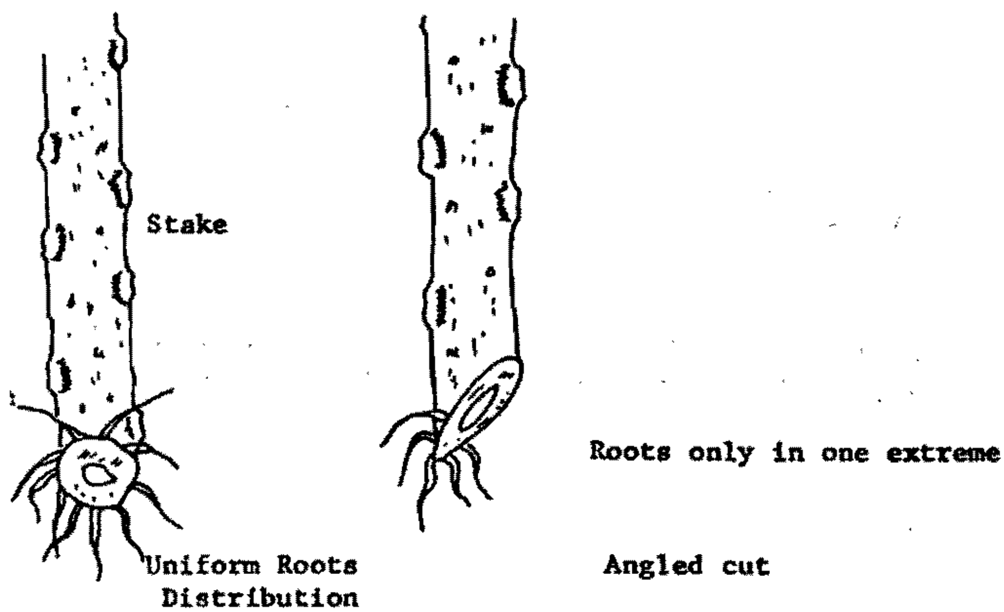
Levees or beds are not recommended for sandy soils since they would not last too long.

D. On Hills

Stakes are planted on the apex of a conical shaped hill mound built manually, generally by the use of a hoe. This method can replace the levees in areas where machinery is not readily available.

Cutting of the stakes

The stake may be cut in a straight or a slant angle. Field observations have showed that when the cut is done by only one blow of the machete, the angle tends to be slant. Two blows will generally result in a straight angle cut. It has also been observed, that as a consequence more roots will differentiate from the straight cut stake than from the slant cut. (Fig. 1).



Straight cut

Stake Position

In any of the planting methods mentioned above, the position of the stake may be :

A. Vertical

The stake is introduced vertically, burying at least four buds to guarantee a good germination. At this position roots tend to form at the lower end of the stake, distributed radially, more or less uniformely.

B. Inclined

The stake is introduced in the soil at a 45 degree angle with the surface. In this case the roots follow the direction of the angle of inclination of the stake. Some farmers think that harvest labor is easier with this method because of the position at which the roots are formed.

C. Horizontal

The stake is placed in the soil horizontally and buried completely. To present, this is the only planting position which has allowed mecanization of this operation. It can be done manually, but in either instance a furrow must be opened prior to placing the stake in the soil. In this position roots generally tend to form at the end opposite to the direction of the buds. When the stakes are too long, roots may form on both sides.

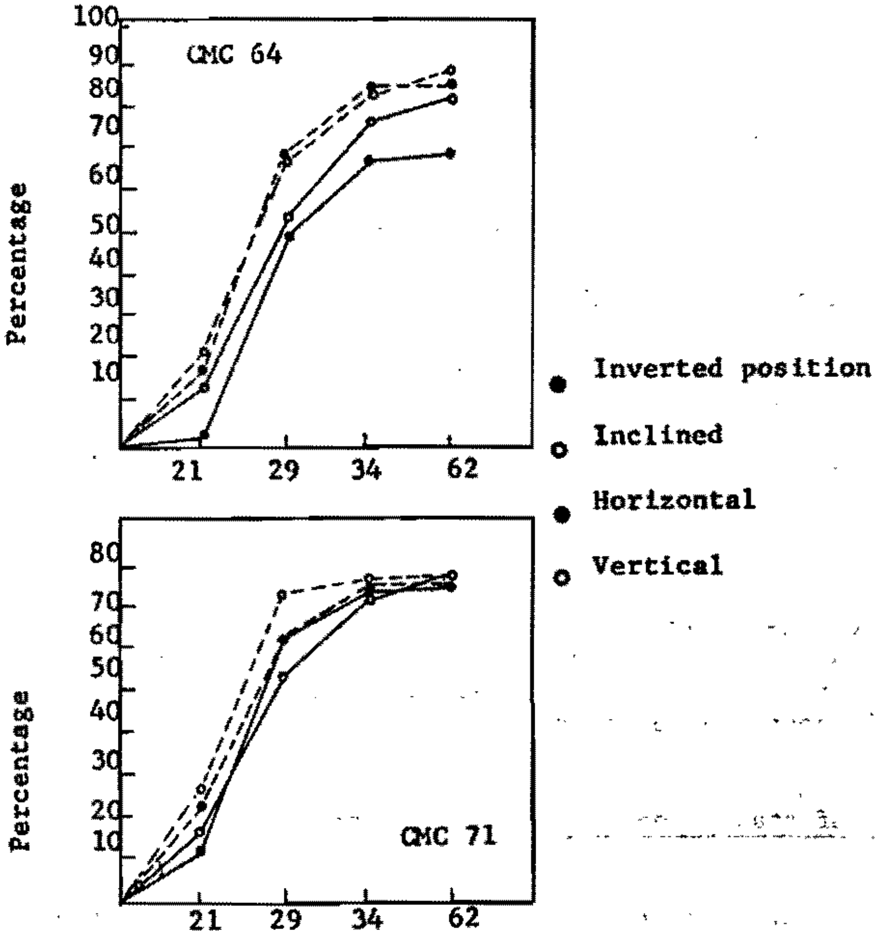
Another system used by farmers consists of placing two stakes horizontally with buds opposing. This method has not been evaluated at CIAT.

A variation of the vertical and inclined positions is the staggered or zig-zag arrangement, which allows a better use of the soil cube and of solar energy. The first year research data at CIAT shows no major advantage of this method versus traditional systems. Studies will continue to ascertain this.

Germination of stakes under field conditions

Stakes 15 cm. long of cultivars CMC 71 and CMC 64, were planted at CIAT in vertical, horizontal, inclined and vertical inverted (with axillary buds facing downwards) positions. In both cultivars vertically planted stakes emerged more rapidly (Fig. 2); those invertedly planted were slowest. Final germination was similar in all treatments for CMC 71, and for CMC 64 germination of inverted stakes was inferior to the other treatments.

Fig. 2 Germination of cassava cuttings planted at four systems. Cultivars CMC 64 and CMC 71.



Depth of planting

Stakes can be planted superficially or deep in any of the methods and positions discussed before.

Literature is highly controversial concerning this topic . Such discrepancies may be due to the fact that reported experimental results are obtained from trials conducted in different countries, and in different regions within the countries, with differing climate , soil, precipitation, altitude and latitude.

A good practical criteria is required; thus, if cassava is to be planted in a dry and sandy soil, stakes should be buried deeper. A moist and heavy soil will require shallow planting. In the latter case it should be remembered that a deep planting, will make harvest difficult, thus increasing production cost.

Initial care

A. Pathogens

They are abundant in the soil and may affect the germination of the stakes as well as early development of the cassava plants. Treating the stakes by immersion in a fungicide solution is recommended. This topic was discussed in a previous section.

B. Insects

Several species may cause damage to the cassava plant at its early stage of development:

1. Lepidoptera and Coleoptera.

   Larvae destroy newly formed roots and/or the basal portion of the sprouts still under the surface, causing death of the plant.

2. Orthoptera adults (cricket)'

   Which destroy the "bark" of the stake.

3. Diptera Larva.

   Which attack the shoots.

4. Thrips.

   Which also attack the tender parts of the plant.

Studies conducted at CIAT showed a 95 percent loss in germination when "chizas" (larval stage of the coleoptera Scarabidae) were not controlled. Good results, 80 and 73 percent germination, respectively, were obtained by the use of insecticides, Aldrin 1.5 kg i.a./ha and Carbofuran 3 g/m^2, in the granular form. The latter, applied under the stake, resulted in 92 percent germination.

Diptera larvae may be controlled by dipterex sprayings, and thrips are controlled by spraying with Diostop at a 0.25 percent water solution. Ants can strip completely the foliage of the plants causing death of young plants; the most effective control is to apply an insecticide around the entrance to the ant hole. This insecticide could be Octaclor. The Cassava Agronomy program has used Toxafeno DDT 40-20 1 gal/ha in 400 lts. of water, immediately after planting, for the control of Lepidoptera and Coleoptera Larvae, with good results. In the 1976 growing season, however, for causes not yet established, control was not effective and resulted in a severe attack of Tierreros with plant losses in Bucaramanga and CIAT trials. It should be noted that in this case cassava followed a grass crop in Bucaramanga and a bean crop in CIAT.

C. Weeds

Weeds may seriously compete with the plants at early growth stages, so their control is needed, either by herbicide use of hand weeding.

Several herbicides could be used for weed control, among others, lasso, diuron and linuron, applied after planting and before the buds begin to sprout. Four days after planting, depending on plant population and stage of growth of the weeds.

D. Water

Lack of moisture may cause serious losses in germination if defficiency occurs during the first 20 days. A severe drought when plants are very small may also cause plant losses. Consecuently, the soil should be irrigated to field capacity when moisture is not enough. If during planting period rain has not occurred for four days and irrigation is not possible, it is recommended to suspend planting and await for rain.

THE EFFECT OF PLANT POPULATION ON THE YIELD OF CASSAVA

Abelardo Castro *
James H. Cock **
Julio César Toro ***

Cassava is a good source of carbohydrates (Vries et al, 1967) susceptible of increase by improved cultural practices. Since the final product is not used as planting material, the increase in the use of reproductive material does not affect the amount of marketable product, and as a consequence, increasing plant density per hectare would be an economical way to increase yield.

Results of a preliminary study on the use of fertilizer and plant population, showed an increase in yield when fertilizer was applied under conditions such that plant density was not affecting yields (CIAT, 1970). Calderon (1972) found, with one variety, yield increases up to 30,000 plants/ha, and with another, no variations in yield were obtained with plant density from 10 to 30,000 plants/ha. For CIAT soils, optimum plant populations are between 10,000 and 20,000 plants/ha depending on the cultivar. Higher densities decreased yields. (CIAT, 1972).

Plant type versus plant density

Based on experimental results we can say that for the cassava crop there exists an optimum plant density which vary according to cultivars.

The use of systematic designs (fan designs) for plant population studies, have yielded abundant and valuable information on the response to plant population. With cultivars M Col 22, Mex 11 (Fig. 1) the total dry matter yield increased with increased plant population, whereas M Col 1080 and M Col 1438 showed no response up to 40,000 plants/ha, after which total yield declined. However, M Col 1467, showed a strong decrease in total dry matter yield with plant populations higher than 10,000 plants/ha (CIAT 1974). Root dry matter yield of M Col 22 was highest with 22 tons/ha of dry matter, while Mex 11 roots yielded 19 tons/ha dry matter (Fig. 1).

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Two short and two tall type cultivars with different branching characteristics were selected at CIAT and planted at densities between 2,500 and 40,000 plants/ha, and the roots were harvested at 12 months (CIAT, 1975). Fig. 2 shows that for all plant types total root weight increases as plant density increases.

This plant population could be a good characteristic for industrial cassava cultivation. However, an optimum plant density must be found for production of roots for fresh consumption (more than 25 cm long and 5 cm diameter). For the short growth habit and for the tall erect growth habit cultivars the optimum plant density was 10,000 plant/ha but for tall branched varieties the optimum was 5,000 (Fig. 3) under CIAT conditions.

Consequently each plant type will have its optimum plant density to express its maximum yield potential.

Present, trials with different plant types, four plant populations and two fertilization levels, are being conducted in three ecologically different regions of Colombia. Previous experiments conducted by CIAT (CIAT, 1974) in different zones showed that optimum plant populations vary according to ecological conditions. In general, poor soils show good response to plant population increases, in rich soils the response to plant population increase will depend on the growing habit of the variety.

In summary, it has been observed that as plant density increases, the total yield also increases, but the number of roots per plant, root size, and harvest index decrease, while weed control by competition improves.

The physiological implications of plant density are discussed in a different section of this course.

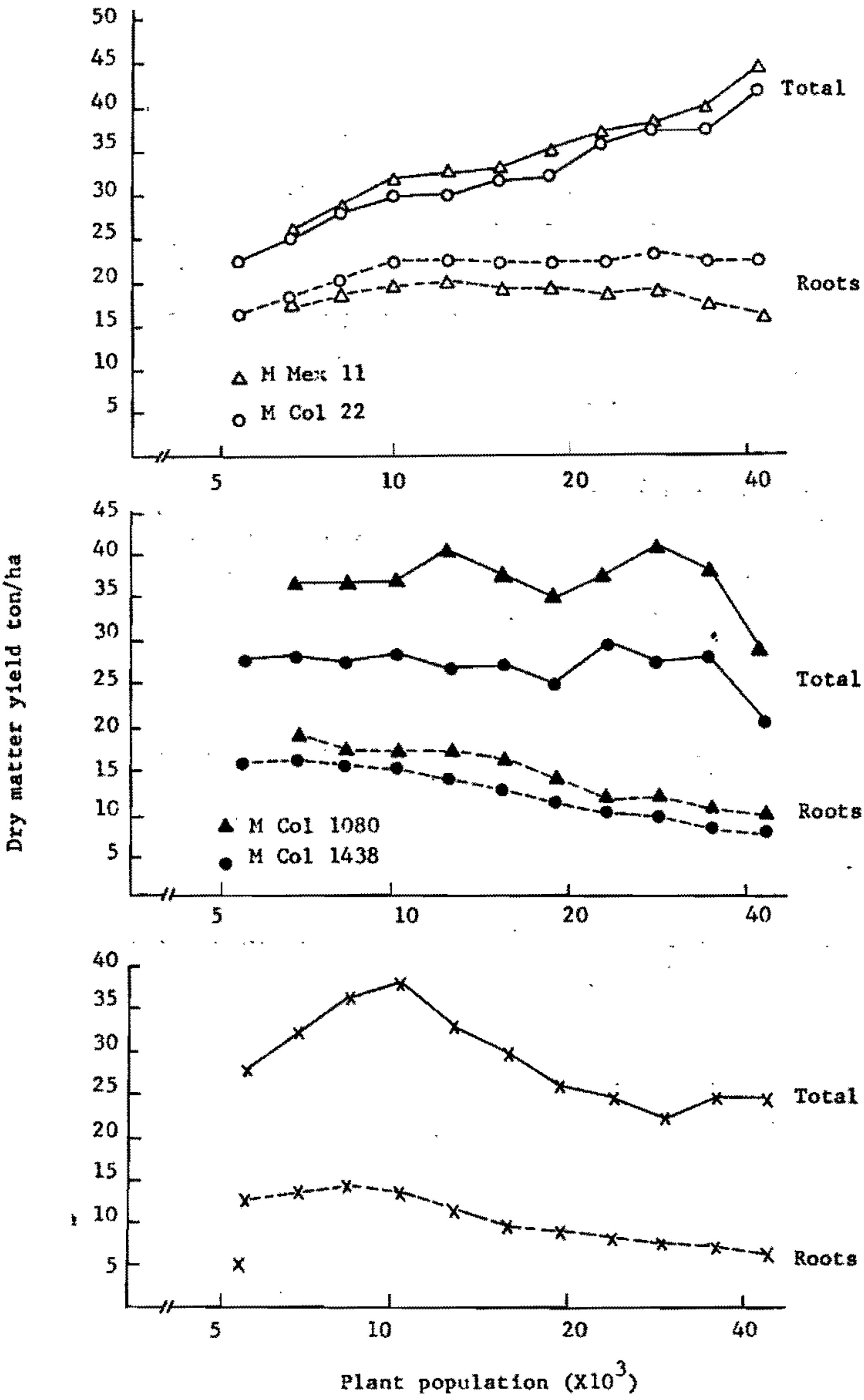

Figure 1.- Total and root dry matter yield for five cassava cultivars 11 months after planting

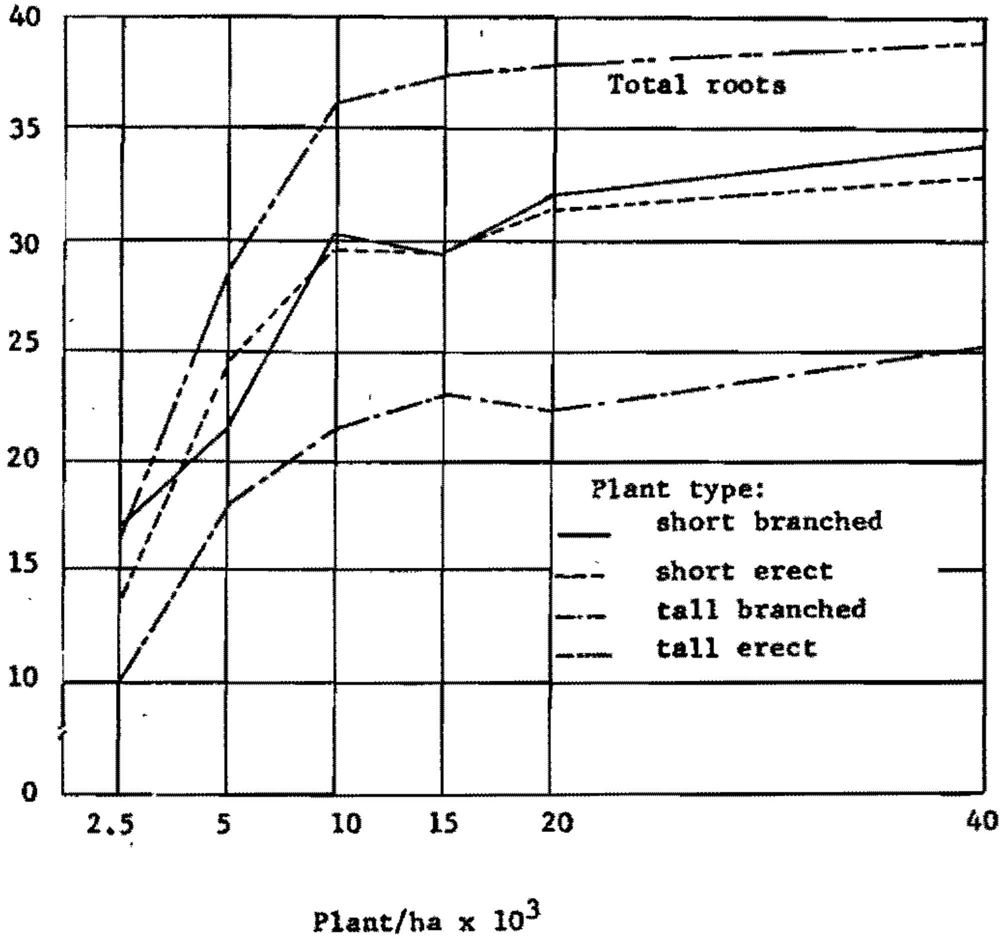

Figure 2. Population effect on yield (fresh weight) of total number of roots, of four plant types.

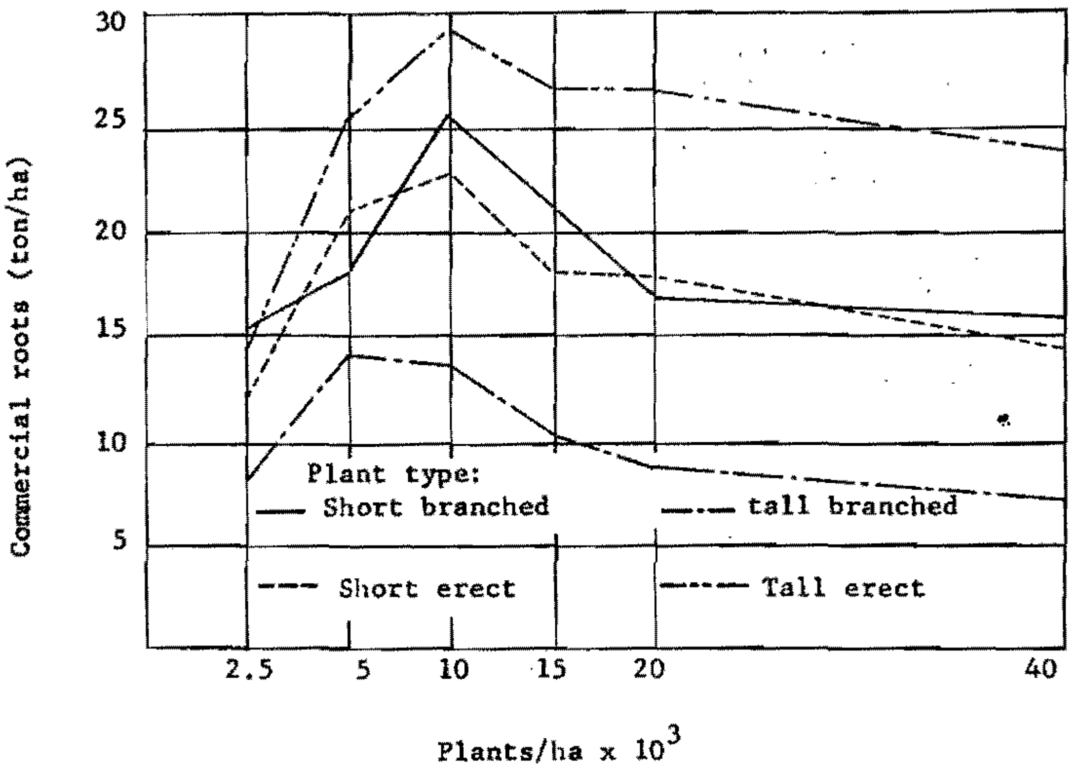

Figure 3.- Population effect on yield (fresh weight) of commercial roots, of four plant types.

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GENETIC IMPROVEMENT OF CASSAVA (MANIHOT ESCULENTA CRANTZ) FOR PRODUCTIVITY [1]

Kazuo Kawano *

Cassava (*Manihot esculenta* Crantz) is one of the most important calorie producing crops in the tropics. It accounts for 54% of tropical root and tuber acreage and produces 57% of root and tuber production (FAO, 1971). Nester (1974) calculated that approximately 300 million people in the tropics depend on cassava as a major source of their calorie intake. According to a World Bank analysis (Anon, 1976), nearly a third of the world population or 75% of the population of underdeveloped countries in the tropics suffers from simple calorie deficiency. Cassava's high calorie yield per hectare therefore makes it a primary means of relieving this food deficit (Nestel, 1973). Furthermore, cassava has important uses as an animal feed, starch and alcohol production. The demand for cassava as an animal feed is expected to rise rapidly in an attempt to expand the production of animal protein in the tropics (Phillips, 1974). Cassava is widely believed to be highly efficient in carbohydrate production, adapted to a wide range of environmental diversity and tolerant to drought and acid soils. The potential of cassava in tropical agriculture has attracted attention within and outside the tropics (de Vries, Ferwerda and Flach, 1967; Martin, 1970; Nojima and Hirose, 1977).

Limited research has been conducted on cassava despite its importance. Cassava yields of up to 50 ton/ha (fresh weight) are occasionally reported under experimental conditions (Arraudeu, 1969) but farmer's yield is usually from 10 to 15 ton/ha. A world center for cassava research has been established at CIAT with the objective of providing a technical package based on improved germplasm to increase the efficiency of cassava production.

CIAT's cassava breeding program aims to obtain new genotypes that give the maximum calorie yield per unit area per unit time over a wide range of environmental conditions. I define a genetic improvement program for major food crops as a research effort designed to reach the maximum level of productivity by genetically modifying the plant

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structure and defend this high level of productivity from yield-reducing factors. We are on the way to upgrading cassava germplasm to its maximum productivity level. The importance of breeding work against yield reducing factors such as disease and insect resistances and tolerances to special soil problems should not be neglected. However, in recent years, our primary interest has been to realize the highest yield potential of cassava. For these reasons, the present paper deals with the methodology of cassava breeding for higher productivity.

Botanical Characteristics related to breeding work

The chromosome number of *Manihot esculenta* is 36 and the species is generally regarded as an allotetraploid (Umanah and Hartman, 1972). Cassava is highly heterozygous species (CIAT, 1975; Kawano *et al*, in press) and this heterozygosity is easily maintainned through vegetative propagation.

Both cross-pollination and self-pollination occur naturally. The proportion of cross-pollination depends on the flowering habit of the genotypes and the physical arrangement of the population (CIAT, 1975; Kawano *et al*, in press). Cassava is a monoecius species with the stigma and anther usually separated in different flowers on the same plant. The male and female flowers almost never open simultaneously on the same branch; however, it is common that the female flowers and the male flowers on different branches of the same plant open at the same time. There is no physiological or genetic mechanism to prevent self-pollination and cross-incompatibility has not been found up to now.

Strong inbreeding depression has been observed in characters such as root yield and total plant weight (Table 1). This strong inbreeding depression, in addition to the vegetatively propagated nature of the species, is the biological mechanism through which the high heterozygosity of the species is maintained. Male-sterility is frequent and this is effective in preventing any self-pollination from taking place.

Vegetative propagation is of great advantage to breeders. Once a favorable type is obtained, the genotype can be multiplied indefinitely.

Existing germplasm

Cassava originated and completed the major part of its diversification in Latin America (Leon, 1976). The CIAT germplasm collection comprises approximately 2.400 cultivars which have been collected from Colombia, Venezuela, Ecuador, Peru, Mexico, Brazil, Panama, Puerto Rico, Costa Rica, The Dominican Republic, Bolivia and Paraguay. The collection represents the major genetic diversity of the species. Tens of thousands of seeds obtained in this collection have been sent to other cassava breeding programs in Latin America, Asia and Africa.

In this germplasm, enormous genetic variability in such characters as harvest index and root yield is found (Fig. 1). As well, resistances to the major cassava diseases such as cassava bacterial blight, phoma leaf spot, superelongation disease and Cercospora leaf spots have been identified (CIAT, 1973, 1974, 1975). However, no cultivar in the collection has been found to meet the standard which we consider the new recommended cultivars should satisfy. Thus, producing a quantity of recombination types through hybridizations is necessary.

Plant Type

The identification of an optimum leaf area index for root yield (CIAT, 1975; Cock et al in press.) may be the most significant contribution of cassava production physiology to the breeders' work up to the present. The optimum LAI exists between 3 and 3.5 (Fig. 2). It stays phenotypically constant over a wide range of temperature variation, although the genotype which attains the optimun LAI may be different under different temperatures (CIAT, 1976; Irikura, Cock and Kawano, in press.).

This leads to a conclusion that to obtain the highest yield, a cassava population must reach the optimum LAI as soon as possible and maintain it as near by as possible until the harvest. Analysis of the components of leaf area suggests that long leaf life and late branching are the most important among others (CIAT, 1975, 1976; Cock et al in press.).

Hybridization

Pollination is easy. Genotypes differ greatly in their efficiency when used as a female parent for hybridization while they all seem to function well as a male parent (Table 2). Approximately 30.000 hybrid seeds are being produced yearly from the controlled pollination of approximately 22.000 female flowers at CIAT.

Open-pollinations offer a fair chance of obtainning high yielding hybrid selections (CIAT, 1976). However, a high proportion of seeds obtained by open-pollinations can be a result of self-pollination and the evidence suggests that self-pollination is self-destructive in many cases (Table 1).

The inheritance of such important characters as harvest index (Fig. 3), root dry matter content (Fig.4) and postharvest root perishability (Fig. 5) follows a simple additive gene manner. Resistances to important diseases such as cassava bacterial blight trials, harvest index is highly correlated with the root yield (Fig.10). As a consequence, in the single-row trials harvest index is a better indicator of true yielding ability than the yield itself (Fig. 11).

This occurs as a result of competition between genotypes. Genotypes with high vegetative vigor and low harvest index can occupy a larger space resulting in higher root yield in seedling or single-row trials. However, when these types are planted in populations, they do not yield well.

Harvest index is an indicator of the balance between leaf and stem growth and root growth. There exists an enormous genetic variation in this character (Fig. 1) and it is highly heritable (Fig. 3). Thus, harvest index is a highly effective character for use as an indicator for the selection of cross parents, seedling selections and single-row trials. We are eliminating the materials which have a harvest index lower than 0.60 and 0.55 in seedling and single-row trials, respectively.

Recent advances at CIAT

On the CIAT farm where the soil is fertile, several hybrid selections gave root dry-weight yields of 15 ton/ha/yr or more, outyielding a local cultivar by 100% with 655 mm of rainfall and without any application of fertilizer, fungicide, insecticide or irrigation (Table 3). On the soil of the Llanos Orientales of Colombia, which is so acid (pH 4.3), so high in aluminium (exch. Al 3.5 me/100 g, 85% sat) and so low in phosphorus (1-2 ppm Bray II) that the majority of food crops can be grown only with a heavy application of lime and phosphorus, several hybrid selections gave root dry weight yields of 10 ton/ha/yr with a moderate application of lime and phosphorus, outyielding a local cultivar by 50% (Table 3). On the Northern Coast of Colombia, which is one of the cassava production centers of that country, several hybrid selections yielded more than 12 ton/ha/yr in root dry weight withstanding 5 months of dry season and outyielded local cultivars by more than 100% (Table 3). A hybrid selection such as CM 308-197 did well in all of these locations, always exceeding the yields of corresponding local cultivars by 50 to 150%.

To answer the question of whether we can go still further in selection for higher productivity, careful studies by physiologists and soil scientists will be required. However, the genotypes with this level of yielding capacity should be able to significantly increase the current yields at the farm level of 3 to 5 ton/ha/yr in root dry weight.

and Cercospora leaf spot can be transmitted relatively easily to offspring when the resitant genotypes are included in the hybridizations (CIAT, 1975, 1976). A great number of high yielding genotypes resulted from the crosses which had included genotypes with a high harvest index (CIAT, 1977; Kawano et al in press.). Controlled hand pollination with selected parents is recommended as a general tool of breeding cassava. When a breeder has to choose open-pollination, the use of male-sterility is recommended.

The simple inheritance mode for many important characters and vegetative propagation makes the method of cassava breeding simple. The details of methodology are not important at this moment. The basic germplasm on which the breeder works and the efficiency of selection both of cross parents and hybrid lines are the most important.

Selection

Seedling trial

Sixty to 95 percent germination is obtained depending on genotypes. The germination percentage seems to be highest about five months after seed harvest (or eight months after pollination) and it drops dramatically when the seeds are stored more than two years at room temperature (Fig. 6).

The yield data of seedling plants are highly correlated with that of the same genotype planted with stakes (Fig. 7). This clearly indicates that that the seedling selection is highly effective. In cassava, inter-genotypic competition is highly significant especially when different genotypes are planted close together (CIAT, 1975; Kawano et al in press.). Thus it is important to plant segregating materials with enough spacing among them. At CIAT, the seedlings are planted at 2 x 1 m distance.

Single-row and population trials

The selected seedling plants are passed immediately to a single-row trial. Those selected lines from the single-row trial are then evaluated in a replicated population trial in which only the central plants free from border effect are harvested.

There is no correlation between root yield data obtained in single-row trials and those obtained in population trials (Fig. 8). Since the valid yield data should come from replicated population trials, the root yield data obtained in single-row trials have virtually no meaning. However, harvest index data obtained in single-row trials are highly correlated with those in population trials (Fig. 9). In population

CONCLUSION

The productivity of the existing cassava germplasm is generally far below the potential of the species. Limited attention has been given to the genetic improvement of the species. Botanical characteristics of the species and genetic behavior of several important characters suggest that the genetic management of the species must be easy. Attaining the maximum level of productivity is easily within reach. One key factor for maintaining a high efficiency of genetic work is the use of harvest index in selection.

After four years of work, the CIAT cassava breeding program has hybrid selections which outyield local cultivars by 50 to 150% under a wide range of environmental conditions. Some of the superior materials may be named as a recommended cultivar and distributed to national cassava programs in the tropics in the near future. The emphasis of breeders' work will gradually shift toward incorporating resistances to the yield-reducing factors such as resistance to diseases and insects.

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TABLE 1. Comparison between self-pollinated offspring (S_1) and parents. *

	No. of S_1	Yield (k/plant)		Total plant (k/plant)		Harvest index		Plant height (m)	
	genotypes	S_1	Parent	S_1	Parent	S_1	Parent	S_1	Parent
LLanera	9	1.9	4.5	4.1	8.7	.32	.52	1.67	1.82
M Col 9	6	0.9	4.0	4.7	12.6	.20	.32	1.64	2.43
M Col 51	23	1.3	3.0	2.8	5.1	.52	.60	1.40	1.67
M Col 173	20	1.3	2.6	5.6	8.2	.21	.31	2.72	2.77
M Col 340	26	1.8	4.8	6.5	12.0	.28	.40	1.78	2.30
M Col 562	14	1.6	3.2	3.7	7.5	.41	.50	1.82	2.30
M Col 647	36	2.0	4.0	4.4	9.8	.45	.40	1.58	2.30
M Col 667	5	0.6	4.8	1.6	11.0	.38	.44	1.52	2.80
M Col 688	10	2.5	4.2	5.3	7.8	.45	.53	2.14	2.43
M Col 971	15	3.8	3.1	9.5	5.4	.40	.57	1.97	1.50
Extranjera	12	1.4	2.9	3.2	7.7	.41	.38	1.43	2.43
M Ven 179	16	1.4	3.5	5.4	13.4	.44	.25	2.00	2.00
Average		1.71	3.72	4.73	9.10	.373	.466	1.81	2.23

* Data from single-row trials (2 m between genotypes, 1 m between plants of the same genotype, average of 3 plants per genotype).

TABLE 2. Genotypic difference in seed setting after pollination

Cross	No. of female flowers pollinated	No. of seeds obtained	No. of seeds set per female flower
M Col 1684 x M Col 22	91	72	0.79
M Col 1684 x M Col 638	350	63	0.18
M Col 1684 x M Mex 55	78	40	0.51
M Col 1684 x CM 309-56	225	53	0.24
M Col 1684 x CM 309-239	115	65	0.57
M Col 1684 x CM 309-260	130	20	0.15
		Average	0.41
M Col 638 x M Col 1684	274	268	0.98
M Col 638 x M Mex 55	220	284	1.29
M Col 638 x M Ven 218	357	402	1.13
M Col 638 x M Pan 70	324	257	0.79
M Col 638 x M Pan 114	217	313	1.44
M Col 638 x Popayan	285	484	1.70
M Col 638 x CM 309-11	105	191	1.82
M Col 638 x CM 309-26	144	212	1.47
M Col 638 x CM 309-29	99	154	1.56
M Col 638 x CM 309-56	143	206	1.44
M Col 638 x CM 309-143	64	136	2.13
		Average	1.43
M Col 755 x Llanera	161	279	1.73
M Col 755 x M Col 22	278	500	1.80
M Col 755 x M Col 647	233	424	1.82
M Col 755 x M Col 667	144	234	1.63
M Col 755 x M Mex 55	284	517	1.82
M Col 755 x M Mex 59	154	284	1.84
M Col 755 x M Ven 185	90	157	1.74
M Col 755 x M Ven 209	162	204	1.88
M Col 755 x M Ven 270	163	308	1.89
M Col 755 x M Ven 307	203	379	1.87
		Average	1.80
SM 76-66 x M Col 638	488	946	1.94
SM 76-66 x M Mex 59	59	132	2.24
SM 76-66 x Popayan	221	427	1.93
SM 76-66 x CM 157-9	111	186	1.68
SM 76-66 x CM 170-2	106	239	2.25
SM 76-66 x CM 204-5	75	156	2.08
SM 76-66 x CM 309-37	112	218	1.95
SM 76-66 x CM 309-56	143	221	1.55
SM 76-66 x CM 334-19	119	241	2.03
		Average	1.96

TABLE 3. Selected results of yield trials in three locations

Location	Genotype	Root yield (ton/ha/yr) Dry wt.	Fresh wt.
CIAT	CM 309-211	17.9	50.8
	CM 308-197	17.6	50.3
	CM 323-30	16.6	48.3
	CM 308-1	16.3	43.3
	CM 321-15	15.9	46.1
	CM 321-170	15.8	47.8
	CM 317-16	15.4	48.1
	CM 307-135	15.4	44.0
	CM 309-84	15.4	41.1
	CM 152-12	14.7	45.0
	M Col 113 (local cultivar)	8.4	25.6
	Llanera (control)	7.9	24.7
	M Col 22 (control)	7.1	19.7
Carimagua	SM 92-73	10.6	33.0
	CM 323-52	10.0	33.0
	CM 308-197	9.9	30.6
	CM 314-2	8.4	25.7
	CM 323-99	7.8	24.3
	CM 323-142	7.5	26.0
	CM 309-2	7.5	23.3
	CM 321-88	7.1	21.5
	CM 305-11	6.9	24.0
	CM 323-41	6.6	24.0
	Llanera (local cultivar)	6.9	21.5
	M Col 22 (control)	6.0	19.4
	M Col 113 (control)	2.7	10.4
Caribia	CM 320-2	13.7	42.0
	CM 309-50	13.7	41.7
	CM 309-163	12.8	44.3
	CM 323-75	12.2	37.8
	CM 323-41	12.2	37.6
	CM 322-20	12.1	36.7
	CM 321-85	11.6	36.1
	CM 308-197	11.4	34.5
	CM 309-128	11.1	34.8
	CM 321-78	11.0	38.0
	M Col 22 (control)	11.4	33.6
	Llanera (control)	6.0	20.7
	Manteca (local cultivar)	5.0	18.1
	Montero (local cultivar)	4.3	12.6

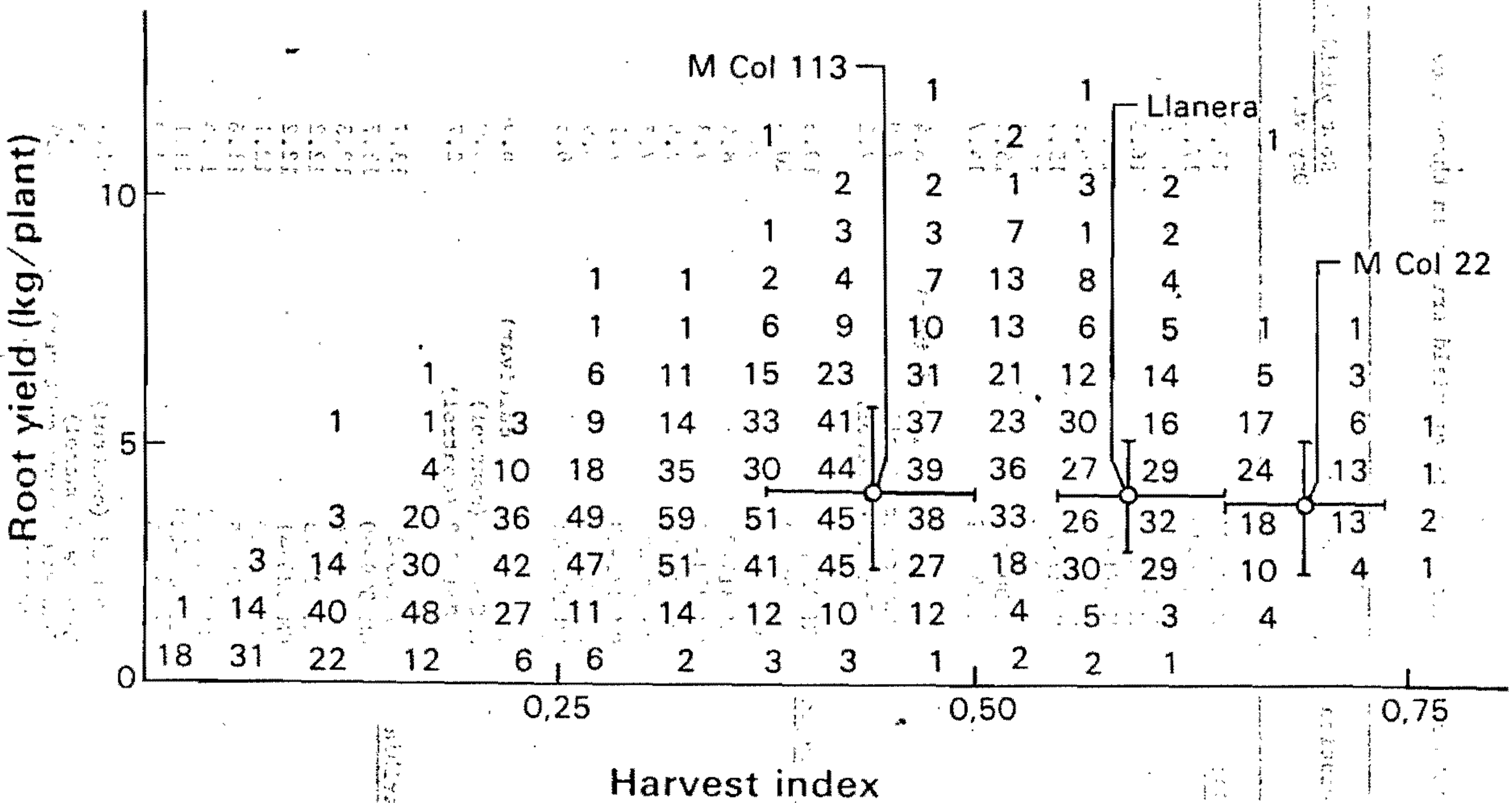


Fig. 1. Relationship between harvest index and root yield of 1,900 cultivars evaluated in single-row trial at CIAT. (The number represents the number of cultivars and the values of control cultivars are shown with standard deviation).

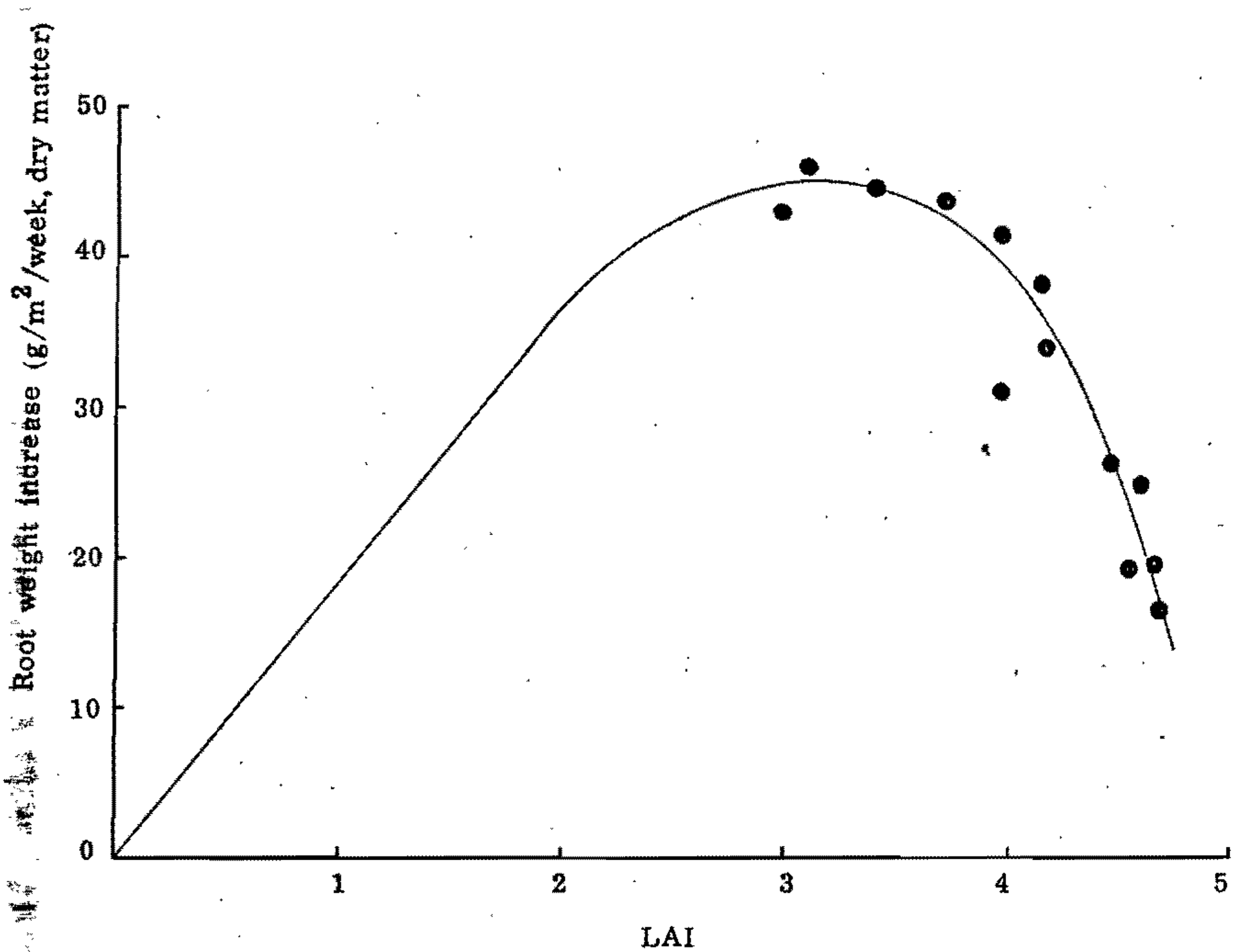


Fig. 2. Root weight increase as a function of LAI in a cultivar M Col 113 at CIAT (Cock-CIAT, 1975).

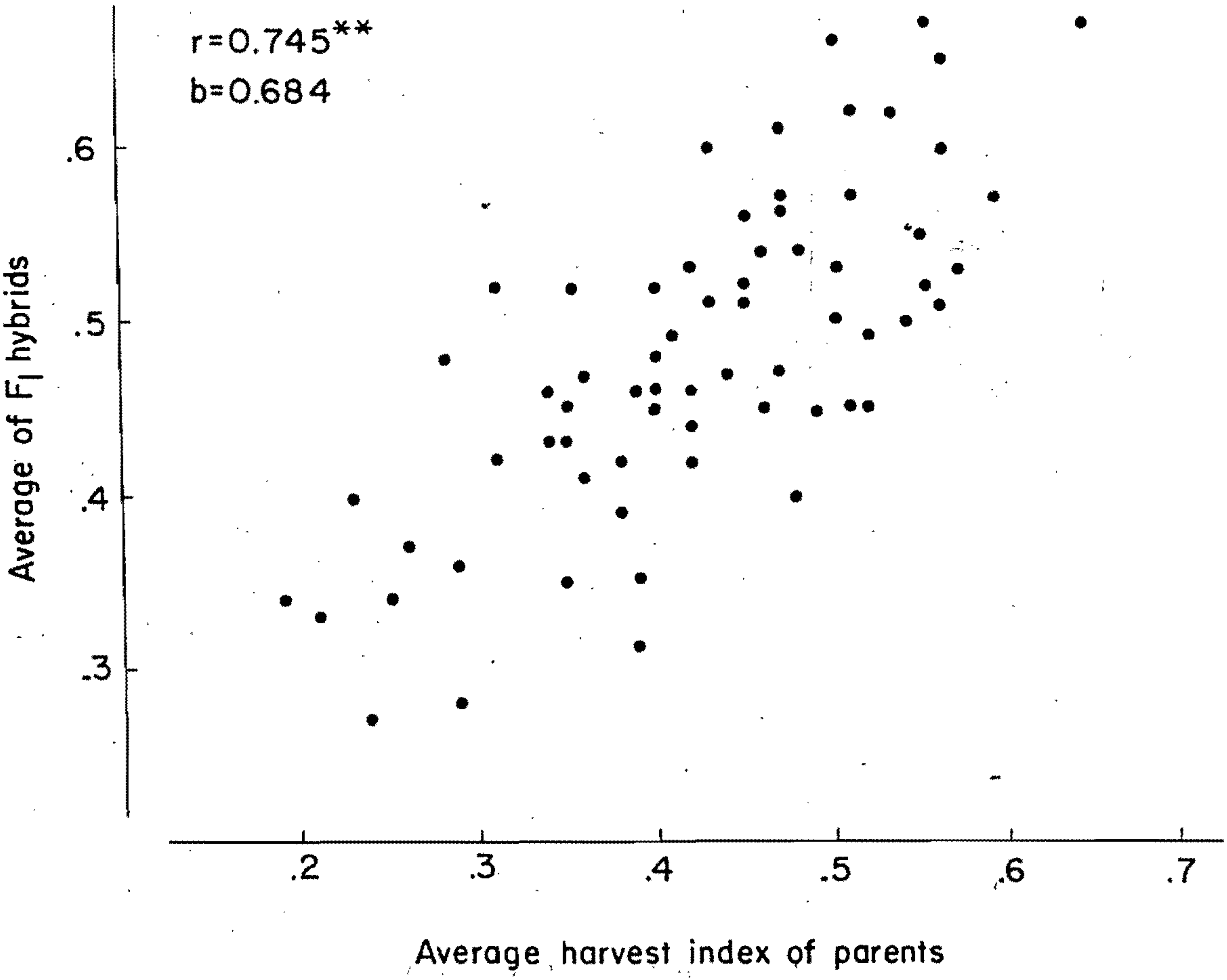


Fig. 3. Regression of F_1 average on the mid-parent value in harvest index (Data taken from [illegible] single-row trials at [illegible]).

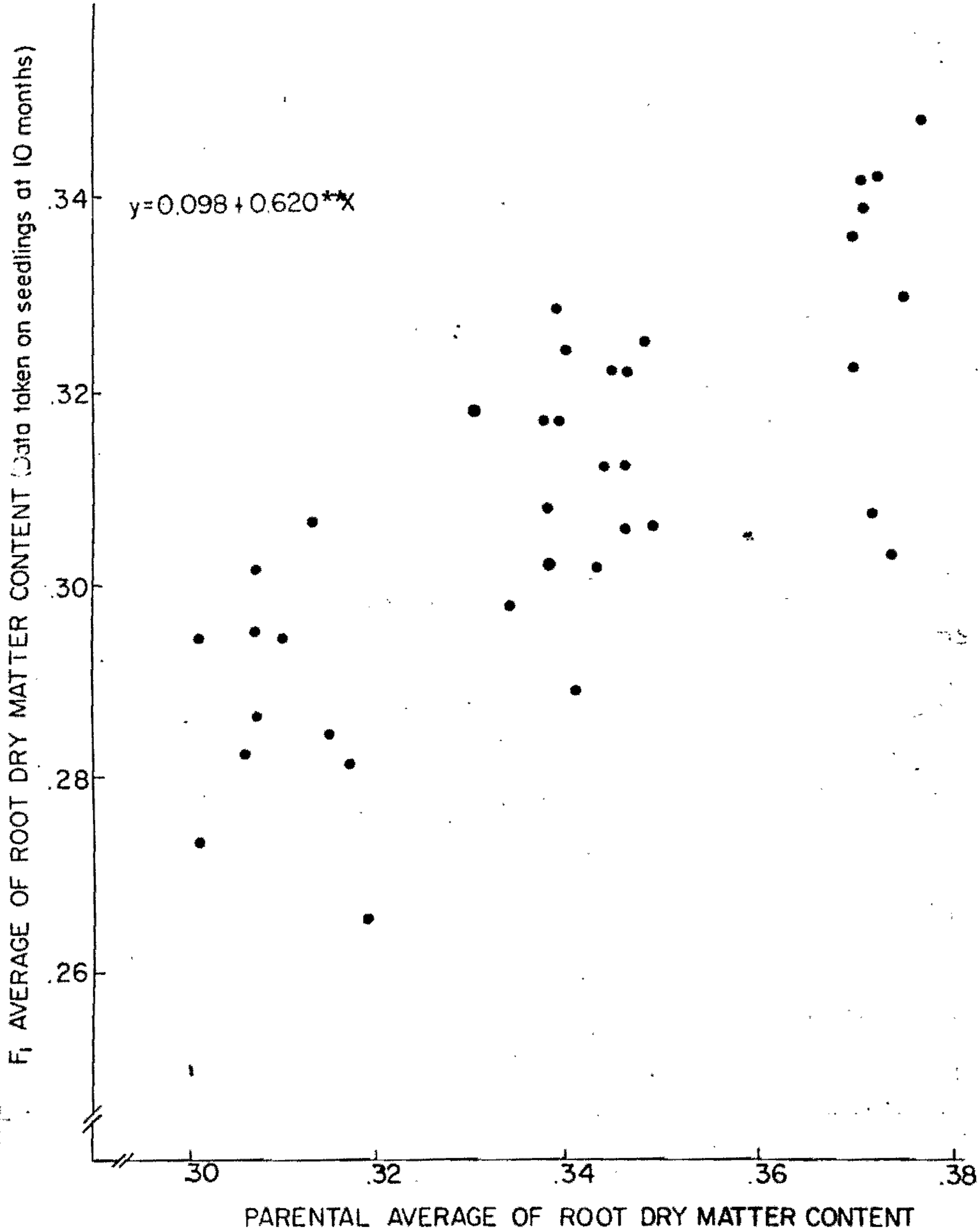
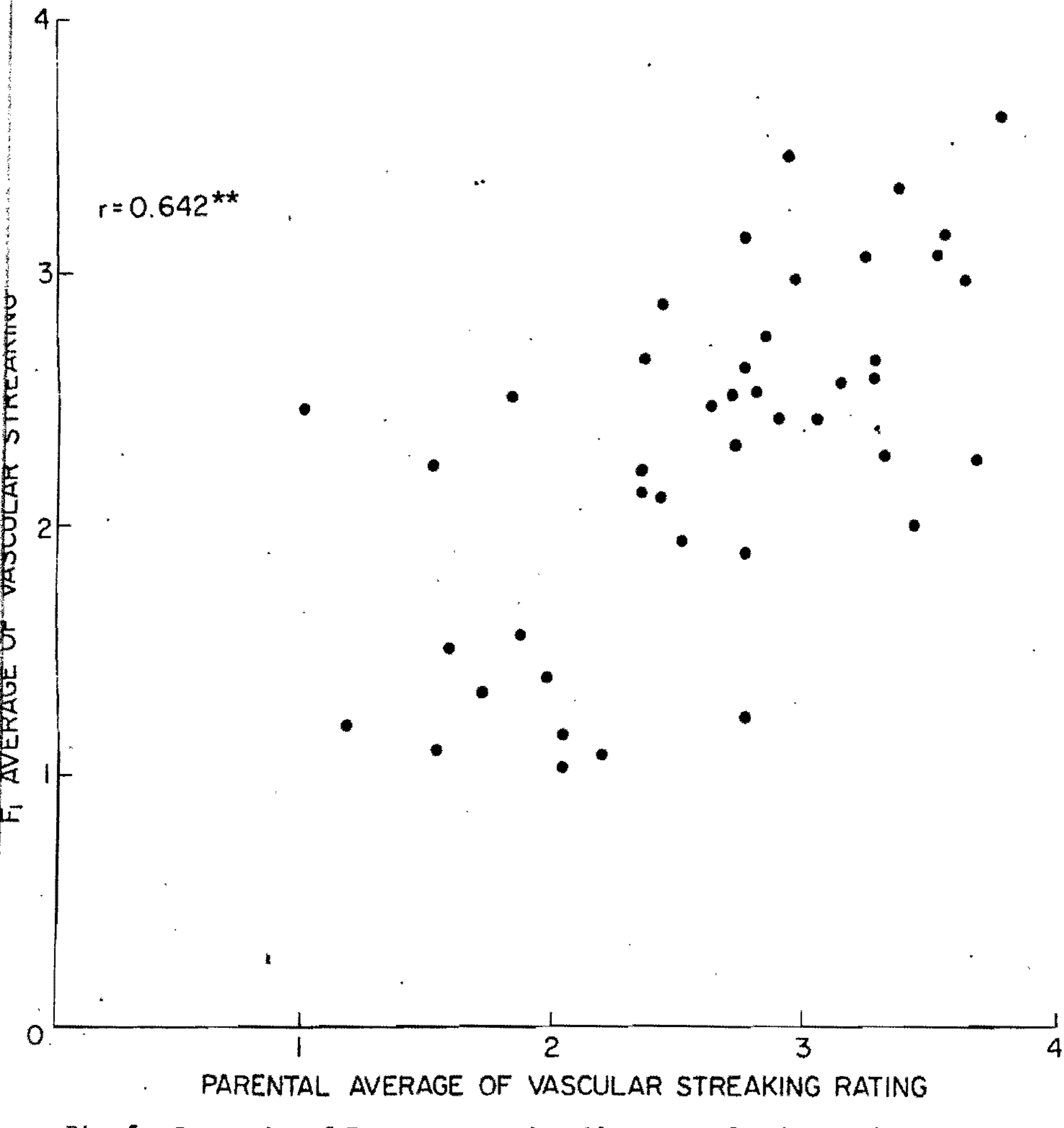


Fig. 4. Regression of F_1 average on the mid-parent value in root dry matter content (Data taken from single-row trials at CIAT).



~~Fig. 5.~~ Regression of F_1 average on the mid-parent value in post-harvest root deterioration (Vascular streaking rating; 0-no damage, 4-full damage).

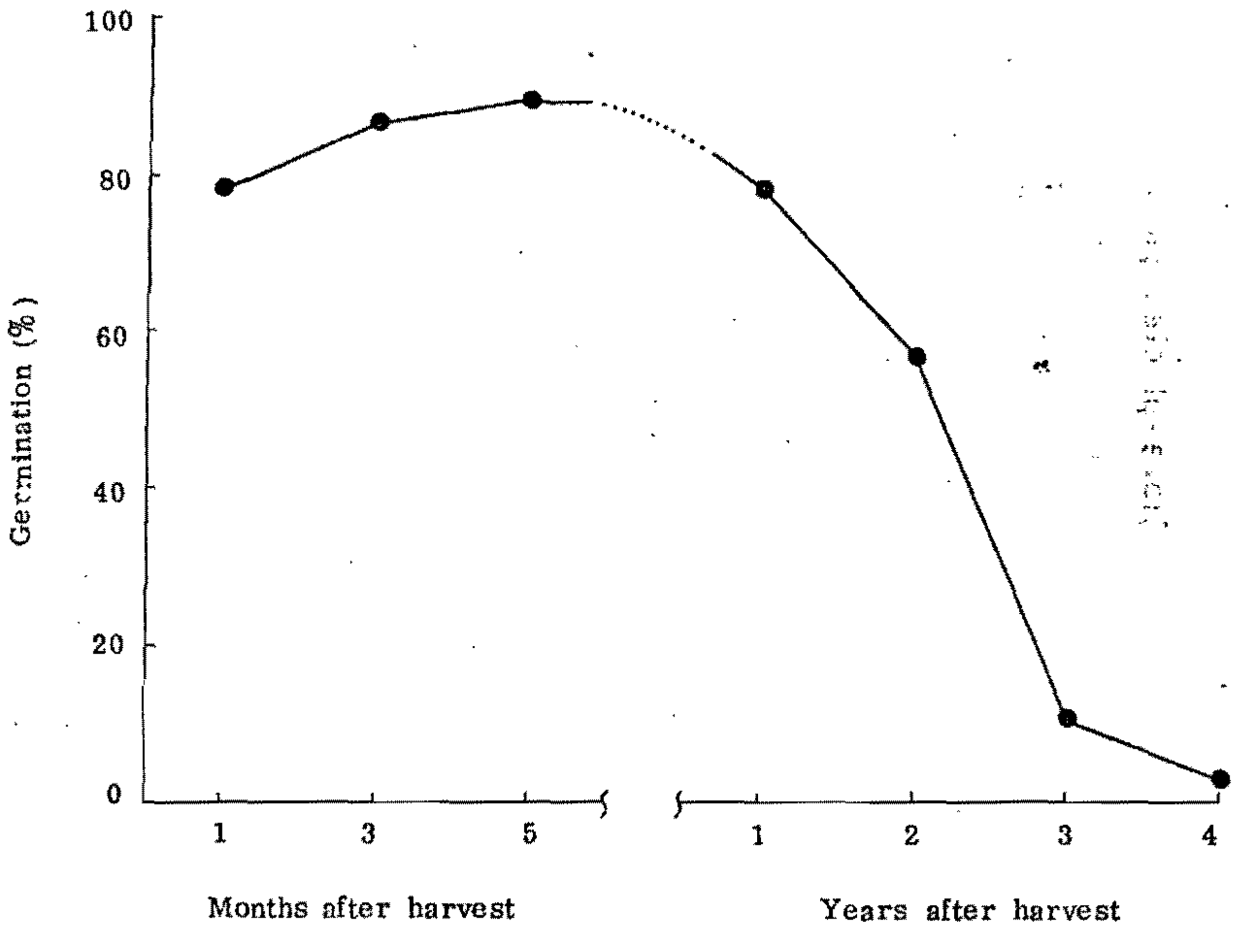


Fig. 6. Germination of cassava seeds at different period storage at room temperature 24°C (each point represents the average of several genetic populations).

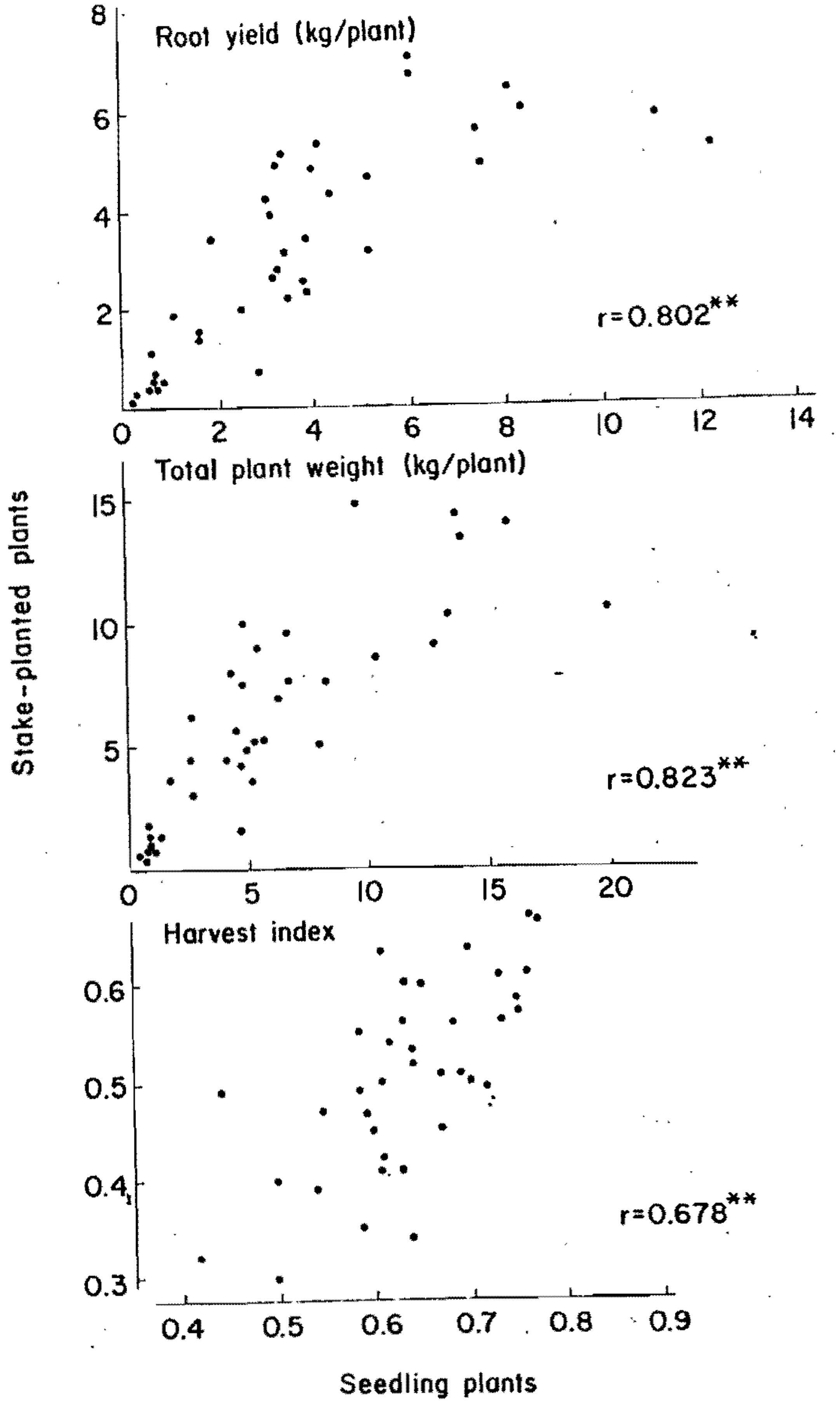


Fig. 7. Correlation of seedling plant data harvested 7 months after transplanting with that of stake-planted plants of the same genotype at CIAT.

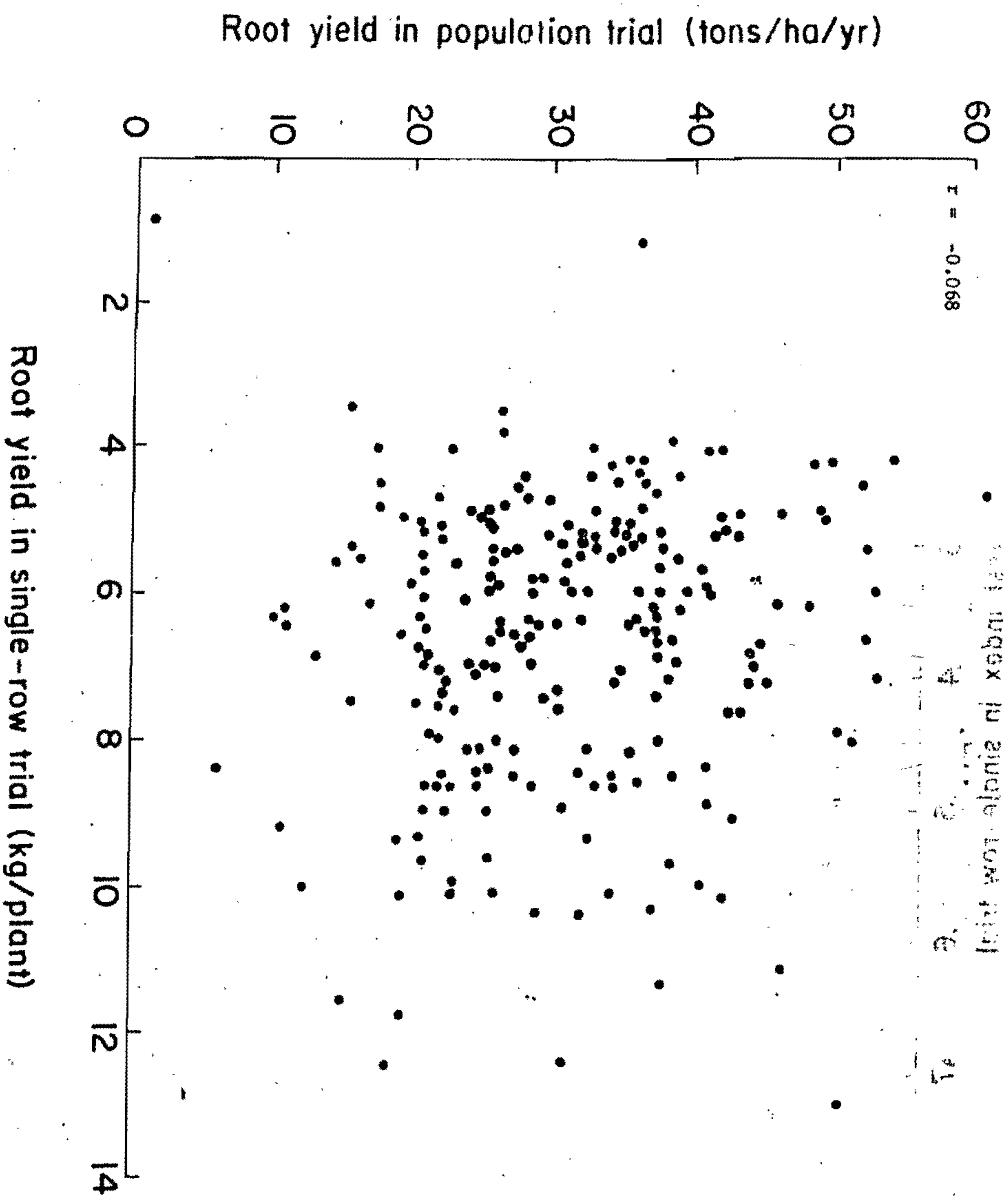


Fig. 8. Relationship between root yield data weight in fresh weight in single-row trial and that in population trial at CIAT.

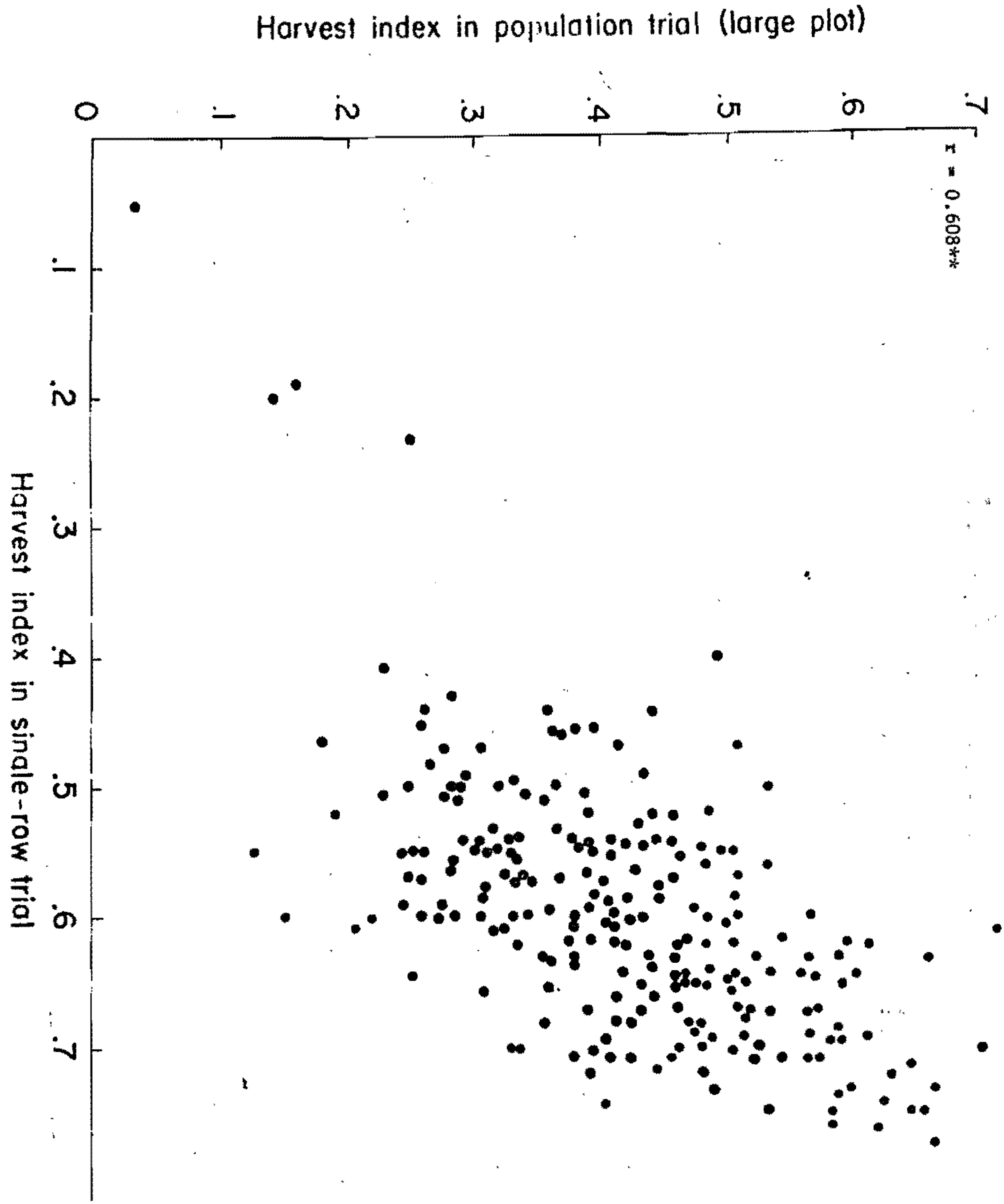


Fig. 9. Relationship between harvest indices in single-row trial and population trial at CIAT.

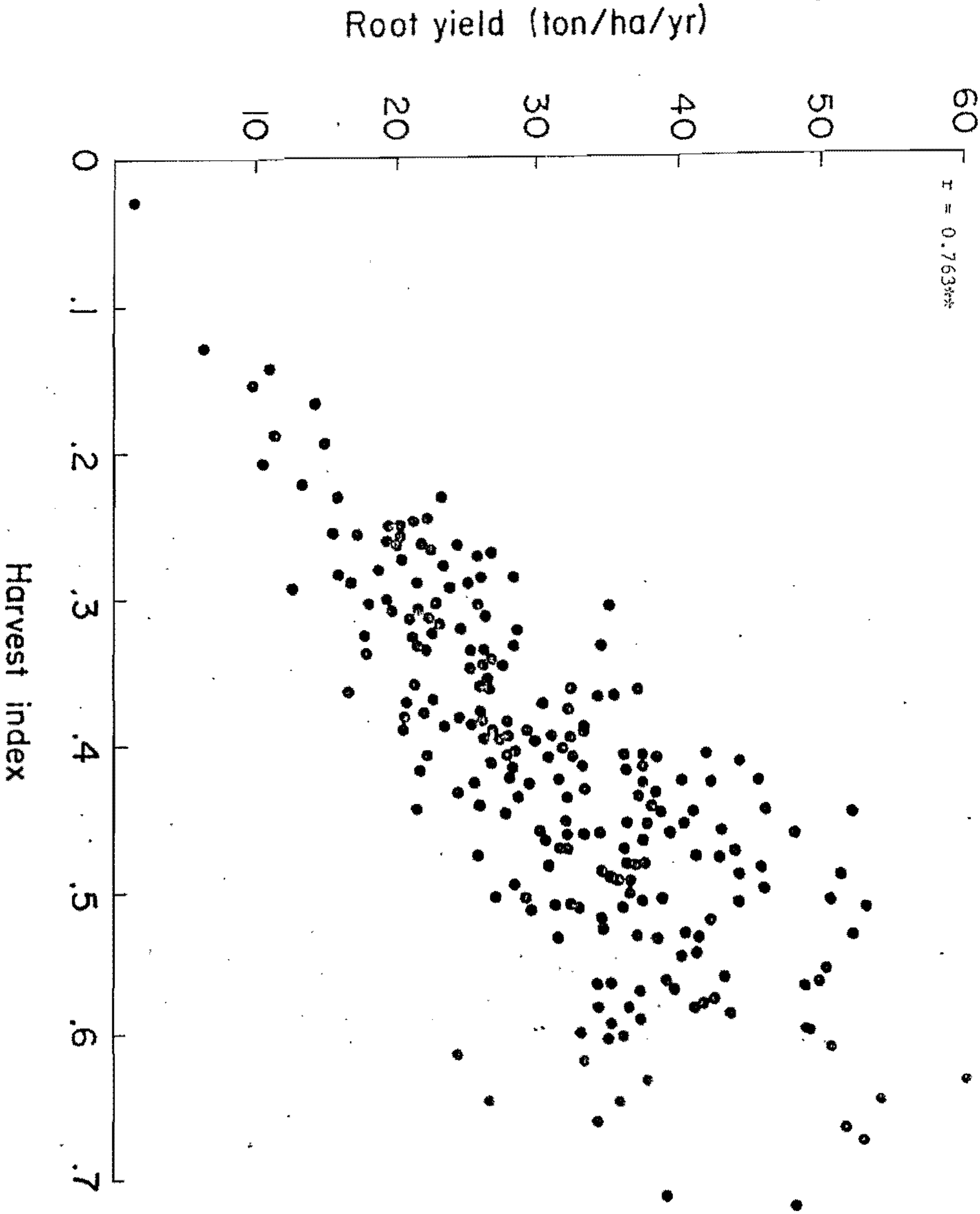


Fig. 10. Relationship between harvest index and root yield (fresh weight) in population trial at CIAT.

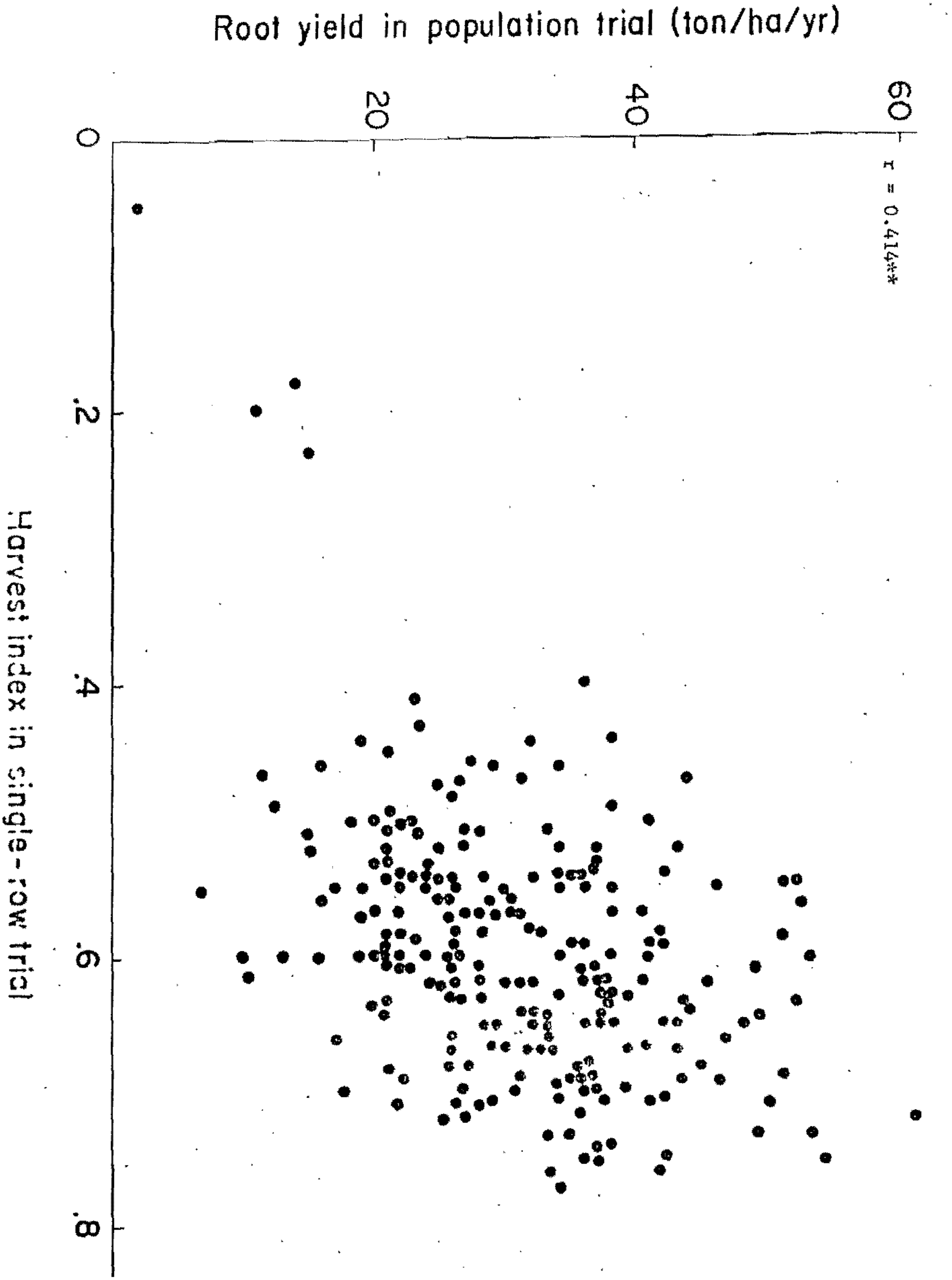


Fig. 11. Relationship between harvest index in single-row trial and root yield (fresh weight) in population trial at CIAT.

Certain cassava diseases can cause total defoliation in a plantation, with the consequent reduction in yields. Phyllosticta (Phoma) sp. is one of the most severe cassava pathogens during the cold and rainy periods.

GENERAL CONSIDERATION ON CASSAVA PATHOLOGY

J.C. Lozano

Introduction

Cassava (Manihot esculenta Crantz) is a long-season, tropical, perinnial, which has been grown traditionally with limited inputs on unfertile soils people from the lower income strata (22).

Cassava has been considered to be a hardy crop, resistant to both diseases and insects. Nevertheless, it is now known that there are devastating diseases and insects that can induce heavy losses of more than 50 percent (2, 3, 9, 10, 11, 12) or even cause complete crop failure in certain areas (9, 38). The world average yield of cassava is only 10 tons/ha. (22, 23, 51). In experimental stations, 40 tons/ha. have been obtained with relative facility (10, 11, 12); and simply by using disease-free planting material and inexpensive cultural practices, more than 20 tons/ha. have been reached with traditional varieties in regions where yields are no higher than 4 to 7 tons/ha. (12, 45).

As a result of the shortage of carbohydrates for both human and animal consumption, as well as the many industrial applications of cassava (51), the cultivation of this crop being expanded continually. This increase in area planted to cassava has obviously led to an increase in pathological and entomological problems.

Research in the field of cassava pathology has been especially limited. Of a total of around 4500 articles on cassava, only 300 deal with cassava pathology, approximately 40 percent of which were written during the past seven years. In addition, few scientists (no more than 20) are presently working in this area; and in many cases they are handicapped by having too many other responsibilities and insufficient physical facilities. A primary objective of this worshop is to suggest how integrated pest control for cassava can be developed. Many of the suggestions will most likely require close cooperation among the different institutes if their implementation is to be successful. I hope that this workshop will provide the bases for this future collaboration.

THE STATUS OF CASSAVA PATHOLOGY

Because of the interest several countries have taken in improving the cassava plant and expanding its cultivation, special programs with full-time researchers trained in cassava pathlogy have already been organized in Brazil, Mexico, Thailand, the Philippines, Malaysia and India, as well as in the international centers. Since some of these researchers were trained at CIAT, a cooperative link has been established with these institutes by means of joint projects, interchange of information, or consultation. This type of link also exists between IITA and several African countries.

About thirty cassava diseases induced by viruses, viruslike causal agents, mycoplasmas, bacteria and fungi have been reported (38). The information available on the etiology of the causal agents, as well as the epidemiology of these diseases, is relatively limited. At present it is not always possible to know whether two scientists are working on the same organism because there is a lack of knowledge as to the true identification of the pathogen. For example, it has not yet been proved that Indian and African mosaic are caused by the same virus. The following is a summary of the important features of reported cassava diseases.

Viruses, viruslike organisms and mycoplasmas

Five viruses have been reported attacking cassava (3, 16, 35). Geographically speaking, the brown streak virus (BSV) and African mosaic virus (AMV) are restricted to Africa, but the latter has also been reported in India (48). Common mosaic (CMV), leaf vein mosaic (LVMV) and latent viruses (LV) are restricted to tropical America, (16,35), but it appears that CMV is also found in Indonesia (Booth, personal communication) and that there is another LV in Africa (3).

In addition to their sharp geographical distribution, there are several differential characteristics for each virus (Table 1). Considering distribution, incidence and losses, AMV is the most important viral disease of cassava it has a motile vector (the whitefly Bemisia spp.), is widely distributed in tropical Africa and can cause losses of more than 80 percent (3).

A great deal of research is needed to elucidate certain aspects of each of these viral diseases. In the case of BSV, for example, there are controversies regarding the shape of its particles (3, 29), hosts and methods of dissemination (3, 20, 29), which have only confused the status of this disease.

A new disease ("frog skin") of cassava was recently described in Colombia (12, 13). Plants affected by this disease do not produce swollen roots. Frog skin can be disseminated by diseased cuttings, mechanically, and by grafting (12, 13). The etiology of the causal agent and the epidemiology of the disease are still unknown.

A mycoplasmal disease of cassava has been reported in Brazil, Venezuela, Mexico, The Amazonian region of Peru (16, 18, 38) and Guatemala (Cock, personal communication) and in the Ivory Coast (21). Known as "superbrotamento" or witches'-broom, the disease can be recognized by several different syndromes: (1) stunting, shortening of internodes and proliferation of branches; (2) proliferation of shoots from the cutting; or (3) only a few weak and stunted shoots germinating from the cutting (16, 46). The reason for the occurrence of these different syndromes is unknown, but it has been suggested that they may be due to the existance of different mycoplasmal biotypes (16, 38). As this disease is only disseminated by using diseased cuttings and by mechanical means (16, 18), its incidence is relatively low (16, 38).

Bacterial diseases of cassava

Several bacterial species have been reported on cassava (38), but only *Xanthomonas manihotis* (cassava bacterial blight) (36), *X. cassavae* (bacterial leaf spot) (58), *Erwinia carotovora* var. *carotovora* (*E. cassavae*) (bacterial stem rot) (24, 47) and *Agrobacterium* sp. (bacterial stem gall) (13) have been established as being truly pathogenic to cassava. *Bacterum robici* was reported as a cassava pathogen (56); however, no type culture is known, nor has it been isolated since it was first reported. It appears that it was mistaken with *E. caratovora* var. *carotovora* (*E. Cassavae*). *Pseudomonas solanacearum* has also been reported as a pathogen of cassava (28); but recent inoculations with races of this bacterium have showed that cassava is not a host. Since *X. manihotis* forms white, mucoid, slimy colonies in sugar media, as does *P. solanacearum*, the identification of this pathogen could also have been mistaken.

The bacterial pathogens of cassava can be differentiated on the basis of symptomatology in addition to their cultural characteristics (Table 2). Cassava bacterial blight (CBB) is the most important bacterial disease and the disease that has been most investigated (10, 11, 12, 25, 36, 38, 40, 41, 43); however, there are many aspects of this disease and its causal agent that are still unkonwn.

Fungal diseases of cassava

Around twenty fungal species have been reported as being pathogenic to cassava, inducing foliar, stem or root rot diseases.

1. Foliar diseases.

The most important in this group are superelongation (*Sphaceloma manihoticola*), Cercospora leaf spots (*C. vicosae*, *C. henningsii*, *C. caribaea* and *C. manihotae*) and Phoma leaf spot *Phoma* (*Phyllosticta*)spp. , inducing yield losses that range from 17 to 80 percent (9, 10, 32, 38). *C. henningsii* and *C. vicosae* also reduce the starch content of the roots (13, 57) . Their incidence is worldwide, except for *S. manihoticola*, which is present only in the Americas, and *Phoma* spp., which are restricted to the cooler cassava-growing areas (32, 38).

Other diseases whose incidence and severity are moderate and thus considered of minor importance are cassava rust six species of *Uromyces*) (33) , anthracnose (*Colletotrichum* spp. and *Gloeosporium* spp.), cassava ash (*Oidium manihotis*) and Periconia leaf spot

TABLE 1. Characterization of cassava viruses

Characteristics	AMV*	BSV*	CMV*	VMV*	LV*
Symptoms	Yellow mosaic, leaf curling and crinkling, stunting (20,	Yellow leaf patches, necrotic vein etch (20, 34, 50)	Yellow mosaic, leaf curling, stunting (16)	Vein clearing, leaf tip curling, stunting (16, 18)	Symptomless
Distribution	Africa, India (33, 48)	East Coast Africa (33, 34, 50)	Brazil, Venezuela, Peru, Colombia (16, 38)	Brazil, Venezuela (16, 18)	Brazil (16, 18) Africa (3, 4)
Losses	More than 50% (3)	Not clearly estimated	10-20%, based on plant yield (16)	Mild (16)	None
Particle Morphology	Paired polyhydral, isometric (3)	Paired, polyhydral, isometric (3 ?); long flexuous rods (29?)	Long flexuous rods (16, 30)	Polyhydral, isometric (30, 31)	Rhabdovirus (16); paired polyhdral (3, 4)
Transmission	Cuttings, *Bemisia* spp. (3, 7)	Cuttings, grafting, mechanical (35), insects (3)	Cuttings, grafting, mechanical (16)	Cuttings, grafting, mechanical (16, 30)	Cuttings grafting insects
Hosts	*Manihot* spp., *Nicotiana clevelandii* (3, 7)	*Petunia hybrida*, *Datura stramonium* *N. glucosa*, *N. rustica*, *N. tabacum*, *D. ferox*, *Solanum nigrum*, *Salpighosis sinuata* (29)	*Manihot* spp., *Chenopodium amaranticolor*, *C. guinoa*, *Malva perviflora*, *Gossypium hersutum* (16, 30)	*Manihot* spp., *D. stramonium* (16)	*Manihot* S. (16), *Euphorbiaceae* and *Solanaceae* spp. (16)
Control	Roguing, disease-free cuttings, resistant cultivars (3)	Roguing, disease-free cuttings (3)	Roguing, disease-free cuttings (16)	Roguing, disease-free cuttings (16)	

*AMV = African mosaic virus; BSV = brown streak virus; CMV = common mosaic virus;
VMV = vein mosaic virus; LV = latent virus

(*Periconia* spp.) (12, 38). Anthracnose appears to be the most common, causing defoliation, dieback and stem cankers (38). The extent of damage and yield reduction induced by these minor disease are still unknown, but anthracnose appears to be quite important in West Africa.

2. Stem pathogens. Are of importance in cassava because they can affect the quality and sanitary conditions of planting material, reducing germination and plant vigor (45). There are several pathogens that can attack the stems, but their incidence is dependent upon high relative humidities and stem injuries caused either by insectos or mechanically. The most common stem pathogens are *Glomerella* spp. and *Botryodiplodia* spp. Several ascomycetes and basidiomycetes, which are still unidentified, are also found attacking stored stem pieces and old cassava stem left in the fields during the rainy seasons (38, 45).

3. Root rot pathogens. Are soil-borne fungi which attack cassava roots before or after harvesting. Those fungi that attack the roots prior to harvesting generally induce soft or dry rot. Their occurrence is related to (a) poor drainage conditions of heavy clay soils (*Phytophthora* spp. and *Pythium* spp.) and (b) the crop or vegetation growing before cassava is planted (*Rigidoporous lignosus*, *Rosellinia bunodes*, *R. necatrix*, *Sclerotium rolfsii*, *Armillariella mellea*, *Rhizoctonia* sp., etc.) (38). Many fungi, both soil-borne saprophytes, can attack harvested roots through wounds caused during the harvesting operations. The intensity of damage induced by these organisms is related to the flora able to metabolize the root tissues and to the mechanical damage done to the roots during harvesting, packing and and shipping.

CHARACTERISTICS OF THE HOST/PATHOGEN RELATION

When looking at pathological problems, the following facts about cassava should be taken into consideration by plant protection specialists when designing research programs.

1. Cassava is a perinnial; this favors the perpetuation of pathological problems in areas where it is cultivated. Although the plants are removed at harvesting, volunteer plants are almost always present because of cassava's good germinating capacity. Volunteer plants may arise from stem pieces that are either left in the field in the form of debris or incorporated into the soil after harvesting. The true seeds also have a good germinating capacity (27).

2. Cassava is a woody crop (53). Many pathogens that attack forest trees, perennial woody crops and even herbaceous annuals can be pathogenic to cassava. Some of these pathogens have already been reported attacking cassava (38), and many others are potential pathogens.

3. Cassava is a long-cycle crop, being harvested from 8 to 24 months after planting. Planting is often done aver a long time period; consequently, plantations of different ages are found in many cassava-growing areas. In the absence of resistant varieties, therefore, susceptible tissue is always available so pathogens are mostly under stress from climatic and edaphic factors. When pathogens require insects vectors for dissemination, the latter are also under this stress.

4. Because of its long growth cycle and lack of critical growth stages for yield, it appears that cassava can tolerate moderate attacks of pests and diseases, often with only minor yield reduction (14).

5. Cassava is normally propagated vegetatively; therefore, top-quality propagating material is essential for good establishment, healthy stands and high yields (45). Moreover, vegetative propagation facilitates the perpetuation of hybrid material that is highly promising for desirable characteristics (27).
Great care must be taken in selecting this propagating material since losses in stand, resulting from the use of diseased and/or poor-quality planting material, affect yields (13, 45). Furthermore, the movement of planting material from one area to another always involves the risk of introducing pests and diseases (37, 39).

SUGGESTED METHODS FOR CONTROLLING CASSAVA DISEASES

In order to obtain a better control of cassava diseases, it is necessary to integrate simple control measures related to exclusion, eradication, protection and host resistance, as unit. The following methods of control, based on Agrios'system (1), have been or should be taken into consideration by cassava pathologists:

Regulatory methods of control

The most important cassava diseases (CBB, African mosaic and superelongation), as well as others that are potential risks (frog skin, American viruses and mycoplasmas, bacterial stem rot and stem gall, are, fortunately, still restricted to certain continents or geographical areas (37, 39, 42). In order to prevent the introduction and spread of these diseases to other areas, countries must not only establish quarantine regulations and inspections but also see that they are enforced by their plant sanitation officers. Since several Euphorbia spp. and Manihot spp., commonly planted as ornamental trees, are also hosts of some cassava diseases (see No. 1 under cultural control methods), quarantine regulations must also cover importations of these species. It might be worthwhile to promote the formation of centers that would produce certified cassava seed under the supervision of sanitation inspectors.

TABLE 2. Differential characteristics of presently identified bacterial diseases of cassava

Characteristics	CBB*	CBLS*	CBSR*	CBSG*
Symptoms	Leaf spotting, blight, gum exudation, wilting, leaf falling, dieback dry rotting of vascular strands of stems and roots (36, 40)	Leaf spotting, leaf yellowing, leaf fall (58)	Top wilting, stem soft rotting, pith necrosis (12, 47)	stem gall, stunting (13)
Species	<u>X. manihotis</u> (40, 41)	<u>X. cassavae</u> (58)	<u>E. carotovora</u> var. <u>carotovora</u> (E. cassavae) (12, 47)	<u>Agrobacteria</u> sp. (13) UH
Cultural features	Fast growth; slimy, mucoid and white colonies (36, 40)	Slow growth, yellow pigment; small slimy colonies (25, 58)	Fast growth; hydrolyses Na-pectates (47)	Fast growth; white slimy colonies (13)
Dissemination	Infected cuttings; rain and soil splashing (10, 36); insects (10); infested tools (41)	Rain splashing (58)	Insects (<u>Anastrepha</u> spp.) (47)	Infected cuttings (13); infested soil
Control	Resistant varieties; disease-free planting material and crop rotation (36, 41, 55)	Unknown	Insect-resistant varieties (12, 47), insect control (2, 46), clean planting material (45)	Clean planting material (13) crop rotation

* CBB = cassava bacterial blight; CBLS = cassava bacterial leaf spot; CBSR = cassava bacterial stem rot; CBSG = cassava bacterial stem gall

Cultural control methods

The following cultural methods can be applied to control some cassava diseases:

1. Host eradication. Euphorbia pulcherrima (12), E. heterophylla and other species of Euphorbia (12, 54) and Manihot glaziovii (32) have been reported as hosts of S. manihoticola, the causal agent of superelongation. Other weeds and Manihot species have also been reported as hosts of viral diseases of cassava (35). The eradication of these species in cassava-growing areas could prevent the perpetuation of such diseases and even eradicate them.

2. Crop rotation. Soil pathogens of cassava can sometimes be reduced in number or eliminated by rotating cassava with gramineous crops or crop fallowing. Phytophthora root rot, for example, can be eliminated after a six-month period of crop fallowing. Since cassava is a long-cycle crop, this particular control measure could be of great importance.

3. Sanitary measures. It has been demonstrated that American viruses and mycoplasmal diseases, as well as AMV, can be controlled effectively by roguing infected plants (3, 16). By using disease-free planting material, disinfesting tools, and applying other sanitary precautions for the laborers, CBB dissemination has also been prevented (36, 41).

4. Improvement of growing conditions For cassava plants can be achieved by planting healthy, high-quality propagating material (45). Cultural practices such as drainage of fields, ridging, proper spacing of plants and weed control will improve plant growth. these practices can also affect, directly or indirectly, the control of damping-off, root rot and foliar diseases of cassava.

5. The formation of high humidity conditions under the plant canopy can be prevented by using appropriate plant spacing, which may inhibit infections caused by foliar pathogens (S. manihoticola, Cercospora spp., etc.). It is interesting to note that Cock (14) suggests a relatively sparse leaf cover for maximun yields, which should also lead to less favorable conditions for such diseases. Good soil drainage can also reduce the number and activity of Pythium spp. and Phytophthora spp., which have induced considerable losses in areas where rainfall is heavy (more than 1200 mm/yr) and planting is done on the flat (8, 49).

6. Tissue culture has been reported to be an useful technique for producing AMV - (26) and CBB-free plants (43; Takatzu, personal communication).

Biological methods

Varietal resistance to CBB (*X. manihotis*) (36, 41), AMV (3,56), Cercospora leaf spots (*C. henningsii* and *C. vicosae*)(11, 12), Phoma leaf spot (*P. manihoticola*)(10, 11, 12) and superelongation (*S. manihoticola*) (11, 12, 32) has been reported. The use of resistant varieties to control these diseases appears to be the best means of producing acceptable yield without expensive inputs. Results to date on resistance to these four diseases have indicated that the variability of their causal agents is limited and that there is good, field-stable resistance. Possible explanations are that these pathogens are specific to cassava, the plant is heterozygous, and continuous susceptible host tissue is available. In the case of superelongation, it was found that the resistance of certain varieties was broken after three years of continuous cultivation. Recently, the existance of physiological races was reported, which was to be expected since the pathogen has other annual and perennial *Euphorbia* host species (12, 54), indicating that cassava is a new host and the pathogen possibly evolved first on these wild host spacies.

The mycoparasitism of *Darluca filum* reported on *Uromyces* spp., pathogenic to cassava (12, 33), should also be taken in consideration.

Physical control methods

Microwave, ultraviolet light and heat treatments have been used to eradicate pathogens infecting cassava suttings (9). Treating cuttings with hot water controlls the mycoplasma witches'-broom successfully (17).

Chemical control

It is economically feasible to use chemicals (a) to sterilize seedling beds when using the rapid propagation system (15);(b) to treat cuttings before storage and/or planting because of the protectant or eradicant in the case of *S. manihoticola* (12, 45) effect (11, 12); (c) to prevent postharvest microbial deterioration of the roots (44); and (d) to reduce the incidence of AMV and BSR, which are disseminated by *Bemisia* spp. and *Amasthrepha* spp., respectively (2, 3, 7). Nevertheless, continued chemical control of foliar diseases would be prohibitively expensive since cassava is a long-cycle crop.

METHODOLOGICAL PROBLEMS

Several problems may be encountered by cassava pathologists, especially during the screning and evaluation of varieties and hybrids. the following are the most common:

1. Plant yiel can be highly variable if appropriate planting material, chemical treatment of cuttings (45), agronomical practices (6, 45) and weed control (19) are not used. As cassava is a shrub, the border

effect between plots may also induce variabilities. Optimun plot size should be used (52).

2. Root rot problems can reduce plant population/ unit area and thus yield. In many cases they are noticeable only when harvesting. The use of high-quality, disease-free planting material (45), as well as good agronomic practices (6), should lead to the reduction or prevention of these problems.

3. In many cases the sanitary conditions and vigor of the aerial part of the plant do not bear a relationship to high yield. Vigorous, healthy plants can yield less than others because of their poor genetic yielding ability. It should be kept in mind that from a commercial standpoint the roots are the most important part of the plant.
It takes more than two years to obtain progenies by sexual recombinations (27), and there are always limitations of planting material for the evaluation of desirable characteristics. Consequently, it seems logical that evaluation programs would, in the short term, be more efficient if they were restricted to promising high-yielding progeny of controlled crosses cross-pollination in cassava is high (27) . In addition, the incorporation of resistance should be restricted to those diseases that have been shown to cause losses of economic significance.

4. There is high degree of overlapping of symptoms induced by diseases, insects and environmental or edaphic factors. This can easily lead to mistakes in final evaluations. Consequently, an accurate definition of the different symptoms for each disease must be kept in mind when evaluation for resistance. For example, cassava bacterial blight , gum exudation on shoots and green stem parts, leaf fall, wilting, dieback, and vascular discoloration of the stems and roots. On the other hand, angular leaf spots are also induced by _Xanthomonas cassavae_;blight by _Cercospora vicosae_ and Phoma spp.; gum exudation by shoot flies or as the result of mechanical injuries; leaf fall by fungi (_Cercospora_ spp., _Phoma_ spp.), bacteria (_X. cassavae_), soil salinity and drought; wilting by _Erwinia carotovora_ var. _carotovora_ (_E. cassavae_) and root rot pathogens; dieback by _Phoma_ spp., _Sphaceloma manihoticola_,mites, thrips, soil salinity and drought; and vascular discoloration by root and stem fungi, as well as _E. carotovora_ var. _carotovora_ (_E. cassavae_).

5. Greenhouse evaluations require space and control conditions which inply costly equipment. Diseases such as Cercospora leaf spots, Phoma leaf spot and superelongation, which are endemic to areas where environments favor their incidence and severity, can be evaluated better under local field conditions. Those diseases where field evaluation did not show even infection and/or there was an overlapping of symptoms induced by other factors (such as CBB), are better and more accurately evaluated under greenhouse conditions. Subsequent field evaluations of the greenhouse selected material are recommended.

The above considerations are given with the hope that they will contribute towards understanding the pathological problems of cassava.

Although the uniqueness of this crop requires that pathologists look at these problems quite differently from other crops, the integrated control of disease and pests could be highly successful in cassava.

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DISEASES OF CASSAVA

J. C. Lozano* and R. H. Booth**

Introduction

With the ever increasing world population and the resultant decrease in food energy sources, scientific attention is turning to some of the less familiar food crops such as cassava. To increase cassava yields to a maximum, as in any other crop, it is imperative that we increase our knowledge of the many diseases that reduce yields and how they may be controlled. Limited information is currently available about cassava diseases. This paper is an attempt to gather together much of this information and present it with recent observations made by the authors.

In general, the literature implies that cassava diseases are of minor importance. Although facts relating to actual losses caused by the diseases are scarce, anyone who has observed cassava in the field will realize that these diseases are of great importance. The large number of publications which merely mention the existence of different pathogens but fail to present data on their importance, epidemiology or control, serve to illustrate our lack of knowledge.

Cassava suffers from a wide variety of diseases caused by bacteria, viruses and fungi. On a global basis cassava bacterial blight is considered one of the most devastating as it results in complete loss of yield under certain conditions. In Africa, cassava mosaic is undoubtedly one of the most important factors limiting production. Also of widespread importance are the cercospora leaf spots. Many other diseases are less widespread or are only important under certain environmental conditions. Several of the root rots, for example, may cause severe loss in yield, particularly in poorly drained soils, and phyllosticta leaf spot may cause complete defoliation and dieback in certain cooler cassava growing areas. Gappy crops may result from damping-off diseases and stem rots may cause severe losses of viability in those regions where storage of planting material is necessary.

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While it is not fully understood whether the cause of the rapid postharvest deterioration of cassava roots is physiological or pathological, or a combination of the two, several microorganisms have been shown to result in postharvest rots and fermentations.

BACTERIAL DISEASES

Cassava bacterial blight

Cassava bacterial blight is the most important of several bacterial diseases reported. It was first recorded in Brazil (Bondar, 1912, Costa, 1940b) but has since been reported in Colombia and Venezuela (Lozano, 1972a; 1973; Lozano and Sequeira, 1973a, 1973b) and has been observed in several other countries in South America and Africa. This disease is now recognized as one of the most important factors limiting production in affected areas where in wet seasons it can cause complete loss of yield (Drummond and Hipólito, 1941; Elliot, 1941; Lozano and Sequeira, 1973a).

The symptoms, epidemiology, nature of the causal organism, and control of this disease have been studied extensively by Lozano and Sequeira (1973a, 1973b). Symptoms are characterized by leaf spotting and blight, wilting, dieback, gum exudation, and vascular necrosis. Primary symptoms resulting from the planting of infected material are indicated by wilting of the young leaves followed by dieback (Fig. 1). Secondary symptoms, resulting from secondary infections, show leaf spotting followed by blight and dieback. Leaf spots are at first small, angular, and water soaked but enlarge to cover part or all of the leaf and turn brown (Fig. 2). These necrotized leaves dry up and remain attached to the stem for a short time but later fall off. Gum is characteristically exuded from young infected stems, petioles and leaf spots. Vascular strands of infected petioles and stems necrotize and appear as brown strings. This vascular discoloration may also spread into and infect roots (Lozano, 1972a). The disease has only been found in species or varieties of the genus manihot (Bondar, 1915; Amaral, 1942b; Burkholder, 1942).

The causal bacterium was first named Bacillus Manihot is Arthaud-Berthet (Bondar, 1912) but was later renamed Phytomonas Manihoti Arthaud-Berthet and Bondar Viegas (Viegas, 1940). However, Drummond and Hipólito (1941) found that some of the characteristics of the bacterium they isolated from cassava were different from those of the species originally described by Bondar (1912). Burkholder (1942) concluded that the organism should be placed in the genus Phytomonas and the name Ph. Manihotis was included in Pergey's Manual (Bergey,; 1948). Comparative studies of a new isolate with the strains of Burkholder and of Drummond and Hipólito were made by Amaral and Vasconcellos (1945). They concluded that all three strains belonged to Ph. Manihotis. Later, Starr, (1946) changed the named to Xanthomonas Manihotis (Arthaud-Berthet) Starr.

Cassava bacterial blight. Plant showing typical leaf wilt and die-back symptoms.

However, as a result of studies on morphology, physiology, serology, and phage susceptibility of the bacterium isolated in Colombia and Brazil, Lozano and Sequeira (1973a) concluded that they were sufficiently different from X. manihotis to be considered a separate strain. They reported that the cassava blight bacterium differs from X. manihotis in cell size, mobility and flagellation, production of H_2S, utilization of nitrate, hydrolysis of starch, and in several serological relationships. They also reported that a comparison with a type culture of X. manihotis revealed differences in pathogenicity, growth rate, serological characteristics and phage susceptibility.

Lozano and Sequeria (1973a) reported the cassava blight bacterium as a gram-negative slender rod, mobile by means of a single polar flagellum, not encapsulated, and not spore forming. It is an aerobic, fast-growing bacterium which forms no pigment on sugar containing media. It hydrolyses starch and gelatin and reduces litmus milk. It does not induce a hypersensitive reaction on tobacco leaves or cause soft rotting of potato tubers, or cassava roots. It produces levan, catalase, arginine dehydrolase and lipase, but does not produce H_2S, indole, urease, tyrosinase or phenylalanine deaminase. It is able to grow on media containing NaC or tetrazolium choloride at maximum concentrations of 2.5 and 0.2% respectively. The bacterium utilizes nitrate and ammonium as sources of nitrogen; most simple sugars can serve as sources of carbon, but acid is not produced; various amino acids and other organic acids are readily utilized. It can be separated by serological and phage-typing methods from species of Erwinia, Pseudomonas and Xanthomonas, including X. manihotis. A species of Bdellovibrio caused lysis specifically on this bacterium and could be used to separate it from other plant pathogenic bacteria. As a result of this Lozano and Sequeira (1973a) concluded that the cassava blight bacterium should be considered a strain of X. manihotis but needed further revision.

The bacterium normally penetrates the host via stomatal openings and wounds of epidermal tissues (Pereira and Zagatto, 1967 ; Lozano and Sequeira, 1973a). The bacterium eventually invades the vascular tissues and causes extensive breakdown of parenchymatous tissues in leaves and young shoots. Movement into the stem and petioles takes place primarily through the xylem vessels (Drummond and Hipólito, 1941; Amaral, 1942b, 1945) and possibly through the phloem (Amaral, 1942b; Pereira and Zagatto, 1967). Movement through the pith tissues has also been reported (Drummond and Hipólito, 1941). In mature, highly lignified tissues of old stems the bacterium remains restricted to the vascular tissues. In general, plants develop typical symptoms within eleven to thirteen days of infection (Amaral, 1942b; Pereira and Zagatto, 1967; Lozano, 1972a, Lozano and Sequeira, 1973b).

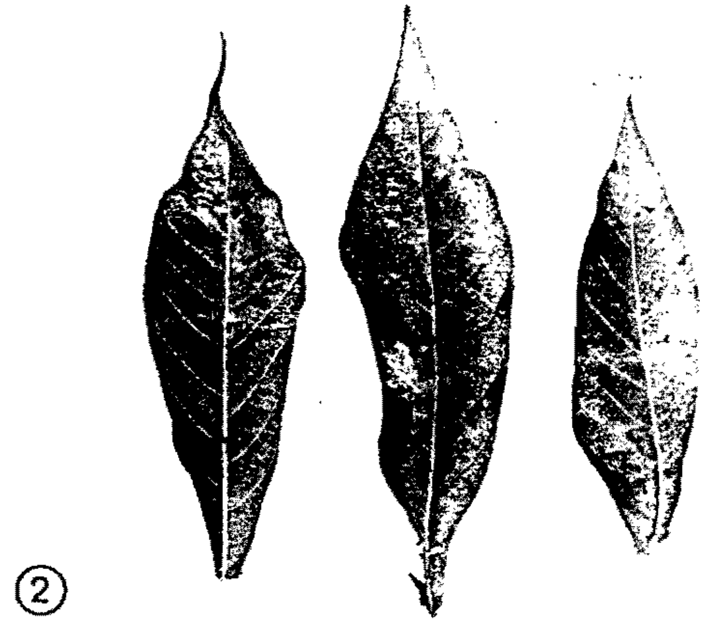
The possibility that the pathogen spreads from one area to another by infected cuttings or contaminated insects was suggested by Amaral (1945). Many workers (Carneiro, 1940; Goncalves, 1939, 1948, 1953; Drummond and Hipólito, 1941; Lozano, 1972a, Lozano and Sequeira, 1973b) have suggested or demonstrated that the pathogen could be spread by the movement of soil during cultural operations and by the use of infested tools. Drummond and Hipólito (1941) reported an increase in leaf spotting during the rainy season. Lozano and Sequeria (1973b) have clearly demonstrated that rain splashing is the most important means of dissemination in localized areas and that dissemination from one area to another or from one growing season to another occurs largely through infected planting material.

It has been reported (CIAT, 1971, 1972; Lozano and Sequeira, 1973b) that by pruning most of the above ground portion of infected plants spread of the disease may be delayed. However, the success of this methods is dependent on the susceptibility of the cultivar and the interval between initial infection and prunning. A successful means of controlling the disease has been developed by Lozano and Wholey (1974, in press). This method involves the rooting of disease free stem tips of infected plants and can thus be used to clean up infected cultivars or stocks and so provide certified bacteria-free cassava 'seed'. The existence of varietal resistance to this disease has also been noted (Carneiro 1940; Goncalves, 1939, 1948; Drummond, 1946; Drummond and Goncalves, 1953; Lozano and Sequeira, 1973b). Both a hypersensitive reaction and a restriction to penetration and systemic invasion have been observed (Lozano and Sequeira, 1973b). A combination of the use of resistant varieties and disease free planting material would thus appear to be a promising means of control.

Other bacterial diseases

Other bacterial diseases of cassava include a disease reported in Uganda (Hansford, 1938) characterized by leaf spotting and necrosis of the petioles with subsequent defoliation. The stems also become infected but wilting is not described. The pathogen was named Bacterium Cassavae (Hansford) Burkholder (Bergey, 1957). This organism is a gram-negative, facultative, anaerobic rod which does not form capsules. It is mobile by means of a few peritrichous flagella; it liquifies gelatin; it forms base from milk and acid from glucose, sucrose, maltose, and glycerol, but not from lactose or reduced nitrates. On agar it forms yellow, smooth, entire and translucent colonies.

Wiehe and Dowson (1953) reported a bacterial disease of cassava in Malawi (Nyasaland). This disease is characterized by leaf spots which are at first yellow and circular. As these spots enlarge, they become angular with a brown centre and a broad yellow halo. The leaf veins rediating from the margins of these spots become dark brown but the leaves are shed before the petioles become infected thus preventing stem infection.



Cassava bacterial blight. Leaflest showing angular leaf spots and leaf blight.

Cassava mosaic disease (African mosaic). Leaf showing typical chlorosis and deformation (Photograp) courtesey of Dr. R. Williams, IITA, Ibadan (Nigeria).

Cassava mosaic disease (African mosaic). Chlorosis reduction of leaf lamina and distortion of severely infected leaf. (Photograp courtesey of Dr. R. Williams, IITA, Ibadán, (Nigeria).

Under humid conditions a sticky liquid containing bacteria is exuded from lower leaf surfaces and rain splashing of this exudate spreads the disease. The causal agent was named Xanthomonas cassavae sp.n. which is a gram-negative rod mobile by means of polar flagellum. Colonies on nutrient agar and glucose agar are pale yellow, confluent, and viscous. It forms acid from sucrose, small amounts of acid from dextrose and maltose, and no acid from lactose, salicin, glycerol, or mannitol. It produces hydrogen sulphide from peptone and nitrites from nitrates (Wiehe and Dowson, 1953; Dowson, 1957).

Pseudomonas Solanacearum E.F.SM. has been reported (Burkholder, 1942; Amaral, 1945; Kelman, 1953; Orejuela, 1965) as a pathogen of cassava in Brazil. It induces wilt in young plants but not leaf spotting or gym exudation. Several other bacterial species have been reported inducing soft rots and/or fermentations of harvested cassava roots. These are discussed below in the section on root rots.

VIRUS AND MYCOPLASMA LIKE DISEASES

Several virus diseases are reported and although considerable losses may result from some of these diseases, such as cassava mosaic disease in Africa, research has been scattered and spasmodic. In a recent review of the status of these diseases, Lozano, (1972b) pointed out that the information available is limited and incomplete. Disease symptoms are frequently described in general terms but full details are rarely given, losses from these diseases are seldom ascertained, and frequently little information is available on such important subjects as host range and transmission. Similarly, few reports give any detailed biological, physiological, physical, or chemical characteristics of the infective agent.

Cassava Mosaic disease

This disease was first reported by Walburg in 1894. It occurs in all parts of East, West, and Central Africa and adjacent islands (Storey, 1936; Storey and Nichols, 1938; Chant, 1959; Jennings, 1960a, 1970) and reported losses in yield from this disease range from 20 to 90% (Lefevre, 1935; Chant, 1959; Jennings, 1960a; Doku, 1965; Beck, 1971). This disease does not appear in other countries and is noticeably absent from the Americans, the recognized source of origin of the crop. It may thus be regarded as a new or introduced disease to this crop.

The symptoms in cassava are characteristic of a mosaic disease. Early in the development of the leaf, chlorotic areas can be observed and leaflets are frequently distorted (Fig. 3). Leaves are sometimes reduced in size, misshapen and twisted, with bright yellow areas separated by normal green tissue (Fig. 4) (Jennings, 1960a).

This disease has only been found in Manihot spp.

Successful transmission by Bemisia spp. (Whitefly) has been reported. For whiteflies to become viruliferous, it is necessary for them to feed for at least four hours on young diseased leaves followed by a further four-hour incubation period (Storey and Nichols, 1938; Chant, 1958; Jennings, 1960a).

Several attempts have been made to purify the infective agent without success. Gálvez and Kitajima (pers. comm.) were unable to find virus like particles in either leaf dip preparations or in ultra thin sections. Their purification trials were also unsuccessful. Barbee (pers. comm.) reports finding two components in a disease extract by his purification procedure. Gálvez (pers. comm.), however, suggests that this disease should not be classified as caused by a virus until further research clarifies the identity of the causal agent.

The only effective control of this disease is by the use of resistant varieties (Storey, 1936; Jennings, 1960a; Doku, 1965; Beck, 1971; Dubern, 1972; Hahn, 1972).

A similar mosaic disease has recently been reported in Kerala, India (Menon and Raychaudhuri, 1970). The symptoms of this disease are similar to those reported above and it is also transmitted by whitefly. As well as being found in Manihot spp. it has been recorded in cucumber (Menon and Raychaudhuri, 1970). Whether this is the same disease as that reported above in Africa is not known.

Cassava common mosaic disease

Common mosaic disease occurs in various parts of Brazil (Costa, 1940a; Costa et al., 1970) and has also been reported in Colombia (Kitajima and Lozano, pers. comm.). Losses in yield range from 10 to 20% but because of its ease of control the disease is considered comparatively unimportant (Costa et al., 1970).

The symptoms of cassava are characteristic of a mosaic disease and consist mainly of chlorosis of the leaf blade. These chlorotic areas are not usually as well demarcated as those of the cassava mosaic in Africa, but otherwise the general symptoms are similar (Fig. 5). The host range of this virus is relatively wide and it is able to attack Manihot spp., Euphorbia Prunofolia, Chenopodium Amaranticolor, C. Guinoa, Malva Parviflora, and Gossypium Hirsutum (Costa et al., 1970).

The disease has been trasmitted mechanically and by grafting, but no natural vector has been recorded (Costa et al., 1970). Virus infectivity is destroyed when infected sap is heat treated at 65-70°C for 10 minutes, but at 20°C infected sap remains infective for at least 24 hours (Kitajima and Costa, 1966a; Costa et al., 1970).

The virus particles are elongated flexuous rods measuring 15 mu diam. with a normal length of about 500 mu (Kitajima et al., 1965; Kitajima and Costa, 1966a; Costa et al., 1970) with good antigenic properties (Silva, 1962; Costa and Kitajima, 1972a).

Effective control has easily been achieved by the use of clean vegetative planting material and by roguing diseased plants from plantations (Costa and Normanha, 1939; Costa el al., 1970).

Cassava brown streak disease

Brown streak disease was first recorded and described in 1936 (Nichols, 1950), and is reported only to occur along the east coast of Africa and at altitudes below 3,500 ft. (Nichols, 1950; Jennings, 1960b). Recent information suggests that this disease is very uncommon . Losses are difficult to estimate because the plants are usually infected simultaneously with mosaic disease. Because diseased roots are unfit for human consumption, losses are considerable (Jennings, 1972; Lozano, 1972b).

Infected plants show chlorosis of the leaves, necrosis of the root storage tissues and leaf scars remain longer than expected after normal leaf drop. Brown lesions sometimes occur on the young green stems (Nichols, 1950; Jennings, 1960b). This virus is able to infect Manihot spp., Petunia Hybrida, Datura Stramonium, Nicotiana Tabacum and N. Glutinosa (Lister, 1959; Jennings, 1960b; Kitajima and Costa, 1964).

Transmission by both mechanical means and by grafting has been reported (Storey, 1936; Nichols, 1950; Lister, 1959) and whereas transmission by vectors is suspected, it has not been demonstrated (Lister, 1959; Nichols, 1950). Virus infectivity is destroyed when infected sap is heat-treated to 50°C for 10 minutes and at 20°C sap is reported to lose infectiveness in less than 24 hours (Kitajima and Costa, 1964). Kitajima and Costa reported the dilution end point of the virus to be 1:1000. They found rod shaped particles about 60 mu long during electron microscope examinations of dried material.

Effective control has been obtained by using disease free planting material. Resistant varieties have been reported (Jennings, 1960b; Nichols, 1950; Storey, 1936).

Cassava vein mosaic disease

This disease is reported to occur in scattered localities in Brazil, but little reliable information is available (Costa, 1940a; Kitajima and Costa, 1966b; Costa et al., 1970). Symptoms of this disease are characterized by vein clearing and leaf curling, and it is reported to be transmitted mechanically and by grafting. Manihot spp. and Datura Stramonium are the only known hosts.

Electron microscope examinations of diseased material have revealed spheroidal particles of about 50-60 mu in vivo (Costa, 1940a; Kitajima and Costa, 1966b; Costa el al., 1970).

Witches broom disease

This has been reported in Brazil, Venezuela (Goncalves et al., 1942; Normanha et al., 1946; Costa et al., 1970; Kitajima and Costa, 1971) and Mexico (Kitajima, Costa and Normanha, 1972; Costa and Kitajima, 1972a, 1972b). Reduction in yield can be relatively high, sometimes in excess of 80% (Goncalves et al., 1942; Silberschmidt and Campos, 1944; Normanha et al., 1946). Diseased plants can be recognized by their stunted appearance, shortening of internodes, and excessive proliferation of branches. However, care must be taken in diagnosing this disease as similar symptoms have been shown to result from heavy thrip infestations (Lozano and Schoonhoven, pers. comm.). In fact, little is known about this disease, but Costa et al. (1970), Kitajima and Costa (1971) and Costa and Kitajima (1972b) have concluded that the disease is associated with a mycoplasma like organism.

Latent virus

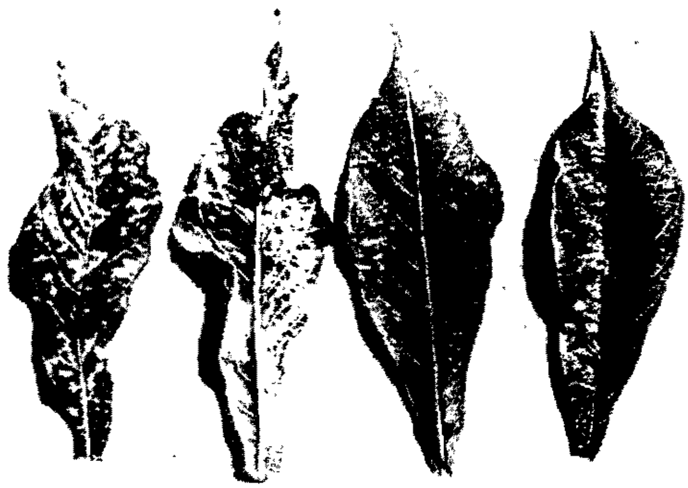
A latent virus has been reported by Costa et al., (1970). This virus has no symptoms in cassava but is thought to be widespread. It is a rabdovirus of 280-300 mu (Costa et al., 1970).

FUNGAL DISEASES

Many fungal diseases of cassava, varying considerably in their distribution and importance, have been reported. Those diseases considered to be most widespread or important in particular situations are described here as leaf diseases, stem rots and root rots.

Leaf diseases

Several Cercospora spp. have been reported to induce leaf spots on cassava. Considering severity and geographical distribution C. Henningsii Allescher and C. Caribaea Chupp and Ciferri appear to be the most important (Cardin, 1910; Ghesquiere and Henrard, 1924; Viegas, 1941; Golato, 1963; Golato and Meossi, 1966; Castaño, 1969). Although the economic importance of these pathogens on cassava is undetermined, several reports (Sydow, 1901; Deslandes, 1941; Chevaugeon, 1956; Normanha and Pereira, 1964; Castaño, 1969; Jennings, 1970; Golato and Meossi, 1971) suggest that they are important in certain geographic areas during the rainy seasons.



(5)

Cassava common mosaic disease (Brazilian mosaic). Leaflets showing mild and severe symptoms.

Brown leaf-sport (*Cercospora henningsii*). Large brown lesions with distinct borders.

Brown leaf spot (C Henningsii) is probably the most important of all the cassava leaf diseases. This disease is widely distributed and can be found in Asia and North America in addition to Africa and Latin America. The pathogen appears to have one of the widest host ranges of the Cercospora spp. attacking Manihot Glaziovii (cera rubber) M. Piauhynsis, and by artifical inoculation, Ipomea Batatas (Sweet potato), in addition to M. Esculenta (Viegas, 1941; Golato, 1963; Ferdinando et al., 1968; Powell, 1968, 1972; Golato and Meossi, 1971).

C. Henningsii grows in the intercellular spaces of the leaves and produces stromata from two to six cells in depth and from 20-45 u in diameter. From these stromata conidiophores are produced in dense fascicles. The conidiophores are pale olivaceous brown (medium-dark in mass), uniform in colour and width, unbranched, 0-2 midly geniculate, rounded at the tip with a small to medium spore scar, straight or nearly so and measuring 3-5 x 10-50 u, rarely as long as 100 u with the longest ones sparingly spetate. The amphigenous conidia, produced singly at the apex of each conidiophore, are cylindric, straight or slightly curved, with both ends bluntly rounded or with a short abconic base, plainly 2-8 septate, pale olivaceous, and measuring 4-6 (7) x 30-60 (85) u (Chupp, 1953; Powell, 1968, 1972). Black perithecia, 100 u diam, occasionally appear scattered in the necrotic tissue of the foliar spots on the upper surface of the leaf. The asci are elongate-clavate, eight-spored, sub-sessile, 55-72 x 10-13 u. The ascospores are ovoid, uniseptate, constricted at the septum, 17-22 x 5.2-6.8 u. The upper cell of these spores is of greater diameter than the lower and is drawn out as a candle flame (Chupp, 1953; Powell, 1972).

The perfect state of C. henningsii was reported as Mycosphaerella manihotis Ghesquiere Henrard non Sydow (Ghesquiere and Henrard, 192t; Ghesquiere, 1932) and later corroborated by Chevaugeon (1956). However the genetic relationship between the stages has not been proven. Powell (1972) suggested a new nomination needs to be provided for the sexual state as the one in use is a later homonym of the name given by Sydow (1901).

C. cassavae Ell. & Ev.; C manihotis P. Henn., C. cearae Petch, C. manihoticola Stev. Ined., C. manihotis P. Henn., Helminthosporuim manihotis Rangel; H. hispaniolae Cif., and Septogloerum manihotis Zinn, are all considered to be synonymous with C. Henningsii (Ciferri, 1933, Chupp, 1953; Powell, 1972).

Symptoms on cassava are characterized by leaf spots on both sides of the leaves. On the upper surface the spots appear uniformly brown with a distinct darker border (Fig.6). On the lower surface the lesions have less distinct margins and in the centre the brown spots assume a greyish cast because of the presence of conidiophores and conidia of the fungus. As these flat circular lesions, 3-12 mm diam, grow they become somewhat irregular and angular in shape as they are limited by the leaf margin or major veins. Small veins within the lesions appear black. Sometimes, depending on the susceptibility of the variety, an indefinite halo or blighted area is present around the lesions. As the disease progresses, infected leaves turn yellow and dry, and eventually drop. Susceptible varieties can thus be severely defoliated during warm rainy seasons.

Primary infections are initiated in new plantings when wind or rain carry conidia from lesions on old faller infected tissues to infection courts on leaf surfaces. If sufficient moistrure is present, the conidia germinate, producing branched germ tubes which frequently anastomose. Penetration occurs through stomatal cavities and invasion of the tissues through intercellular spaces. In warm, humid conditions infection usually occurs within twelve hours (Wallace, 1931 Ciferri, 1933; 1933; Viegas 1941, 1943a, 1943b; Chevaugeon , 1956).

When these lesions mature, conidiphores are produced from the stomata. Secondary disease cycles are repeated throughout the rainy season whenever conidia are carried to new sites of infection by wind or rain. The fungus survives the dry season in old lesions, often on fallen leaves, and renews its activity with the coming of the rainy season and the renewed growth of the host.

Chevaugeon (1956) demonstrated that on a given plant the older, lower leaves are more susceptible than the younger, upper leaves. This is corroborated by other authors. However, it has been observed that some susceptible species (M. carthagenensis) and cultivars of M. esculenta may be severely and evenly attacked. Leaflets, young leaves, petioles, and even fruits of M. carthagenensis have been observed with severe disease symptoms. It is reported that plants that have been " hardened " by unfavorable growing conditions become more resistant (Viennot-Bourgin and Grimaldi, 1950) but no differences in susceptibility between plants grown or rich or poor soil were found (Chevaugeon, 1956).

Cultural practices, such as wider spacing, directed towards reducing excess humidity in the crop stand are recommended to reduce infection (Springensguth, 1940; Golato, 1963, Golato and Meossi, 1966). The use of copper oxides and copper oxychlorides suspended in mineral oil applied at a rate of 12 l/ha have been reported to give good control (Golato, 1963; Golato and Meossi, 1971). However, the best control of this disease is obtained by planting resistant varieties. Significant differences in varietal resistance have been reported in Africa (Chevaugeon, 1956; Umanah, 1970), Brazil (Viegas, 1941, 1943a. 1943b) and in the extensive collection of cassava varieties at CIAT, Colombia (CIAT, 1972) .

White leaf spot (C.caribaea) is commonly found in the humid but cooler cassava growing regions and has been reported in certain areas of Asia, North America, tropical Africa, and Latin America (Viegas, 1941; Chevaugeon, 1956).

C. caribaea forms slight stromata in infected leaves from which conidiophores are produced in loose fascicles. The conidiophores which emerge through stomata are usually olivaceous brown, uniform in colour and width; rarely branched, 1-15 geniculate, sub-truncate at the tip with a fairly large spore scar and measure 3-5 x 50-200 u. The hypophyllous conidia are hyaline to subhyaline, obclavate-cylindric, with bluntly rounded ends, 1-6 septate, straight or nearly so, and measure 4-8 x 20-90 u (Chupp , 1953; Powell 1968, 1972).

While the name C.caribaea Chupp and Ciferri is widely accepted for this fungus, Powell (1972) states that the name is not at present valid and will only be validated by the publication of a full latin description. This species can easily be distinguished from other Cercospora spp. on M. esculenta by the leaf symptoms and by the hyaline conidia produced (Chupp, 1953; Powell,1968).

Lesions caused by C. caribaea are smaller and different in colour to those induced by C. henningsii. They are circular to angular, usually 1-7 mm diameter, and white, or rarely yellowish brown (Fig.7). The lesions are sunken from both sides to about one-half the thickness of the healthy leaf blade. While the white spots remain distinct, the lesions frequently have a diffuse coloured border on the lower leaf surface. The border sometimes appears as an irregular violet-brown line surrounded by a yellow or brownish halo. The centre of the spots are given a greyish velvety aspect during the fructification of the pathogen which occurs predominantly on the underside of the leaf.

Penetration occurs through stomatal cavities and invasion of the tissues through intercellular spaces. When the leaf spots thus produced reach about 5-7 mm a stroma is formed from which the conidiophores are later produced. Secondary disease cycles are repeated throughout the rainy season when the conidia are dispersed by rain splash. The fungus survives the dry season in old, infected tissues and renews its activity with the coming of the rainy season and the renewed growth of the host.

Recommended control measures for this disease are similar to those for brown leaf spot. Specific resistant varieties have not been reported, but field observations suggest such resistance exists.

The development of the two diseases, brown and white leaf spots, is similar but generally brown leaf spot is more common in hot, dry regions and white leaf spot in humid, cooler cassava growing areas. These distribution differences reported in Africa (Chevaugeon, 1956) and Latin America (CIAT, 1972) are probably the result of differences in temperature and moisture responses of the two causal fungi. The optimum temperatures for conidial germination of C. henningsii and C. cariabea are 39 and 33°C, respectively, and the maximum temperatures to allow germination are 43 and 33°C, respectively, Conidia of C. henningsii will germinate at 50 percent R.H. with optimum germination at 90 percent while conidia of C. caribaea need to be immersed in water for normal germination. Nutritional studies have also revealed differences between the two fungi; C. henningssi is able to utilize acetate, citrate, and various amino acids but not pentoses. C. caribaea however utilizes pentoses as energy and carbon sources but does not generally utilize trioses (Chevaugeon, 1956; Powell, 1968).

C. viscosae Muller and Chupp is the causal agent of a diffuse leaf spot in the warm cassava growing areas of Brazil and Colombia (Viegas , 1941; CIAT, 1972). Leaf spots are large and brown without definite borders. Each spot frequently covers one fifth or more of the leaf lobe. The upper surface of the spot is uniformly brown but on the under surface the centres of the brown lesions assume a greyish cast because of the presence of conidia and conidiophores of the fungus. The general appearance of the lesions is similar to those induced by Phyllosticta sp. but can be distinguished from the latter which usually have concentric rings around the lesions on the upper leaf surface.

The fungus does not form a stromata but sporulates profusely. The conidiophores produced in coremoid fascicles are dark reddish-brown, measuring 4-6 x 50-150 u. The conidia produced are cylindro-obclavate and 4-6 x 25-100 u (Chupp, 1953).

C. viscosae has only been found infecting Manihot spp. The disease occurs during the rainy season in warm cassava growing areas where brown leaf spot is also usually prevalent. The disease is not usually serious and is confined to the older leaves where some defoliation may occur.

C. manihobae Viegas has been reported to induce distinct leaf spots on M. esculenta in Brazil (Viegas, 1941, 1943b; Chupp, 1953). Leaf spots are reported (Viegas, 1941, 1943b) to be characteristically snow-white in appearance, but a full description of the disease is not available.

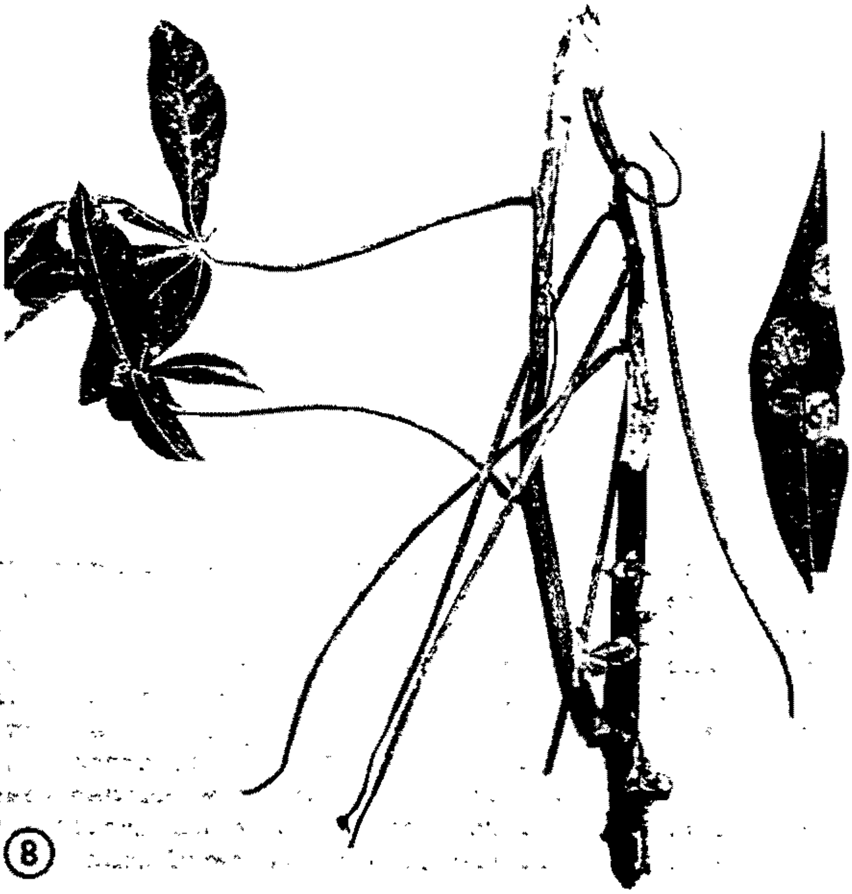
The fungus produces medium dark coloured conidiophores measuring 3-5 x 50-200 u. The conidia are hyaline to subhyaline, obclavate-cylindric, and 4-8 x 20-90 u (Chupp, 1953).

__Phyllosticta leaf spot__

This disease is commonly found in the cooler cassava growing areas of Colombia (CIAT, 1972) and Brazil (Viegas, 1943a) and has also been reported in the Philippines (Sydow, 1913), Tropical Africa(Cincens, 1915), and India (Ferdinando et al., 1968). During rainy seasons and when the temperature is below 22°C, this disease may cause severe

(7)

White leaf-sport (Cercospora caribaea). Small white lesions with distinct violet-brown border and diffuse yellow halos.



(8)

Phyllosticta leaf-sport (Phyllosticta spp.). Leaflet showing large brown lesions with concentric rings. Young stem showing die-back and presence of pycnidia.

defoliation of susceptible varieties, finally resulting in dieback of the plants. The disease has also been reported to occur on Manihot heptaphylla, M. dichotoma (Reinking, 1919, Viegas, 1943a) and M. aipi (Spegazzini, 1913; Viegas 1943a) in addition to M. esculenta (Viegas, 1943a).

The causal agent of this disease has not been clearly defined, and several Phyllosticta spp. have been reported (Sydow, 1913; Vincens, 1915; Reinking, 1919; Viegas, 1943a; CIAT, 1972) as inducing the same disease syndrome. Vinvens (1915) first described the causal agent as Haplographium manihoticlo Vincens, but the pathogenicity of this fungus was later questioned by Viegas (1943a). Phyllosticta manihoticola Sydow (Sydow,11913), P. manihot Sacc. (Saccardo, 1931), and P.manihobae Viegas (Viegas, 1943a) have all since been reported as pathogenic on cassava. As the full definition and tazonomic validity of these species have not been fully determined, the possibility remains that they could be synonymous and that there is only a single cassava pathogenic species. Recent studies and observations indicate that this fungus should be classified as a Phoma sp. (Powell, personal communication). A full taxonomic study of a wide range of pathogenic isolates is urgently needed to clarify this point.

The causal fungus produces numerous epidermal pycnidia which are dark brown, globose, and borne singly or in small clusters on infected; leaves and stems. The pycnidia are 100-170 u in diameter with walls formed of polyhydrical cells and have an ostiole measuring 15-20 u. The conidiophores are short and hyaline and produce small (15-20u), one celled, ovoid to elongate conidia (Viegas, 1943a; Ferdinando et al., 1968). The fungus isolated in Colombia forms profuse pycnidia in concentric rings on lima bean agar.

The disease on cassava is characterized by the presence of large brown leaf spots, usually with indefinite margins. These lesions are commonly found at the tips or edges of the leaf lobes or along the midrib or main veins. The upper surface of the lesions initially consistes of concentric rings formed by brown pycnidia((Fig. 8). These rigns are frequently absent from old lesions as mature pycnidia are washed off by raindrops. In these cases the uniformly brown lesions may resemble those caused by C. viscosae. On the lower surface few pycnidia are produced so the lesions are uniformly brown. Under conditions of high relative humidity, the lesions may be covered with a greyish-brown hyphal weft. On the underside of the leaves the veins and veinlets around the lesions become necrotized thus forming black strings radiating out from the lesions. These lesions grow, causing a leaf blight, and finally the whole leaf and petiole become dark brown and are necrotized. At this stage the leaves wilt and then drop, in some cases causing extensive defoliation. In severe infections the fungus also attacks the young shoots causing a dieback (Fig. 8). Diseased stems turn brown and are frequently covered with pycnidia.

Field observations suggest that the older lower leaves may be more resistant than younger upper leaves, However, young leaves, fully expa.ded mature leaves, and green stem parts have all been seen with severe disease symptoms. It has also been observed that disease occurrence is correlated with conditions permitting spore germination. Maximum spore germination has been observed between 20 and 25°C and artificial inoculations succeeded only at temperatures below 25°C. Similarly, under field conditions the disease is always found at higher altitudes or in lowland areas during the rainy season. Survival of the fungus during dry periods or from one season to another is not understood. Is is suggested (Viegas, 1943b) that the fungus may produce a sexual stage in infected stem and leaf debris, but this has not yet been confirmed.

No control measures have been reported for the disease, which can cause serious losses in certain areas under specific environmental conditions. Although no reports of varietal resistance are available, field resistant cultivars have been observed in naturally infected plantations in Colombia. Chemical treatment during rainy seasons could also be beneficial in those areas where the disease is known to be endemic.

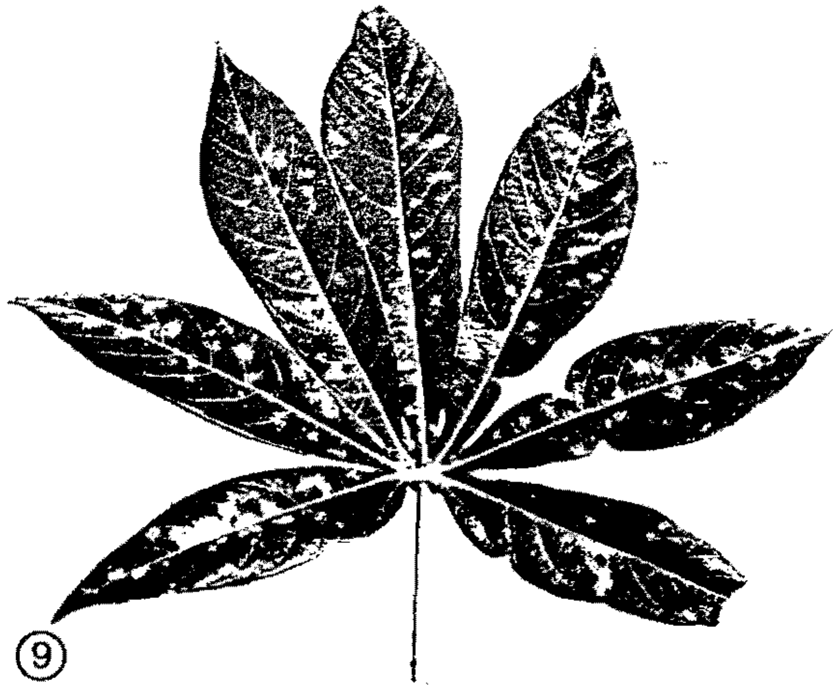
Cassava ash disease

The disease was first reported in Africa (Saccardo, 1913) but has since been reported in Latin America (Viegas, 1943a; CIAT, 1972) and Asia (Park, 1934) and observed in several other countries. The disease is known only to cause yellowish undefined leaf spots on M. esculenta. Although widely distributed and of common occurrence, this disease is considered to be of relativelyminor importance.

The causal agent has been named as Oidium manihotis P. Henn. the sexual stage of which has been described as Erysiphe manihotis (Ferdinando et al., 1968). The fungal mycelium is white, producing numerous haustoria on the host epidermis. Conidiophores are upright and simple with the upper portion increasing in both length and width as conidia are formed. The conidia are oval or cylindrical, one celled, hyaline, measuring 12-20 x 20-40 u, and produced in basipetal chains (Saccardo, 1913; Viegas, 1943b; Ferdinando et al., 1968).

The first symptom of the disease is the appearance of white mycelium growing over the leaf surface. The fungus penetrates the cells by means of haustoria, infected cells becoming chlorotic and thus forming yellowish undefined lesions (Fig.9). Within these yellowish areas pale-brown angular water-soaked spots of different sizes frequently develop and necrotize.In certain varieties, the disease never progresses beyond the yellowish undefined lesion stage. These symptoms are sometimes confused with those induced by insects and spiders.

Mature, fully expanded leaves appear to be the most susceptible, but young leaves of certain varieties are also frequently infected. The disease is found commonly during dry seasons in the warmer cassava growing areas.



Cassava ash disease (Oidium manihotis). Typical underfines yellowish leaf lesions.

The superelongation disease (Taphrina sp. or Sphaceloma sp.). General symptoms showing young stem and petiole elongation, leaf deformation and distortion, and cankers.

Although specific control measures against this disease are not generally considered necessary, resistant varieties have been observed (CIAT, 1972). It has also been suggested (Ferdinando et al., 1968) that spray applications of sulphur compounds control the disease.

Superelongation disease

Superelongation disease has recently been found inducing epiphytotics in several areas of Colombia (CIAT, 1972; Lozano, 1972; Lozano and Boot, 1973). The disease has been found during rainy seasons, and at the onset of dry periods, infection and disease spread decline. The yield of heavily infected plants is severely reduced.

A fungus, according to CMI* it is possibly a species of Taphrina or Sphaceloma, has been found to be the causal agent. This organism grows well in any artifical media containing peptone and sugar forming yeast like colonies. Each colony is circular, corrugated, slightly sunken and of a hard consistency. Initially the colonies are yellowish but after fifteen days incubation they turn dark brown. These colonies are formed of a promycelial type of structure. A delicate septate mycelium composed of binucleate, elongate or vasicular cells is formed around each colony. On artificial media tiny binucleate spores are produced in ten days. Preliminary observations suggest that these are blastospores capable of multiplying by budding (Lozano and Booth, 1973).

Histological studies have shown that the fungus initially grows over the epidermis and that following penetration it grows in the intercellular spaces of the epidermis and cortex. Following infection, mycelial aggregates which are formed in the cortex push up and rupture surrounding epidermal cells to form a canker. Most cells around such cankers are abnormally large (Lozano and Booth, 1973).

In the field the disease is recognized by the exaggerated elongation of the internodes of young stems which appear thin and weak (Fig. 10). Infected plants are considerably taller than healthy ones. Young shoots, petioles and leaves frequently show a distortion which is usually associated with lens shaped cankers formed along the midribs or veins of leaves and on the petioles and young stems. Often leaves are not completely developed and leaf lamina not fully expanded. White irregular spots are frequently present on young leaves (Fig.11). Partial or total necrosis of young leaf laminae sometimes occurs and results in considerable defoliation. The cankers vary in size and are normally lens shaped but may be more diffuse on the stems and resemble damage by thrips.

During the rainy seasons the spread of the disease is extremely rapid. Dissemination is thought to occur by wind and/or rain borne spores. High relative humidity appears to be necessary for spore germination and infection. Symptoms in the form of yellow leaf markings

* Commonwealth Mycological Institute

appear within six to eigh days of inoculation and cankers are rapidly formed.

Field observations of more than two hundred cultivars of M.esculenta have indicated possible sources of resistance. Preliminary studies to control this disease using chemical sprays also showed promising. A similar disease causing stem elongation and leaf spotting and characterized by pustules on stem, petioles and midribs has been reported in Mexico (Normanha, pers. comm.).

Anthracnose (wither-tip)

This disease has been reported as a disease of cassava in many countries (Bouriquet, 1946; Vanderweyen, 1962; Affran, 1968; Doku,1969; CIAT, 1972) but it is generally considered to be of minor importance. Sunken leaf spots about 10 mm diam. and similar to those caused by C.henningsii are produced at the base of leaves, which may subsequently die. Stems may also be attacked causing a wilt of very young stems and producing cankers on older ones (Vanderweyen, 1962; Irvine, 1969). New leaves produced at the beginning of rainy seasons are reported to be the most susceptible, and the disease tends to disappear at the approach of dry seasons (Doku, 1969; Irvine, 1969). Similarly, it has been found that artificial inoculations using spore suspensions are only successful when the plants are kept for 60 h at 100 percent R.H. (CIAT, 1972).

The causal organism has been variously reported as Glomerella manihotis Chev., Colletotrichum manihotis Henn. (Vanderweyen, 1962), Gloesporium manihotis (Bouriquet, 1946), and Glomerella cingulata (Irvine, 1969). It is possible that all these refer to the same fungus.

A stem anthracnose caused hy a Colletotrichum sp., has recently been reported in Nigeria (IITA, 1972). On young green stems oval, pale brown , shallow depressions bearing a spot of normal green tissue in the centre are formed. On the bark of woody stems it produces raised, round, stringy lesions which develop into deep cankers and may distort the stem. The importance is not known.

Leaf and stem rust spot

This has been reported in Brazil (Amaral, 1942a; Normanha, 1970) and appears at the end of dry periods causing a kind of witches broom at the apex of the stems (Normanha, 1970). In Colombia leaf, petiole and stem pustules have been observed on cassava growing in cool upland regions, but Normanha (1970) states that the disease is rarely serious except occasionally in the northeast of Brazil during the hot, dry seasons.

The superelongation disease (Taphrina sp. or Sphaceloma sp.). Leaf showing leaf curl symptoms, irregular white spots on the leaf lamina, and cankers on the midribs, veins and petiole.

B. Stem rot disease

Three stem rot diseases have been observed on stems stored for planting (CIAT, 1972). (The storage of planting material is necessary in those areas which do not have a continuous growing season.) at CIAT these diseases greatly reduce viability, directly and also indirectly through increased desiccation of the cuttings. About 18 percent of apparently disease free planting material was discarded because of disease after fifty days storage at ambient conditions in the laboratory. To reduce loss of viability because of desiccation stem cuttings were dipped in paraffin wax which, however, considerably increased disease incidence.

While three distinct diseases have been recognized, it is not always possible to distinguish among them. Macroscopically, these diseases may appear similar, particularly during their early stages of development. Furthermore, more than one of the rot producing organisms may be present.

Glomerella stem rot

This disease is the most common stem rot of stored cassava cuttings. The same fungus also infects old stem debris left in cassava plantations. The rot first appears at the cut ends and gradually spreads throughout the cuttings. A black discolouration of the vascular strands precedes the development of surface blisters which later rupture the epidermis exposing black groups of perithecia in a well developed stroma (Fig.12).

According to CMI the causal organism appears to fall within the general broad concept of Glomerella cingulata (Stonem.) Spauld. Schrenk. Ascospores are hyaline, one celled, and slightly curved. Infection is thought to occur through wounds and to be favoured by high relative humidities. The relationship between this fungus and the Colletotrichum sp. that causes anthracnose of cassava has not been determined. However, the possibility exists that these may be two different stages of the same fungus.

Botryodiplodia stem rot

This disease has been found infecting stored stem cuttings and old stem debris in the field but is much less common than glomerella stem rot. The disease characteristically shows black discolouration and necrosis of the vascular strands spreading outwards from wounded parts of the stem. Blisters are produced on the epidermis beneath which the internal infected tissues appear dark brown or black. These blisters rupture to reveal masses of black confluent pycnidia.

According to CMI the causal agent of the disease is Botryodiplodia theobromae Pat. In both host and artificial culture this organism produces black mycelium and pycnidia which are erumpent, confluent, stromatic, and ostiolate. The conidiophores are short and simple and produce dark conidia that are two celled at maturity and slightly elongate. Infection is thought to occur through wounds and to be favoured by high relative humidites.

An unidentified stem rot

A third stem rot is caused by an unidentified basidiomycete. This disease, although relatively uncommnon has been observed on old, mature and young stem pieces both in the field and in storage. Infected stem pieces are necrotized showing slight brown discolouration and at times a white mycelium can be observed growing beneath the epidermis. Under certain humid conditions small white cup shaped basidiocarps arise from the epidermis of heavily infected cuttings (Fig.13). The identification of this basidiomycete and the importance of all three stem rots need to be investigated.

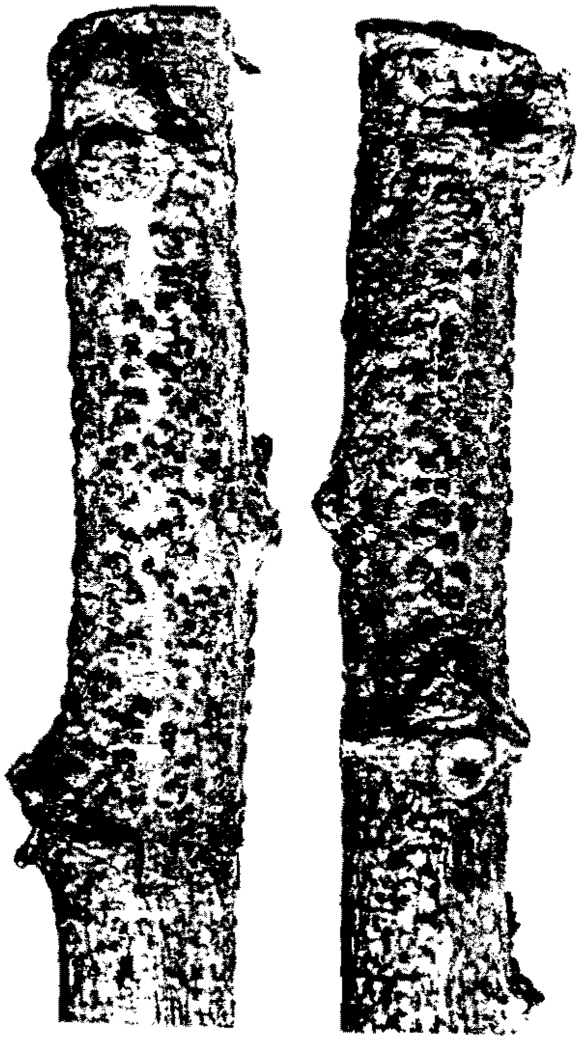
Other woody pathogens reported in the section on root rots infect the stem bases of cassava plants and may also be involved in losses of stored stems.

The occurrence of these stem rots is favoured by high relative humidity; infection probably occurs through wounds. Stem material intended for planting purposes should be handled with extreme care and carefully selected so that only cuttings with viable buds are used. The use of fungicides and surface sterilants to reduce the incidence of these diseases is being investigated.

C. Root rot diseases

Root rot diseases of cassava are important in areas with badly drained soils or during periods of excessive rainfall. Many of these pathogens induce damping-off during the early stages of plant grownth and rot of the thickened roots during later stages. Although several root rot diseases have been reported, few details are available and the symptoms described for each disease are similar. Generally, infection of young plants causes damping-off while infection of older tissues results in a partial or complete wilting and a soft or dry rot of the thickened roots. Frequently, following infection by one or several pathogens, a broad spectrum of weak pathogens and/or saprophytes invade the diseased roots, masking the identity of the initial causal agent and causing all root rots to appear similar. Several of these diseases caused by woody pathogens are more commonly found when cassava is planted following a woody crop, such as coffee, or immediately after forest clearance. Root rots of the growing crop are caused by both fungi and bacteria. Several organisms are reported to cause postharvest deterioration of cassava roots.

The control of these diseases is similar and is best achieved through such cultural practices as good drainage, selection of lighter soils and the avoidance of waterlogged areas, crop rotation, and early



12

Glomerella stem-rot (Glomerella cingulata). Pieces of stem showing eruptive blisters and groups of back perithecia.

Stem-root (unidentified basidiomycete) piece of stem showing typical basidiocarps, together with and uninfected control. 178-179.

harvest. For damping-off diseases fungicides may aid establishment. In a few cases, resistant varieties have been reported (Drummond and Goncalves, 1946, 1957; Castaño, 1953; Fassi, 1957; Muller and Carneiro, 1970).

Phytophthora root rot

This disease has been reported infecting cassava plantations in both Africa (Fassi, 1957) and tropical America (Vanderweyen, 1962; Muller and Carneiro, 1970) where it has caused yield losses of up to 80 percent. The pathogen attacks mature or young plants, frequently near drainage ditches, causing sudden wilting and a severe soft rot of the swollen roots. Initially infected young roots show spreading water-soaked patches which later turn brown (Fig.14). Infected swollen roots frequently exude a pungent watery liquid and eventually decompose completely in the soil (Fig.15).

Three Phytophthora spp. have been reported as inducing disease in cassava roots: P. drechsleri in Brazil (Muller and Carneiro, 1970) and Colombia (CIAT, 1972), and P. erythroseptica and P. cryptogea Path, in tropical Africa (Fassi, 1957; Vanderweyen, 1962). These fungi which also cause root-rots of several other plant species are well known.

White thread disease

This is the most widespread and serious root disease of cassava in Africa where its appearance on swollen roots is sometimes taken as an indication of the maturity of the crop. Although this disease is known in Latin America it is not of major importance there at present. The disease is recognized by a white mycelial mat under the bark of swollen roots and by the presence of white cotton like mycelial threads coating part or all of the exterior of infected roots up to the stem base. Internal infected tissues of swollen roots appear dry and have a characteristic rotting wood odour. Occasionally young plants are infected resulting in a sudden wilt and defoliation, all the roots being necrotized. The causal organism of the disease is Fomes lignosus (Klot.) Bre. (Vanderweyen, 1962; affran, 1968; Doku, 1969; Jennings, 1970; IITA, 1972), a basidiomycete belonging to the Polyporaceae.

Rosellinia root rot

This disease has been reported from many cassava regions with wet soils which are high in organic matter, and most frequently where cassava is grown following a woody or forest crop (Drummond and Goncalves, 1946; Castaño, 1953; Viegas, 1955). The disease has also been named "black rot" on account of the characteristic black discolouration and cankers on portions of infected plants below the ground. In the early stage of infection white rhizomorphs that eventually turn black cover root surfaces. Internally, the infected tissues of swollen roots become slightly discoloured and exude a watery liquid when squeezed. Black mycelial strands penetrate into and grow throughout the infected tissues and small cavities containing whitish mycelium may be formed (Fig. 16).

Infected swollen roots have a characteristic rotting wood odour. There are no reports that young plants are infected by this disease, but care should be taken to select planting material that does not come from infected plants.

Rosellinia necatrix (Hartig). the perithecial stage of Dematophora necatriz is the causal agent (Castaño, 1953; Viegas, 1955). This fungus induces root rots in other woody and herbaceous plants (Castaño, 1953; Viegas, 1955; Alexopoulus, 1962) and is adequately described in the literature. Little information is available, however, about the epidemiology of this fungus on cassava, the sexual stage is thought to occur rarely (Cataño, 1953; Alexopoulus, 1962).

Sclerotium root rot

This root rot is commonly observed on young cuttings, on more mature roots, and as a coating on swollen roots of cassava in Latin America (Viegas, 1943a, 1943b; Ferdinando et al., 1968; Martin,1970; CIAT, 1972). White mycelium radiates into the soil from infected roots or stem bases. This mycelium may on occasions penetrate the roots through wounds and cause rotting. While young plants are rarely killed by this disease considerable root necrosis may occur.

The disease is caused by Sclerotium rolfssi Sacc., a common but weak soil pathogen which has cottony-white mycelium and characteristically forms numerous rounded sclerotia, both on the host and in artificial culture.

Other root rot diseases

Several other fungi may induce damping-off and root rots of cassava, but little or no information is available regarding their occurrence or importance. Armillariella mellea Vahl. is reported associated with a stem base and root rot of mature plants (Vanderweyen, 1962; arraudeau, 1967; CIAT, 1972). Pheolus manihotis (Heim, 1931), Lasiodiplodia theobromae Griff. et Mubl.(Vanderweyen, 1962), Pythium sp., Fusarium sp. (CIAT, 1972), Clitocybe tabescens (Arraudeau, 1967), Sphaceloma manihoticola B. et Jenkins (Bitancourt and Jenkins, 1950), Rhizopues spp. (Majumder et al., 1956),Rhizoctonia sp. (Goncalves and Franco, 1941), and Aspergillus spp. (Clerk and Caurie, 1968 are all reported as causing rotting of cassava roots.

Species of Bacillus, Erwinia, and Corynebacterium have been reported as inducing soft rots and/or fermentations in swollen roots (Collard, 1963, Akinrele, 1964; Averre, 1967). The symptoms of these soft rots are similar and are frequently accompanied by fermentations. The bacteria are thought to enter swollen roots through wounds induced by man during cultural operations, by animals or insects, or by fungi, and are frequently accompanied by many other saprophytic microorganisms.

Pathogenic species of the genus Bacillus form spores in most media containing sugar. Erwinia spp. can be isolated and distinguished using the Kado and Heskett medium (1970); their pectinase activity as detected

Phytophthora root-rot (Phytohpthora drechsleri). Root-rot of young plants together with and uninoculated control.

Phytophthora root-rot (Phytohpthora drechsleri). Typical root-rot of swollen roots.

16

Rosellinia root-rot (Rosellinia necatrix). Root-rot of swollen roots .

on sodium-polypectate medium, and their peritrichous flagella. Corynebacterium spp. can also be isolated and distinguished by the use of selective media (Kado and Heskett, 1970), pleomorphism of their cells, and their gram-positive reaction.

Cassava blight bacteria may also induce necrosis, discolouration, and dry rot of the vascular tissues of swollen roots (Lozano, 1972a; Lozand and Sequeira, 1973b).

Core root rot is a physiological disorder that causes damage to swollen roots in tropical Africa (Barat et al., 1959; Averre, 1967). It also occurs in wet, badly drained soils where it takes the form of a dry internal necrosis, irregularly spreading out from the centre into the cortical tissues. This disorder is observed in only 10-20 percent of the roots of an infected plant, and only the larger thicker roots are thought to be susceptible.

While it is not fully inderstood whether the rapid deterioration of cassava roots that occurs after harvest is the result of physiological or pathological causes, or a combination of both, numerous microorganisms have been isolated from deteriorated roots. Several of these are known to cause discolouration and rotting. The literature relevant to the post harvest deterioration of cassava roots has been reviewed by Ingram and Humphries (1972). The important role of mechanical damage in deterioration and its possible control by wound healing and curing has been described by Booth (1972, 1973a, 1973b).

CONCLUSIONS

It can be seen that many diseases which in general are poorly understood, attack and reduce cassava yields. It is also well known that extensive losses occur following harvest of the roots. If full use is to be made of this important food crop it is necessary to increase our understanding and to intensify research into all aspects of cassava production and utilization. The importance of reducing losses from fungal, bacterial, and viral pathogens cannot be over-emphasised. However, with the possible exception of cassava bacterial blight, little or no information is available on the means of controlling many cassava diseases. In several instances the existence of resistant cultivars has been noted but these have rarely been fully described or confirmed in controlled experiments. In some cases disease resistance may be found in agronomically acceptable cultivars, but in the other cases breeding will be required to transfer resistance into proven agronomic types. Thus, extensive research is required to evaluate host/pathogen reactions and determine the sources of resistance to the many diseases so that this information may be used by breeders and agronomists in selecting and breeding for improved cultivars. For those diseases to which sources of resistance cannot be found, other means of disease control, need to be sought.

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CASSAVA DISEASES AND THEIR CONTROL

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For the purpose of control, cassava pathogens are classified as (a) those that attack vegetative propagating material (b) those that attack foliage and green stem portions, and (c) root rot pathogens that can induce pre-harvest and postharvest deterioration. Control measures for each of these categories are discussed and recommendations are made. These measures, however, should be applied as part of an integrated system for any cassava cultivation program.

Until recently cassava was considered to be resistant to deseases and pests; it is now accepted that diseases can cause severe losses and that they are economically important. Cassava is affected by more than 30 fungal bacterial, viral, or viruslike and mycoplasmal agents (Lozano and Booth 1974). These diseases can affect plant establishment and vigour, inhibit photosynthetic efficiency, or cause pre-harvest or postharvest deterioration. Some causal agents are distributed worldwide, appearing endemically in almost all cassava plantations (leaf spots induced by Cercospora spp. and Oidium spp.) (Lozano 1976; Terry 1975a). Others are limited to geographical areas or continents (the cuasal agents of cassava bacterial blight, American viruses, and mycoplasmal diseases) (Lozano 1972, 1975), possibly because their dissemination occurs mainly through the use of infected planting material for propagation.

African mosaic disease and brown streak virus are limited to Africa (Lozano 1972, Terry 1975a), Asian mosaic disease to Asia, and superelongation disease to America (Lozano and Booth 1974; Lozano 1972). Apparently the causal agents of African and Asian mosaic diseases are not present in America, although the vector (Bemisia spp.) was recently identified on this continent (Bellotti personal communication). Other widely distributed pathogens attack cassava only during the cool and rainy periods of the year or in areas located at high elevations (more than 1200 m), where temperatures are below 22°C (Phoma sp. and Cercop Cercospora caribaea (Lozano and Booth 1974; CIAT 1974, 1975).

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There are other pathogens whose incidence is limited by environmental conditions, possibly because they require high relative humidity (nearly to the saturation point) for germintation and establishment (CIAT 1974).

PATHOGENS OF VEGETATIVE MATERIAL

Cassava is vegetatively propagated by planting pieces of stem cuttings; consequently, cassava pathogens can be disseminated easily by the movement of planting material from infected to uninfected areas. These pathogens can cause considerable damage during the establishment of the crop or at any time during its growth cycle, including: (1) reduction in germination, (2) damping-off, (3) decrease of normal plant vigour, and (4) reduction of the potential number of swollen roots due to initial root damage.

These pathogens are mainly fungi, which attack epidermal, cortical, and woody stem tissues (Sphaceloma manihoticola, Gloeosporium sp.); facultative saprophites or parasites (Rosellinia necatriz, Fusarium spp., Armillaria mellea, Sclerotinia sp., Sclerotium rolfssi, Penicillium spp., Asperigillus spp., etc.). These fungi are frequently found in the soil (Lozano and Booth1974). Other pathogens include (1) bacteria (Xanthomonas manihotis, Lozano 1975; or Erwinia sp., Lozano et al. 1976 ; CIAT 1976).(2) mycoplasma, and (3) viruses or viruslike diseases (Lozano 1972; Terry 1975a). These are generally vascular pathogens located inside pieces of stem used for propagation.

The occurrence of these pathogens in a plantation may be due to the use of planting material taken from infected plantations (Lozano 1972, 1975), the use of infested machinery or tools during the preparation of land and while planting stem pieces, or infested soils.

Control Measures

Taking the foregoing factors into consideration, the incidence of these pathogens in a country, region, or plantation can be prevented by following these recommendations:

(1) A careful selection of all planting material must be initiated by choosing the appropriate area and field for the collection of propagating material. Once in the field, plants and plant sections used for propagation should also be carefully selected. Generally, it is not advisable to take planting material from Africa or Asia to America due to the presence of mosaic disease in the former. Cuttings should not be taken from areas where CBB or superelongation disease is present. The use of cuttings from plantations infected with the common mosaic or vein mosaic virus and mycoplasmal diseases must also be avoided (IDRC 1975; Lozano 1976; Terry 1975a). Cuttings should always be selected from vigorous, apparently healthy plants. The elimination of any stem section with suspicious signs of disease is extremely important in the control of these diseases.

(2) Avoid damage to vegetative propagating material. Germination and establishment can also be improved by the careful handling of cutting during preparation, packing, shipping, and planting, which prevents injury to both the stem and bud tissues. Some vascular pathogens of cassava are disseminated by the use of infected tools. When handling propagative material, all tools and machinery should be desinfected prior to each use with a 5 percent solution of commercial formaldehyde.

Fungicide "seed" treatment of cuttings may be valuable. Germination and establishment can be increased by more than 10 percent by dipping cassava cuttings into a 5 percent solution of Demosan (1,4 dichloro-2,5 dimethoxybenzene), Arasan (tetramethythiuram disulfide), Agallol (methoxyethylmercury chloride) or Brassicol 75 (pentachloronitrobenzene) for 3-5 min before planting (CIAT 1974).

(3) Selection and preparation of land are also important factors for successful cassava cultivation. Heavy soils, with a high organic matter content; are difficult to drain and may remain flooded for several hours after a heavy rainfall. These soils may also contain high populations of organisms that can attack the recently planted cuttings. Land that has been previously used for forest (woody trees, bushes, coffee, etc.) or perennial crops (plantain, sugar cane, etc.) may also contain high populations of root rot pathogens (e.g. Rosellinia necatrix, Armillaria mellea, Fusarium spp., Sclerotium rolfsii, Rhizoctonia sp., Pythium spp., Fomes lignosus, Phytophthora drechsleri, etc.). which normally attack cassava roots and woody stems (Lozano and Booth 1974).

Adequate cultural practices to ensure good soil preparation and drainage should always be followed. Planting on ridges may also be effective in preventing disease. Soil must be well plowed and drained. In regions where rainfall is high (more than 1200 mm), planting should be done on ridges to improve drainage and reduce root damage.

Good quality cuttings, about 20 cm long, should be planted so that half the cutting is covered by soil. Water should be applied soon after planting.

FOLIAR AND GREEN STEM PATHOGENS

Several fungi (Cercospora spp., Phoma sp., Oidium sp., Colletotrichum gloesporioides, Uromyces spp., etc.), bacteria (Xanthomonas manihotis and Erwinia sp.), cycoplasma, and viruses or viruslike causal agents attack the leaves and green stem portions of the plant, or show the most characteristic symptoms in these areas. Damage induced by these agents can lead to a reduction of photosynthesis, thereby decreasing the production and storage of carbohydrates. Reduction in photosynthesis can result from: (1) leaf spotting (chlorotic or necrotic areas) induced by certain fungi, viruses, viruslike causal agents, and bacteria; (2) blight and dieback induced by certain bacteria and fungi; (3) distortion and leaf stunting induced by certain mycoplasma, viruses, and viruslike

agents; (4) bud proliferation induced by mycoplasma; and (5) hypertrophia caused by certain variants of mycoplasma (Costa and Kitajima 1972) and the superelongation causal agent (Lozano and Booth 1974; Krausz et al., 1976).

Several pathogens included in this group are endemic in major cassava growing areas (Lozano and Booth 1974; Terry 1975a). Disease severity appears to be related to susceptibility of the cultivar and climatic conditions in each area.

Some other causal agents that can be disseminated mechanically or by using diseased planting material are viruses and mycoplasma, found scattered in certain regions of America but whose incidence is low. Cassava bacterial blight, superelongation disease, and Afican mosaic disease are also disseminated by infected planting material (Lozano 1975; Krausz et al. 1976; CIAT 1976; Lozano 1972). However, since their specific means of dissemination are highly effective, thay may suddenly spread in a given region, country, or continent, causing serious epiphytotics a relatively short time after their introduction (Lozano and Sequeira 1974; Terry 1975b).

Control Measures

The control measures suggested for the diseases induced by the aforementioned group of causal agents are:

(1) Varietal resistance. Even though there are no resistant commercial cultivars for many cassava diseases, good sources, of resistance have been identified and promising hybrids are now being multiplied by IITA and CIAT (IITA 1973, 1974; CIAT 1974, 1975). Resistant genotypes for CBB, Cercospora leaf spots, superelongation disease, and Phoma leaf spot have been tested during several growing cycles. Good yielding commercial lines, resistant to the major cassava diseases, should be available in the near future.

(2) Disease free planting material. This is the best control measure to prevent the introduction of causal agents that attack vascular and cortical tissues. These causal agents include viruses or viruslike diseases (common mosaic virus, vein mosaic virus, and African mosaic disease), mycoplasma (witches'broom disease), bacteria (X. manihotis and Erwinia sp.), and epidermal and cortical fungi (Sphaceloma manihoticola, etc.). Methods for producing CBB-free planting material have been developed at CIAT (Lozano and Wholey 1974; Takatzu and Lozano 1975; Cock et al. 1976). The culture of meristematic tissues has also been reported (Kartha and Gamborg 1975). Both techniques are useful tools for producing disease free planting material. They could be used to supply basic stock for the rapid multiplication method recently reported by Cock et al. (1976).

(3) Roguing. Pathogens reported to be disseminated mechanically from diseased to healthy plants (Costa and Kitajima 1972; Lozano 1972) can be eliminated by roguing. The common mosaic virus, the vein mosaic

virus, and the witches'broom mycoplasma diseases are also included in this group. Rogued plants must be destroyed by fire. We also suggest that tool surfaces be sterilized.

(4) Cultural practices. Within a few days after planting, the cassava foliar system provides a microclimate with lower temperatures, high relative humidity, and low air circulation between the ground surface and the top of the plants. The formation of this microclimate depends upon the variety planted (varieties with low or high leaf area index), as well as on the plant population. These conditions may favour the incidence and severity of fungal and bacterial foliar diseases such as Cercospora leaf spots, Phoma leaf blight, cassava bacterial blight, etc. Their incidence and severity may be reduced by selecting varieties with low leaf area index. Plant population and foliar index should be just high enough to supply satisfactory weed control and good yield. A leaf area index of about 3 appears to be optimal for root yield (Cock personal communication; CIAT 1975, 1976). Appropriate planting time may also reduce the incidence of these diseases; planting at the beginning of the rainy season ensures good establishment. The canopy will close across the rows during the dry season, approximately 4 months after planting. Because of the dry environment, a favourable microclimate for these pathogens will not be formed.

ROOT ROT PATHOGENS

Cassava roots often deteriorate before or after harvesting. Preharvest root rot is the result of attack by soilborned pathogens. Post-harvest root rot appears to be a combination of physiological-pathological factors, generally accelerated by mechanical injury to the roots during the harvesting operations (Booth 1975).

Pre-harvest Root Rot

The appearance of preharvest root rot problems in a cassava plantation is generally a result of using poor quality, diseased cutting. Inadequate preparation of the land can also result in pre-harvest root rot. Therefore, the aforementioned recommendations for selection and treatment of cuttings before planting and the cultural practices suggested for land selection, preparation, and maintenance should be strictly observed to prevent or reduce root rot incidence. If root rots increase to levels higher than 3 percent, which is considered to be economically important, crop rotation with cereals (maize, sorghum, etc.) or crop fallowing for a 6 month period is also recommended. These practices should decrease the inoculum potential of root rot pathogens; however, effective control of these diseases through the use of crop rotation or crop fallowing has not been demonstrated. It is possible that longer periods of rotation or crop fallowing are needed in order to decrease the incidence of pathogens that produce resting structures, such as sclerotia, chlamydospores, rhizomorphs, etc. It has also been observed that some cultivars are more susceptible to root rot disease than others. The development of resistant cultivars could be considered for

the control of these diseases.

Postharvest Root Rot

Cassava roots cannot be kept in a fresh state for more than a few days after harvest if certain precautions are not taken. This presents serious problems in the marketing and utilization of the crop and results in heavey losses. Two types of deterioration have been reported (CIAT 1974, 1975; Booth 1973): physiological or pathogenic, or a combination of the two.

Several control measures to reduce postharvest deterioration have been suggested:

(1) Leave the roots in the ground until needed. Once harvested, the roots should be used immediately or dried for longer storage life. This necessitates a scheduled program of planting and processing.

(2) The rate of primary deterioration varies among cultivars (Montaldo 1973; Booth Noon, and Kawano, personal communication), so those which display the slowest rate of deterioration should be used.

(3) One of the most important factors in the success of cassava storage is the condition of the product to be stored (Booth 1975). Care should be taken during harvesting and handling to minimize damage, and only the least damaged roots should be stored.

(4) Deterioration can be delayed by the use of various surface sterilants and fungicides (Booth 1975), regrigeration and waxing (Singh and Mathur 1953; IIT, 1973). However, the high cost and low efficiency of these techniques severely limit their use.

(5) Small quantities of roots can be preserved for several days by using simple techniques such as reburial, or coating in mud and placing under water. Burying the roots in a trench or covering them with soil or a mixture of straw and soil gives good results (Ingram and Humphries 1972). Booth (1975) was able to store roots for up to 3 months in field clamps similar to those used for storing potatoes in Europe. He also reported that cassava could be stored in boxes with moist sawdust at room temperature. As a result of this research, it was concluded that cassava roots, like many other root and tuber crops, can be cured, requiring only high relative humidities at temperatures between 25 and 40°C.

CONCLUSIONS

There are very few economically feasible chemical control measures for cassava diseases. The most practical control methods are to: (1) plant disease resistant cultivars; (2) use adequate cultural practices; and (3) plant disease free material treated with fungicide. At present cassava improvement programs are concerned with long-term research to produce and release high yielding multiple disease resistant cultivars

This will take some time; however, the foregoing recommendations should provide effective short-term control which should minimize the incidence and spread of cassava diseases.

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THE THREAT OF INTRODUCING CASSAVA DISEASES AND PESTS ON PROPAGATION MATERIAL

J.C. Lozano*

Introduction

Manihot esculenta Crantz (cassava, manioc, mandioca, yuca or tapioca) probably originated in northern South America (Brazil, Guyana), with a secondary center of origin in Mesoamerica (Mexico, Guatemala, Honduras) (Rogers, 1963). Its present distribution is worldwide between latitudes 30°south, at elevations ranging from sea level to more than 6,500 feet (Jones, 1959; Rogers, 1963). This ecological zone, the "cassava belt," coincides roughly with the FAO Economic Class 2, or less developed countries. This belt accounts for 46 percent of the world's arable land, 46 percent of the world's population and only 13 percent of the world's Gross Domestic Product (FAO, 1971 and 1972). In 1971 (FAO, 1972), world production of cassava was estimated at 92.2 million tons from 9.8 million/ha, giving an average yield of 9.4 tons/ha.

Cassava is one of the major sources of carbohydrate for more than 300 million people living at close to subsistence levels in tropical areas. Fresh and dried roots, as well as leaves, are used either as human or animal feed. Fifty-five million tons are consumed by humans, and recent projections estimate that by 1980 consumption will rise to about 71 million tons (Phillips, 1974). Commercial products include tapioca, adhesives and starch for sizing and laundry purposes.

Cassava cultivars are important as sources of energy: The root is 30-40 percent dry matter, 90 percent of which is in the form of soluble carbohydrates; but there are relatively small amounts of crude protein (averaging 1 to 2 percent of dry matter, fats, vitamins and minerals (Barrios and Bressani, 1967). However, the protein content of young cassava tops (leaves) is around 20 percent (Cock, personal communication). The amino acid content of cassava roots is similar to that of corn, with low methionine, high threonine, and intermediate levels of lysine and other amino acids (Olson et al., 1969).

Prior to 1971, limited knowledge was available on all aspects of cassava production. In general, the literature implies that diseases and pests were not important in cassava although information of losses due to these was scarce and limited. A large proportion of these

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publications mention the existence of different pathogens, but few deal with their importance, ecology or control. In the last four years, two international institutions (Centro Internacional de Agricultura Tropical and International Institute for Tropical Agriculture) have established an international network of cassava researchers somewhat analogous to those already existing for wheat and rice. Furthermore, national institutes and organizations, such as the Central Tuber Research Institute in India, have now given high priority to cassava research programs. As a consequence, cassava cultivation has been increasing dramatically during recent years, and it is anticipated it will continue to increase further in the near future.

Cassava is propagated asexually by planting stem pieces as seed. To satisfy the need for a continuous planting program to supply a steady market, propagating material is usually produced by the farmers themselves, who must often introduce material from neighboring regions because planting stakes cannot be stored for an extended lenght of time. To obtain new cultivars with promising characteristics, to introduce or to increase a cultivar with desirable characteristics, farmers, institutions and governments have often interchanged cassava planting material. This interchange of material appears to have increased during the fast few years due to the expansion of cassava cultivation.

The efforts to increase yield and production are threatened by the underestimation of the importance of diseases and insects in cassava and the need for effective quarantine measures. This paper discusses some problems arising from the international transfer of planting material.

GEOGRAPHIC DISTRIBUTION

Cassava is affected by more than 25 pathogens including fungi, bacteria, viruses, virus-like diseases and mycoplasma (Lozano and Booth, 1974). More than 90 species of insects and 6 species of mites have been recorded as pests of cassava (Montaldo, 1967), and several nematode species are cassava parasites even though the literature on this is sparse. These organisms can cause considerable losses and, at times, are limiting factors in crop production. The potential danger of introducing some of these organisms into uninfested areas is serious.

Except for *Cercospora henningsii* and *C. vicosae*, which have been observed in almost all warm cassava-growing areas of the world, cassava pathogens appear to be confined to specific geographical zones; i.e., continents or ecological regions within the continents. Some of these pathogens, such as *C. caribaea* and *Phoma* sp., occur endemically in tropical America in those cool cassava-growing areas where the average maximum temperature is below 20°C, or in the warmer regions, during the coolest periods of the year (Lozano and Booth, 1974; CIAT, 1974). Other pathogens occurring in the Americas, such as *Sphaceloma* sp. and

Colletotrichum gloesporoides fs. manihotis, induce epiphytotics in warm cassava-growing areas during the rainy season (Lozano and Booth, 1974; Krausz, 1975); or, as in the case of Oidium manihotis, during the dry season. Root rot fungi of cassava are commonly present around the world since they are also pathogens of perennial and forest crops; their incidence seems to be related to edaphic and cultural conditions as well.

In the Americas (Brazil, Venezuela and Mexico) there is a low incidence of cassava (mycoplasma and virus diseases which occur independently of environmental and edaphic conditions. In contrast, the African mosaic disease of cassava is observed in almost all cassava plantings in tropical Africa, primarily because it is disseminated by insects (Bemisia spp.). A similar disease, also disseminated by Bemisia spp., is found endemically in India (Lozano, 1972).

Among the bacterial pathogens, Xanthomonas cassavae appears to be restricted to Africa (Dowson, 1957; Wiehe and Dowson, 1953). The causal agent of cassava bacterial blight, X. manihotis, is present in America; but it has been found recently in Africa and Asia (Thailand and Malaysia), causing severe epiphytotics (Lozano, 1975). Even though Pseudomonas solanacearum has been reported as a cassava pathogen (Kelman, 1953; Castaño, 1972) and its different races are found in many cassava-growing areas, there is no conclusive evidence that this bacterial species is a cassava pathogen. A new bacterial species recently found in association with certain stemborer insects of cassava (Lozano and Bellotti, unpublished data) is present in the Americas, but its distribution and importance are unknown.

Mites appear to be a universal pest of cassava. The Tetranychus mite (T. urticae) is recorded as a pest in Africa, Asia and the Americas, while the Mononychellus mite (M. tanojira) is reported in the Americas and Africa. Thrips, whiteflies, stemborers, leaf-cutter ants and cutworms attack cassava in Africa and the Americas. The cassava hornworm (Erinnyis ello) shoot flies (Silba pendula), fruit flies (Anastrepha pickeli and A. manihoti), and gall midges (Cecidomya sp.) attack cassava only in the Americas. Grasshopper feeding on cassava is restricted to Africa while white grubs, termites and scale insects are reported from Africa, Asia and the Americas (Schoonhoven and Belloti, 1975).

DISSEMINATION OF DISEASES AND PESTS

Based on the above general distribution of cassava pathogens, any movement of cassava planting material represents a serious risk of disseminating these diseases and pests. The most important pathogenic agents in cassava --for example, those that cause cassava bacterial blight and African mosaic disease, vascular pathogens, and superelongation disease, an epidermal and cortical pathogen-- are disseminated unsuspectingly through the use of diseased stalks as planting material (Lozano, 1972; Lozano and Booth, 1974); Krausz, 1975).

For example, the causal agent of cassava bacterial blight is restricted to the host xylem tissue in mature stems because the bacteria is unable to degrade lignified tissues (Takatsu and Lozano, 1975; Lozano and Sequeira, 1974). Therefore, the presence of bacteria in these tissues, which are normally used for plant propagation, is very difficult to detect. Also the severity of the disease is considerably reduced during the dry periods of the year; thus visual selection of healthy material for propagation from an infected plant is sometimes impossible. Considering its potential of spreading by rainwater , tools, unhealthy planting material (Lozano and Sequeira, 1974), infested soil and insects (CIAT, 1974), the rapid dispersion from a few unhealthy plants in a plot can occur in relatively short periods of time (Lozano and Sequeira, 1974), causing economic losses of more than 50 percent (Lozano, 1975). Considering that (a) cassava originated in the Americas; (b) Xanthomonas manihotis is specific to Manihot spp.; and (c) that cultural, morphological, physiological and serological studies of isolates from Africa, Asia and America show similar species characteristics (CIAT, 1975; Lozano, 1975), it is concluded that this pathogen was probably introduced from America to Africa and Asia by the introduction of infected plant material. This introduction caused serious economic damage in Nigerian and Zaire cassava-growing areas (Maraite and Meyer, 1975) and poses a threat to Thailand's and Malaysia's cassava production in the near future.

The extraordinary severity, ability to be disseminated and lack of effective control measures make the African mosaic disease of cassava one of the most serious diseases of the crop in the world. Although the disease is not present on the American continent, the vector, Bemisia spp., has recently been found (Bellotti, personal communication). Hence, its introduction into America or other uninfected areas represents a most serious threat to these cassava-producing areas. Although the consequences of such an event are unforeseeable, it is known that the disease is capable of reducing production by 20 to 90 percent (Lozano, 1972).

In general, all viruses and mycoplasma of cassava in the Americas invade the vascular system (Costa and Kitajima, 1972) and are disseminated mainly by propagation of vegetative material. Their introduction into uninfected areas within the Americas or other disease-free areas represents a serious risk. The mycoplasma disease (witches'-broom) has recently been reported in the Ivory Coast (Dubern, 1972), possibly introduced to Africa by infected propagative material, since there were no previous reports of this disease there. The brown streak virus is another disease originating in Africa that can be introduced into the Americas through vegetative material (Lozano, 1972; Lozano and Booth, 1974).

Little is known about the dissemination of fungal pathogenic agents of cassava through infected stalks, with the exception of the causal agent of the superelongation disease (Sphaceloma sp.). This pathogen grows into the cortex and epidermis, producing spores in epidermal cankers which are capable of maintaining enough inoculum for secondary infections. Its ability to sporulate and to be disseminated by wind flow during the rainy season appears to be responsible for the observed spread of the disease in cassava-growing areas (Colombia, Venezuela and Panama) (Lozano and Booth, 1973; Krausz, 1975). If this pathogen is introduced to other countries or continents, it is suspected that a similar rapid spread over long distances will occur in a relatively short period of time (Krausz, 1975).

Because of their possible adhesion to the epidermis of the stalks, the spores of other fungal organisms, particularly those that attack the stem (Glomerella sp., Fusarium sp., Sclerotium rolfsii, Botrydiplodia sp ., etc.), could also be introduced into other regions with material for propagation.

Except for cassava bacterial blight (Lozano, 1975), the African mosaic disease (Lozano, 1972) and the common mosaic virus (Costa and Kitajima, 1972), which appear to be specific to Manihot spp., no information is available on host range of other cassava pathogens or pests. However, propagating material of species belonging to Euphorbiaceae (forest or ornamental crops) also represents a serious risk of disseminating cassava diseases. This risk is emphasized by the recent finding that a Sphaceloma sp. found on Poinsettia sp. is also pathogenic to cassava.

The possible dissemination of the pathogens of cassava through true seed is unknown, except for cassava bacterial blight which is not seed transmitted (CIAT, 1974). Although the risk of dissemination through the use of true seed appears limited in cassava, there are many examples in literature of its occurrence in other crops, especially for viral agents. Because of this, it is logical to suggest that precautions be observed until convincing studies on the matter prove otherwise.

The dissemination of insect eggs and of mites in vegetative material is more probable than that of larvae and adults. Generally, adults and larvae living on the epidermis of the stem are relatively easy to detect. Nevertheless, stemborer, scale and mite eggs (Belloti, personal communication) can be disseminated via stem pieces. A recent example of insect dissemination, possibly through the importation of stem pieces for propagation, is that of the introduction of mites into Uganda. This pest was disseminated into western Kenya and Tanzania, causing serious losses for the cassava growers in these areas (Nestel, 1974; Nyiira, 1973).

GENERAL CONCLUSIONS AND RECOMMEDANTIONS

Although the economic effect on yield is unknown, the sanitary condition of the vegetative material used for propagation can become the most important factor in successful cassava cultivation. For instance, it is known that more than 25 percent of the propagation material does not germinate when cassava cuttings are infected with bacterial blight and that losses in germination of cuttings attacked by scale insects (*Aonydomitilus albus*) are often as high as 80 percent (Schoonhoven, personal communication).

Based on the aforementioned considerations, it is concluded that (a) the spread of pests and diseases of cassava through vegetative propagation material represents a serious threat to the crop; (b) strict quarantine provisions are necessary in order to avoid the possible introduction of pathogenic organisms and pests into uninfected areas; (c) more information is needed about the potential damage that many plant pathogens and pests can cause to cassava cultivation; and (d) cassava requires careful selection and treatment of all vegetative material before distribution for experimental or commercial propagation.

Recent research shows that clean vegetative planting material can be produced; thus, it may be possible to eliminate the dissemination of vascular pathogens, such as the causal agents of cassava bacterial blight (Lozano and Wholey, 1974) the American viruses (Lozano, 1972; Costa and Kitajima, 1972), and the superelongation (CIAT, 1974) diseases. Similarly, pests and propagules of pathogens that may be disseminated on the surface of planting material can readily be eliminated through the use of chemicals. The use of tissue culture techniques produces symptom-free material from plants infected with the African mosaic disease (Kartha and Gamborg, 1975); however, it cannot be asserted whether the disease is present in latent form. Nevertheless, the use of these techniques to transfer material within the African continent is suggested.

Applying general quarantine principles specifically to cassava, the following recomedantions relating to the international movement of cassava planting materials were discussed and suggested at the Workshop for International Exchange and Testing of Cassava Germplasm, held at CIAT in February, 1975 (IDRC/CIAT, 1975).

A. General recommendations

1. The expertise in pest and disease recognition available at CIAT and IITA should be utilized to train national crop protection specialists who could then return to their respective countries and conduct courses on pest and disease symptomatology and recognition for quarantine purposes.

2. It is recommended that the smallest possible amount of planting material be imported; the smaller the amount, the less the chance of its carrying a pathogen or pest. Inspection of this material, as well as post entry quarantine, will be simplified.

3. The implementation of the recommendations for minimizing the risk of disease and pest introductions is the joint responsibility of the donor and recipient.

4. These recommendations merely supplement existing quarantine regulations of recipient countries.

B. Recommendations relating to the movement of vegetative propagating material

1. Material should never be imported from countries where African mosaic diseases and brown streak virus disease are present.

2. For importations from all other countries, the following procedures are recommended:

a. In the donor country

1. Use only select material from a disease-free source.
2. Treat the material with a combination of fungicide (Thiram or Chloroneb) and insecticide (Methamidophos or Carbofuran).
3. Handle material with extreme care; disinfect and sterilize all tools and packing materials.

b. In the recipient countries

1. Burn on arrival all material which shows pest infestation or disease symptoms.
2. Retreat the material with fungicide and insecticide.
3. Establish the material in an isolated area and make regular and thorough plant inspections over a one-year period.
4. Burn any of the established plants with pest infestation or disease symptoms not found in the country.

3. In addition to these general recommendations, material being exported from a country where superelongation is known to be present should receive a hot water dip (50°C for 30 min) (CIAT, 1974). Countries importing material from countries where cassava bacterial blight is known to be present should undertake shoot-tip indexing within twenty days of germination (Lozano and Wholey, 1974; Takatsu and Lozano, 1975).

C. Recommendations relating to the movement of true seeds

1. In the donor country

a. Select the seed from disease-free plants.

b. Select the best-quality seed (visually).
c. Treat with a fungicide (Thiram) and an insecticide (Malathion).
d. Handle the seed with care and disinfect and sterilize handling and packing materials.

2. In the recipient countries

a. Burn on arrival pest-infested or obviously diseased seed.
b. Establish the material in an isolated area and make regular and thorough plant inspections over a one-year period.
c. Burn any plant with pest infestations or disease symptoms not found in the country.

D. Proposals for future consideration

1. Consideration should be given to the establishment of an intermediate quarantine station in a noncassava-producing country or island.

2. The possible future use of the tissue culture technique for quarantine purposes should be examined. It is considered that the technique could give a large margin of security to the known virus diseases and cassava bacterial blight; nevertheless, it is not recommended in the case of the African mosaic disease since the causal agent of this disease is still unknown.

By following these recommendations, the author consideres that the risk of introducing new pathogens and pests into an area could be greatly reduced or eliminated. In many countries, quarantine regulations are nonexistent and should therefore be imposed; in other countries excessively strict quarantine regulations have been formulated because of lack of knowledge. From the recommendations presented in this paper, regulations could be formulated that would not only protect countries against the introduction of new diseases and pests but would also give them the advantage of obtaining better genetic material.

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INSECT AND MITE PESTS OF CASSAVA AND THEIR CONTROL

Anthony C. Bellotti*

Introduction

Cassava pests represent a wide range of arthropodal fauna; approximately 200 species have been recorded. Many of these are minor pests and cause little or no yield losses. Several, however, must be classified as major pests which can cause severe damage to growing plants and result in yield losses. The major pests of cassava are mites, thrips, the cassava hornworm, scales, mealybugs, stem borers and whiteflies. Other pests such as grass hoppers, white grubs, cutworms, leaf cutter ants and fruit flies may cause sporadic or localized damage.

Insects can cause damage to cassava by reducing photosynthetic area, which results in yield reductions; by attacking stems, which weaken the plant and inhibits nutrient transport; and by attacking planting material, which reduces germination. They may also attack roots and cause secondary rots. Some are vectors and disseminators of diseases.

Indications are that pests that attack the plant over a prolonged period, such as mites, thrips, scales, mealybugs and stem borers, will reduce yield more than those that defoliate and damage plant parts for a brief period i.e., hornworms, fruit flies, shoot flies and leaf cutter ants. This is because the cassava plant appears able to recover from short-term damage under favorable environmental conditions.

The greatest diversity of insects reported to attack cassava is in the Americas. This is expected since where there exists great genetic variation of the host plant, there is also a great variability, of organisms which attack the plant or are in symbiotic relationship with it. The 17 general group of pests described in table 1 are found in the Americas, 12 are reported from Africa and 6 are reported from Asia.

I. INSECTS ATTACKING VEGETATIVE PLANTING MATERIAL

The planting of insect free and undamaged cuttings is important in obtaining good germination and in the establishment of young plants.

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1.1 Scale Insects

Several species of scales have been identified that attack cassava stems in many cassava growing regions throughout the world. The quality of planting material can be greatly reduced if cuttings are infested with scale insects. The white scale, Aonidomytilus Albus, can reduce germination by 50-60 percent depending upon the degree of infestation. Infested cuttings dipped in insecticidal solutions reduced infestation but heavily infested cuttings still germinated poorly after dip-treatments. It is therefore recommended that scale infested cuttings not to be used as propagation material. A. Albus is a pest throughout most of the cassava growing regions of the world.

1.2 The cassava fruit fly

Two species of fruit fly, Anastrepha Pickeli and A. manihoti have been identified as attacking cassava in the Americas. The fruit fly was originally reported to attack the fruit of cassava which causes no economic losses. The larvae may also tunnel in the stems, resulting in brown galeries in the pith area. A bacterial pathogen (Erwinia caratovora var. caratovora), often found in association with fruit fly larvae, can cause severe rotting of stem tissue. Cuttings taken from damaged stems show reduced germination.

1.3 .tem borers

Mainly of the order coleoptera have been found in cutting used for planting. It is likely that infestation occurred in the growing plants but infestation may also occur on stored planting material. Planting material should be closely inspected prior to planting.

II. PRE AND POST GERMINATION DAMAGE TO CUTTINGS AND YOUNG PLANTS

2.1 Grubs

White grubs (Leucopholis rorida and Phyllophaga sp.) attack planting material or the roots of young plants. Several species of white grubs have been found attacking cassava throughout much of the cassava growing areas of the world. The adult stage of the grub is a beetle, usually of the Scarabeidae or Cerambycidae family.

Damage of these grubs is characterized by the destruction of the bark of planted cuttings which may rot and die. When young plants (1-3 months) are attacked, damage is evidenced by wilting of the leaves. The larvae will feed on the bark of the lower part of the stem usually below the soil or tunnel into the cutting. The larvae are white in color with a darkened head and up to 5 cm. in length. They can usually be located around the cutting or roots of the plant. The biology of L. rorida on cassava has been described in Indonesia (62). Adults become active after the rains have started, and the most severe damage occurs about 4-6 months later. The adult beetles initiate oviposition about nine days after mating, laying up to 37 pearly white eggs singly, 50-70 cm. deep in the soil. Larvae hatch in about three weeks. The larval stage is about 10 months, with 4- to 6- month-old larvae being the most destructive. Larvae live about 20-30 cm deep in the soil where they feed on roots. Pupation taken place at a depth of about 50 cm. The pre-pupal stage is 14 days and the pupal stage about 22 days. Additional hosts include maize, rice and sweet potatoes.

Observations of Phyllophaga sp. in Colombia indicate that there is a one year cycle, with heaviest damage occurring at the onset of the rainy season. Attacks often occur if cassava is planted after pasture or in a weedy, abandoned field. High populations can often be detected at the time of land preparation.

Control: White grubs are best controlled with Aldrin (2.1/2%, 50 Kg/ha) and Furadan (3 gr m^2) applied below the cutting in the soil. Insecticidal dip treatments for cuttings has not proven as successful as soil applications. A. Muscardine fungus, Metarrhizium anisopliae, is pathogenic to the grub.

2.2. Cutworms

There are several species of cutworms that attack cassava and they injure plants in three principal ways.

1) The surface cutworms, such as the black cutworm (Agrotis ypsilon) eat off plants just above, at, or a short distance below the surface of the soil leaving the plant lying on the ground. The larvae is greasy gray to brown, with faint lighter stripes. 2) The climbing cutworms such as the southern armyworm (Prodenia eridania) climb the stems, eat buds and foliage and may girdle stems causing plants to wilt and die. The full grown larvae is dark grey to nearly black in color and marked with lateral yellow stripes. 3) The subterranean cutworms remain in the soil to feed upon roots and underground parts of the stems, causing a loss of planting material. Losses of young plants may rearch 50 percent making it necessary to replant. Cutworm attacks occur sporadically but are more frequent when cassava follows corn in rotation. The biology of the three categories of cutworm species attacking cassava is similar. Eggs are laid in masses on the undersides of leaves near the soil. Eggs hatch in 6-8 days and develop in 20-30 days. The pupal stage (8-11 days) is passed in the soil or under plant debris. Oviposition is initiated about one week after adults emerge. A generation lasts about two months, and under favorable environmental conditions, several generations will occur in one year.

Control: Cutworm attacks are sporadic but occur more frequently when cassava follows maize or sorghum or when planted adjacent to these crops. Longer cuttings (30 cm) will allow plants to recover from surface cutworm attack. Cutworms attacking plants above or at ground level may be controlled effectively with poison baits (10kg bran or sawdust, 8-10 liters water, 500 g sugar or 1 liter molasses and 100 g trichlorfon for 1/4 to 1/2 ha). Subterranean cutworms can be controlled by applications of aldrin or carbofuran around the cuttings.

2.3 Termites

Termites attack cassava mainly in the tropical lowlands. They are reported as pests in several areas of the world but primarily in Africa. Coptotermes voltkowi and C. paradoxis (Rhinotermitidae) have been identified from Madagascar. They feed on propagation material, roots, swollen roots, or growing plants. Principal damage appears to be loss of cuttings; plant establishment can also be affected severely, especially during prolonged dry periods. We have observed swollen root damage and subsequent root rot caused by termite attack.

2.4 Crickets

Crickets damage cassava plants by clipping young shoots after emergence. They can also damage the base of the cassava plant, rendering them more susceptible to lodging by wind.

III INSECTS AND MITES ATTACKING ARIAL PARTS OF THE PLANTS

3.1 Foliage Consumers

3.1.1 The cassava hornworm

The cassava hornworm, Erinnyis ello is generally considered as one of the most serious cassava pests in the Americas. This insect has not been reported from Africa nor Asia.

High populations of hornworm larvae can rapidly defoliate large plantations of cassava. Defoliation during the initial months of plant growth can cause yield losses. Yield reductions of 10 - 50 percent have been estimated, depending on plant age and intensity of attack. Heavy attacks can kill young plants. Damage simulation studies indicate than defoliation of young plants (2-5 months reduces yield more than that of older plants (6-10 months). Although each larva can consume 1107 cm^2 of leaf area, large populations can be tolerated since under favoreble environmental conditions, there can be up to 80 percent defoliation with no reduction in root yield. The ash colored, nocturnal females oviposit their large, light green eggs on the upper surface of cassava leaves. The larvae can vary greatly in color: yellow, green, black, dark grey and tan are common. Fifth instar larvae may reach 10 to 12 cm. When mature in about 12 days, and migrate to the soil where under plant debris they form a chesnut brown, black lined pupa. The adult moth emerges in about 2 weeks. Outbreaks generally occur after the beginning of the rainy season, but are erratic and may be absent for years.

Control: A biological control program appears to be the most effective means of hornworm control. Egg parasitism by Trichogramma sp. can effectively reduce populations. The paper wasp (Polistes sp.) is an important larval predator and simple protective shelters can be erected in cassava fields. Apanteles sp. is a hymenoptera larval parasite. Effective control with the bacterial disease Bacillus thuringiensis has been obtained.

Dipterex is effective against young larvae but the use of pesticides should be avoided as it interupts the biological control system.

3.1.2 Leaf cutter ants:

Several species (Atta sp. and Acromyrmex sp.) have been reported as feeding on cassava in the Americas. Cassava plants can be defoliated when large numbers of worker ants move into a crop. A simicircular cut is made in the leaf; and during severe attacks, the buds may also be removed. These parts are carried to the underground nest and chewed into a paste, on which the fungus Rhozites gongylophora is grown. Outbreaks frequently occur during the early months of the crop; the effect on yield is not known.

Control: Insecticides are the most effective means of control. Nests, which are often readily visible by the sand piles around the entrance hole, can be destroyed by fumigation with carbon disulfide and sulfur smoke or arsenates. Chlorinated hydrocarbons around the nest or granular mirex baits applied along the ant trails give effective control.

3.2. Sucking mites and insects

3.2.1 Mites

Mites are probably the most serious pests attacking cassava. They are frequently a pest during the dry season and cause serious damage in most cassava growing regions of the world. The green cassava mite, Mononychellus tanajoa, native to the Americas, has caused considerable yield reduction in parts of East Africa after its introduction into this area. Recent reports indicate that this mite is spreading trhoughout other areas of Africa.

The mite Tetranychus urticae is universal but appears to be a significant pest in parts of Asia.

The distribution of Oligonychus peruvianus is limited to the Americas and East Africa and has not been reported from Asia.

Mites can be found in great numbers on the undersides of leaves during optimum environmental conditions. Usually older plants are more susceptible to attack.

The Mononychellus mite is usually found around the growing points of plants, on buds, young leaves and stems; lower levels are less affected. Upon emerging, leaves are marked with yellow spots, lose their normal green color, develop a mottled, bronzed, mosaiclike appearance and become deformed. Under severe attack, shoots lose their green color, stems become scarified, first turning rough and brown, and eventually presenting dieback. Stems and leaves necrotize progressively from top to bottom.

Damage from the Tetranychus mite appears first on the lower leaves of the plant. It first shows as yellow dots along the main leaf vein, eventually spreading over the whole leaf, which turns reddish brown or rusty in color. Beginning with the basal leaves, severely infested leaves dry and drop, and plants may die.

The presence of the Oligonychus mite is characterized by small white spots, which are webs the female spreads on the leaf undersides, commonly along the central and lateral leaf veins and margin. Eggs are oviposited under this web where the immature stages develop. Corresponding yellow to brown dots form on the leaf upper surface. Damage is more pronounced on the lower leaves.

Yield reductions as high as 40 percent have been reported by Nyiira in Africa for the green cassava mite (M. tanajoa). Recent studies in Venezuela (Doresta pers. comm.) show a 30 to 40 percent yield reduction for this same mite. Mite infestations at CIAT consist of all three aforementioned species and recent experiments resulted in a 20 percent yield loss when the mite attack occurred from the 5th to the 7th month of plant growth.

Control: Evaluation of the CIAT germplasm bank for mite resistance indicates that there are low levels of resistance or tolerance to the Tetranychus mite and moderate levels to the Mononychellus and Oligonychus mite.

There also appears to be several effective biological control agents for supressing mite populations.

Control with Monocrotophos (Asodrin), Galecron (Fundal) and other organo-phosphates with a commercial dosis is effective.

3.2.2 The Cassava Lace bug

Lace bug (Vatiga manihotae) damage has been reported only from the Americas. Yield losses due to this insect are not know. The adults are grey in color and measure about 3 mm in length. The whitish nymphs are smaller and both adults and nymphs can be found in great numbers on the leaf underside. Damaged leaves show yellow spots which eventually turn to reddish brown, resembling mite damage. Considerable damage to the foliage can occur.

Laboratory studies at CIAT showed five stages, lasting 2.9, 2.6, 2.9, 3.3 and 4.8 days, respectively (totaling 16.5 days). The egg stage is about 8 days; females oviposit an average of 61 eggs. Adult longevity averages about 50 days. Prolonged dry periods are favorable for increased lace bug populations, which were highest during the first three months of plant growth.

3.2.3 Whiteflies

Whiteflies (Aleyrodidae) attack cassava in the Americas, Africa an certain parts of Asia. Although they may not cause economic damage by their feeding, they are of particular importance as vectors of cassava mosaic disease in Africa and India. Bemisia tabaci is the most important species in these areas. B. gossypiperda and B. nigeriensis are also reported from Africa. The species most frequently found on cassava in the Americas are Trialeurodes variabilis, Aleurotrachelus sp., Bemisia tuberculata and Aleurothrixus sp. Although B. tabaci has been reported from the Americas, there is some doubt as to its capacity to feed on cassava. African mosaic disease, reviewed by Lozano and Booth, is not present in the Americas.

High whitefly populations may cause yellowing and necrosis of the lower leaves of the cassava plant. Severe infestations of Aleurotrachelus sp. have been observed in Colombia, where leaf damage was manifested as severe mottling or curling, with mosaiclike symptoms on susceptible varieties. A black, sooty mold, fungal disease, often found on whitefly excretions, may have an adverse effect on plant photosynthesis.

Adult whitefly populations are almost always found on the undersides of developing leaves, where they oviposit. One generation of B. tabaci lasts 4-5 weeks, depending upon climatic conditions; there may be up to ten generations per year.

Studies on the biology of T. variabilis showed that females oviposit an average of 161 eggs, with 72 percent survival from egg to adult. Average female longevity was 19.2 days and for the male, 8.8 days. The oblong pupal stage is normally pale green, but that of Aleurotrachelus sp. is black, with a white waxy excretion around the outer edge. Heavily infested leaves are almost covered with immature stages and pupae, giving the undersurface a glistening white effect. Infestations have been observed on upper as well as lower leaves.

High populations are usually associated with the rainy season when plants are more vigorous. Population levels may depend more on the plant's physiological conditions than on climate.

Control: Varietal resistance to the Aleurotrachelus sp., found in high populations in Colombia, has been evaluated. The varieties CMC-72 and CMC-57 show moderate levels of resistance.

Control of whiteflies, if needed, can also be achieved with the insecticides Roxion, Diostop, Metasyptox, and Dimecron.

3.3 Rasping Insects

3.3.1 Thrips

Several species (Frankliniella williamsi Hood, Corynothrips stenopterus, and Caliothrips masculinus) of thrips, all belonging to the Family Thripidae, have been identified as attacking cassava. Thrips are a major pest in Central and South America and have also been reported from Africa.

The most important species is F. williamsi which damages the terminal buds of the plant. The leaves do not develop normally, leaflets are deformed and show irregular chlorotic yellow spots. Stylet damage to the leaf cells during expansion causes deformation and distortion, with parts of leaf lobes missing. Brown wound tissue appears on the stems and petioles and internodes are shortened. The growing points may die, causing growth of lateral buds which also may be attacked, giving the plants a witches'-broom like appearance. The attack is most frequent during dry periods and plants will recover with the initiation of the rainy season.

Yield reductions due to thrip attack were studied at CIAT. Results indicate a 15 to 20 percent yield loss due to thrips which is consistant with literature reports.

Control: It is best achieved through the use of resistant varieties which are readily available. Resistance is based on the morphological characteristic of leaf-bud pilosity and nearly 50 percent of the CIAT germplasm bank (2.300 varieties) show high levels of resistance.

Systemic insecticides such as Roxion E 38 (160 cc a.i./ha). thiometon E 28 (113 cc a.i./ha) applied every 15 to 21 days also gives excellent control. However this can upset the biological control balance for hornworms, mites and other insects.

3.4 Insects Goring in Stems

3.4.1 The cassava shoot fly:

Damage due to the shoot fly (Silba pendula, Carpolonchacae chalybea) can be observed throughout most of the cassava growing regions of the Americas. The pest has not been reported from Africa nor Asia.

Feeding damage of shoot fly larvae is manifested by a white to brown exudate flowing from the growing point, which eventually dies. This retards plant growth, breaks apical dominance and causes side buds to germinate, which may also be attacked. In some cases only part of the tip is killed, and the shoot continues to grow. Younger plants are more susceptible to attack; repeated attacks may cause plant stunting. During severe outbreaks, 86 percent of the plant population has been reported affected, simulated damage studies, removing 50 and 100 percent of the shoots on plants 2-5 and 6-9 months of age, showed that the degree of economic damage is dependent upon plant variety and age. The late-branching variety Mecu 150 was more susceptible than Llanera at early stages (2-5 months), and yield was reduced by about 30 percent. Shoot removal from 6-9 months did not affect yields of either variety. On an individual plant basis, there was a 15.5, 16.7 and 34.12 percent yield reduction when natural attack occurred at

4.5, 5.5 and 6.5 months, respectively. Affected plants were shorter and may have been shaded by healthy neighbors, hence these yield losses may be an over estimate.

The dark, metallic-blue, adult shoot fly oviposits between the unexpanded leaves in the growing points or in a small cavity made in the tissue by the ovipositor. As many as 22 eggs per shoot have been observed but 3-8 eggs per shoot is average. The eggs hatch in about four days, and the young larvae tunnel in the soft tissue, eventually killing the growing point. Several whitish larvae may be found in the affected tip. The larval period is about 23 days; larvae pupate in the soil and the adult fly emerges about 26 days later. The fly is especially active on sunny days.

Attacks may occur throughout the year, but in many areas they are seasonal, often at the onset of the rainy season. At CIAT the dry period was favorable for higher shoot fly populations.

Control: Larvae are difficult to control. Systemic organophosphates are recommended during early attacks if populations are high. Insecticides and a sugar solution sprayed on plants act as a bait for adult control. Fly traps using decomposing fruits, casein or yeast with an insecticide as an attractant are also recommended.

3.4.2 The cassava fruit fly (*Anastrepha manihoti* *A. pickeli*).

The cassava fruit fly is frequently reported as attacking the fruit of cassava where it causes no economic losses. However this pest has been found causing severe damage to the stems of the cassava plant. Attacks of *Anastrepha* in the stem occur about 10-20 cm below the apex where a small entrance or exit hole is visible. The yellow to tan colored female inserts the egg in the stem tissue and upon hatching the white to yellow larvae bore into and down through the pith region of the stem.

A bacterial pathogen is often found in association with the larvae and this can cause severe rotting of stem tissue. Often a white exudate is found flowing from the larval tunnel. Severe attacks may cause death and colaspe of the growing points which retards plant growth and encourages growth of lateral buds. This secondary rotting may cause a reduction in yield and a loss of stake planting material.

The extent of crop losses due to this pest is not yet known but it appears that plant age at the time of attack is important. Younger plants (2-5 mo.) suffer more from fruit fly attack.

Control: By using attractants or poison baits appear promising. A Hymenoptera parasite (*Opius* sp.) has been identified. The insecticide Lebaycid (Fenthion) gives good control of the larvae in the stem.

3.4.3 Stem borers

Numerous insect species have been reported to feed on and damage stems and branches of the cassava plant (Table 2). Although nearly worlwide in distribution, they are of particular importance in the Americas, especially in Brazil (78). They generally cause sporadic or localized damage, and none can be classified as universal pests.

The most important stem borers belong to the orders Coleoptera and Lepidoptera. Stem borers appear to be highly host specific, and few are reported to feed on alternate hosts. Several lepidopteran and coleopteran stem borers are identified from Africa the only one reported from Asia is *Lagochirus* sp. from Indonesia. Seven species of Coelosternus reportedly attack cassava in the Americas, and *C. manihoti* is reported as a pest in Africa. Only *Coelosternus* spp. and *Lagochirus* spp. are discussed in more detail here.

Larvae vary in size and shape depending on the species. Some may measure up to 30 mm in length. Larvae are usually white to yellow to tan in color and can be found tunneling through the arial parts of the plants. Stems and branches may break or be reduced to sawdust. During dry periods branches may lose there leaves or die and under heavy infestation plants can completely die. Frass and exudate from the stemwood ejected from burrows by larval feeding can be found on infested branches or on the ground below the plant. Female *Coelosternus* spp. may oviposit on various parts of the cassava plant but prefer the tender parts. In *C. alterans* oviposition has been observed near broken or cut ends of branches or beneath the bark in cavities made by the proboscis. Oviposition by *C. granicollis* begins three days after copulation; the female penetrates the stem, and oviposits up to several white eggs.

Larvae vary in size depending upon the species. Fully grown larvae of *C. alternans* are 16 mm in length, with a maximum width of 4 mm, whereas those of *C. tardipes* are 9 x 2.5 mm (18). Most larvae are curved, with a yellowish white to pale brown body, a reddish brown head capsule and black mandibles. In *C. rugicolis* only a single larva is found in each stem; whereas in the other species, there may be several. The larval period ranges from 30-69 days. The fully grown larvae of all species pupate within a cell constructed in the pith region. The pupa is held securely in place in its chamber at one end of the burrow with larval frass; duration of the pupal period is about one month. After emerging from the pupal case, the adult may remain in the chamber for several days before leaving the stem. Adults range in sizes from 6 mm in length for *C. granicollis* to 12 mm for *C. alterans* and *C. rugicolis*. Adults are light to dark brown and may be almost completely covered with yellowish scales. They are active throughout the year, but activity may decrease during cooler months in some areas. *Lagochirus* spp. adults oviposit in stems and branches about 2.5 cm below the bark; eggs hatch in 5-6 days. The larval development period is about two months; larvae measure up to 29 mm; they feed at the base of the plant and many can be found in one plant. The pupation period, which is about one month, takes place in the larval chamber. Adults are nocturnal, rapid fliers, and active throughout the year. They are brown in color, about 17 mm long, and feed on leaves and bark.

Control: Since adult stem borers are difficult to kill and larvae feed within the stems, pesticidal control is impractical. Cultural practices that will reduce pest populations include removal and burning of infested plant parts. Only uninfested and undamaged cuttings should be used for propagation.

3.5 Leaf Deformers

3.5.1 Gallmidges

Several species of Gallmidges (*Cecidomyiidae*, *Iatrophobia* sp.) have been reported on cassava in the Americas. These fragil flies are usually found on the leaf under surface where they lay their eggs. The emerging larvae cause abnormal cell growth in the leaf and the formation of a gall. Leaf galls on the upper surface of the leaves are yellow-green to red, narrower at the base and often curved. When opened, the galls show a cylindrical tunnel with the larvae inside. Gallmidges are considered of little economic importance and generally do not require control. Retarded plant growth, however, has been reported due to severe attack on young plants (2 to 3 months). Collection and destruction of affected leaves at weekly intervals is recommended to reduce populations.

3.6 Stem feeders

3.6.1 Scale Insects

Several species of scales (*Aonidomytilus albus*, *Saissetia* spp.) have been identified as attacking cassava stems throughout most of the cassava growing regions. Yield losses recorded at CIAT on a per plant basis reached 19 percent on heavily infested plants.

Attacked stems can cause leaves to yellow and drop. In severe attacks the plants are stunted and stems can dessicate, causing plant mortality. The greatest damage due to scale attack appears to be the loss of planting material. When cuttings heavily infested with scales are planted,germination is greatly reduced and roots will be poorly developed and unpalitable. The adult scale of *Aonidomytilus albus* is mussel-shaped and covered with a white waxy secretion. It attacks the branches of cassava, especially in the dry season, thus aggravating regions of the world.

The biology of *A. albus* has been studied in detail by Swaine (1950). The cast skins of the 1st and 2nd nymphal stages are incorporated in the scale. Unlike the females, males have well-developed legs and wings. The female produces an average of 47 eggs, ovipositing them between the upper scale covering and the lower cottony secretion. During oviposition the female shrinks and shrivels up. Eggs hatch in 4 days; the first nymphal instars (crawlers) are locomotive and can disperse.

These crawlers become fixed in 1-4 days, cover themselves with numerous fine threads, molt in 11 days and become immobile. After four days the adult female appears and commences oviposition in 1-2 days. One female generation passes in 22-25 days.

Dispersal occurs by wind, active crawling or via infested cuttings. The most important means of dissemination is by storing infested cuttings with healthy ones.

Control: The most effective means of control is through the use of uninfested planting material and cutting and burning infected plants to prevent the spread of infestation. Chemical control may be required during the dry season. Measured in percentage of adults killed, systemic insecticides and parathion were most effective. As for chemical control of cuttings, dipping those that are infested with crawlers in DDT emulsions for 5 minutes reduces infestation; however, heavily infested cuttings still germinate poorly after dip treatments. Preventive control of stored cuttings has been sucessful.

Heavy predation of A. albus by Chilocorus distigma (Coccinellidae) is reported (64). Hymenopterous parasites (Aphelinidae), Aspidoiphagus citrinus and Signiphora sp., are reported in Cuba. We have observed heavy parasitism and predation of S. miranda in the field, but the species have not been identified. We have also found a brown, spongelike fungus, Septogasidium sp. growing on A. albus.

3.6.2 Mealybug

Mealybug damage to cassava has been reported from Colombia, Brazil and parts of Africa. The species at CIAT has been identified as Phenacoccus gossypii, the Mexican mealybug, while P. gossypii and Phencoccus sp. are reported from Brazil.

Mealybugs reported from Africa are Pseudococcus virgatus (Ferrisiana virgata, Dastulopius virgatus), P. citri and P. adonidum. High mealybug populations cause defoliation of cassava plants and drying of stem tissue, resulting in a loss of planting material. Leaves will turn yellow and dry and defoliated plants will form new buds, which are also attacked.

P. gossypii has a wide host range, including food crops as well as many ornamentals. Females deposit sacks containing a large number of eggs around the axil of branching stems or leaves, on the underside of the leaf where the leaf petiole joins the leaf, or around the buds on the main stem. The young nymphs, shortly after initiating feeding, exude a white, waxy material from their bodies which forms a cover over the insect. High populations give a cottony appearance to the green or succulent portion of the stem and to the leaf undersurface. They do not remain fixed but move slowly over the plant surface. Adults measure about 2.4 by 1.5 mm. The life cycle of this insect has not been studied on cassava.

Control: There are numerous predators and parasites of mealybugs. Chemical control with malathion has been successful.

IV. DRIED CASSAVA STORAGE PESTS

Approximately 38 insects, mainly Coleoptera, are reported to be found on dried cassava chips or products. Many are polyphagous; only those that are able to reproduce on dried cassava are important. These include *Stegobium paniceum*, *Araecerus fasciculatus*, *Rhizopertha dominica*, *Dinoderus minutus*, *Tribolium castaneum* and *Latheticus oryzae*. Most damage is reported from Asia, Africa, or from Europe on imported dried cassava.

No data are available on losses in dried cassava due to insects. Cassava chips were reduced to dust in 4-5 months in India. Recent studies at CIAT indicate that *A. fasciculatus*, the coffee bean weevil, and *D. minutus*, the bamboo powderpost beetle, can cause considerable losses.

Control: Proper sanitary measures, such as cleaning and disinfecting warehouses prior to restocking and rapid removal of infested material, are the most effective control measures. Bitter varieties of cassava are reported to be more resistant to weevils than sweet ones; however, this needs confirmation. Standard grain fumigations also give effective control of these pests.

V. BASIC PRINCIPLES OF CASSAVA INTEGRATED CONTROL SYSTEM.

Cassava is ideally suited for Biological Control Program.

High levels of pest resistance are not needed and resistance to some pests are available.

It is necessary to understand the insect- plant -environment interaction. Rainfall appears to be key factor.

Cultural practices (selection of planting material, crop rotation etc.) con reduce pest incidence.

The use of insecticides intelligently and only when needed.

The indiscriminate use of pesticides will interrupt Biological control programs.

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TABLE I. THE CASSAVA MITE AND INSECT COMPLEX

COMMON NAME	IMPORTANT GENUS/SPECIES	REPORTED FROM	PLANT PARTS ATTACKED
Thrips -	Frankliniella williamsi Corynothrips stenopterus Caliothrips masculinus	Mainly in Americas but also in Africa	Deformation of foliage and outer stem tissue
Mites -	Mononychellus tanajoa Tetranychus urticae Oligonychus peruvianus	Americas and Africa All regions Americas	Leaf yellowing, necrosis and death of buds
The cassava hornworm	Erinnyis ello	Americas	Foliage, buds, and tender stem consumed.
The cassava fruit fly	Anastrepha pickeli A. manihoti	Americas	Fruit (seed) and stem boring
The cassava shoot fly	Silba pendula Lonchaea chalybea	Americas	Death of apical buds
Whiteflies	Bemisia tabaci Aleurotrachellus sp.	Africa, Asia, Americas	Foliage deformation, necrosis and virus transmission.
Stem bores	Coelosternus spp.	All regions but mainly Americas	Stem and possibly swollen roots.
White grubs	Leucopholis rorida Phyllophaga sp.	All regions but mainly Americas and Indonesia	Planting material, roots

COMMON NAME	IMPORTANT GENUS/SPECIES	REPORTED FROM	PLANT PARTS ATTACKED
Cutworms	*Prodenia litura* *Agrotis ipsilon*	Americas and Madagascar	Planting material, stem girdling and folliage
Gall Midges	*Jatrophobia brasiliensis*	Americas	Leaf galls
Lace Bugs	*Vatiga manihotae*	Americas	Leaves
Grasshoppers	*Zonocerus elegans* *Z. vareigatus*	Mainly Africa but also Americas	Foliage consumed
Mealybugs	*Phenococcus gossypii*	Americas And Africa	Foliage and stems
Scales	*Aonidomytilus albus* *Saissetia* sp.	All regions	Stems
Leaf cutter Ants	*Atta* sp. *Acromymex* sp.	Mainly the Americas	Foliage
Crickets		The Americas and Africa	Young plants cut off
Termites	*Costotermes voltkevi* *C. paradoxis*	All regions but mainly Africa	Planting material, roots, stems and swollen roots

METHODS OF WEED CONTROL IN CASSAVA

(*Manihot esculenta* Crantz)

J.D. Doll*
W. Piedrahita C.*

It has been recognized that cassava yields can be greatly increased by eliminating weed competition during the initial growth periods; nevertheless, many consider that it is able to survive, compete and produce with only minimal weed control efforts. Even under ideal growing conditions, it takes two months or longer for the cassava canopy to close; under less favorable conditions, it may take up to four months. Until a complete canopy is formed, attention usually needs to be given to controlling weeds.

Cassava yields, four times greater than the national production averages of many countries, are being obtained experimentally as a result of the integration of many technological advances (i.e., improved varieties, proper pest and weed control measures, adequate fertilization and other cultural practices). A very essential part of this cassava production package is weed control. This bulletin presents the results of three years' research efforts at CIAT and highlights the importance of timely weed control and the adoption of an adequate control program.

Effects of weed competition

As with any crop, cassava is subject to weed competition for light, water and nutrients. For most short season annual crops, the critical period of weed competition occurs during the first few weeks after planting (Kasasian and Seeyave, 1969). If crops are kept weed free during this period, optimal yields are obtained. An experiment was conducted to determine the critical period of competition in cassava, based on hand weedings performed at various frequencies and intervals. The variety CMC-39 was planted in ridges at a population of 10.000 plants per hectare in a field where the principal weeds were *Cyperus rotundus* (purple nutsedge), Rottboellia *exaltata* (Raoul grass), *Sorghum Halepense* (Johnson grass) and *Ipomoea* spp. (morning-glory).

Results indicate that the weeding operation must begin 15 to 30

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days after planting and continue until a canopy has formed; in this trial, it was 120 days due to the high density of aggressive weeds (Table 1). Weeding after 120 days did not increase production. One weeding was not sufficient, whereas two well-spaced weedings produced 75 percent of the maximum yield. When weeds competed during the first 60 days, yields were reduced by nearly 50 percent. The highest yield was obtained by chemically weeding the cassava, never allowing weeds to compete with the crop. Under the foregoing conditions, the critical period of competition began at planting and continued for 120 days.

Plant populations and weed control systems

The weed complex, soil fertility level and characteristics of the cassava variety are not the only important factors that effect the degree of weed competition; crop density is also very important. Under weed free conditions, a crop maximizes its use of essential nutrients, water and light; and a low cassava population yields as much as higher ones (CIAT, 1973). On the other hand,when weeds are present, it is expected that higher crop populations will compete better with the weeds than lower densities. This expected interaction was studied. The varieties CMC-9 (a tall, branching type) and Mexico 11 (a shorter, nonbranching type) were planted in populations ranging from 2,940 to 25,000 plants per hectare. The results are presented in Figure 1.

Cassava kept weed free during the ten-month period with herbicides (alachlor plus diuron in preemergence and directed, shielded applications of paraquat in postemergence) gave the highest yields for each variety; optimal production was reached around 15,000 plants/ha. When the traditional methods of one or two hand weedings were employed, the highest yields were obtained at 15,000 to 20,000 plants/ha for Mexico 11 and between 20,000 and 25,000 for CMC-9 (Fig. 1). Two hand weedings were nearly as effective as the use of herbicides.

Higher crop density will compensate for the effects of weed competition when the weed control system is not sufficiently intensive to keep the cassava relatively weed free. The data also illustrate that by keeping the crop totally weed free, especially during the early growth stages, fewer plants per hectare are needed to achieve maximum production. When no weeds were removed, cassava yields were extremely low; nevertheless, yields increased as plant density increased.

Herbicide selectivity

Preemergence and preplant-incorporated herbicides

In Latin America up to the present, relatively few large-scale, preemergence herbicide applications have been made in cassava in comparison to other food crops. In part this is due to incomplete knowledge of safe and effective herbicides; therefore, four trials

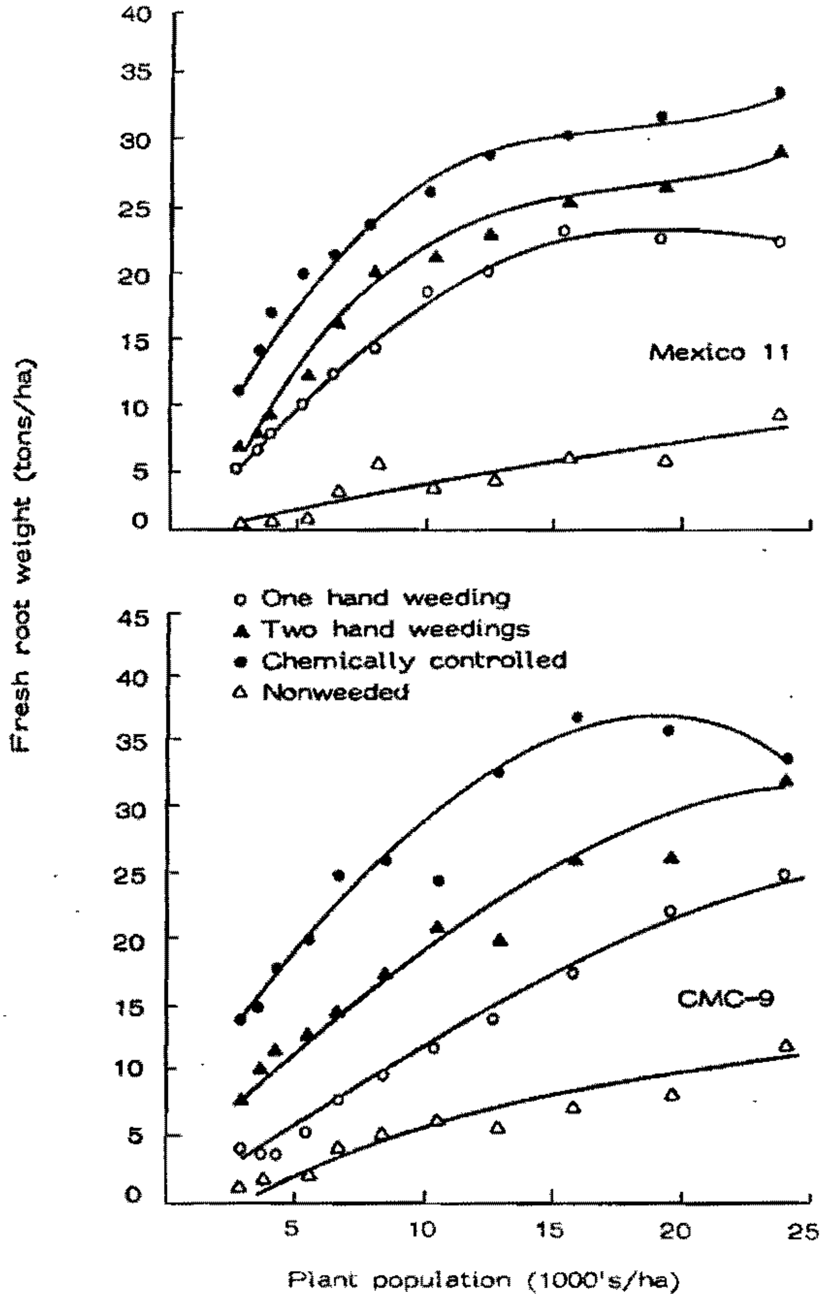

Figure 1. Effect of cassava population and weed control system on fresh root weight 10 months after planting for Mexico 11 and CMC-9.

Table 1. Effect of hand weedings at different times and frequencies on the fresh root yield of cassava (CMC-39) at 280 days after planting.

No. of hand weedings	Frequency of hand weedings (days)	Fresh root yield (tons/ha)	Fresh root yield % of maximum yield *
4 + **	15, 30, 60, 120, UH***	18.0	86
3 +	30, 60, 120, UH	16.0	76
2 +	60, 120, UH	11.0	52
1 +	120, UH	7.0	33
4	15, 30, 60, 120	19.5	92
3	15, 30, 60	12.9	61
2	15, 30	13.3	63
1	15	5.8	28
2	30, 60	16.3	77
2	15, 45	15.4	73
0	Weedy check	1.4	7
0	Chemical control ****	21.1	100

* Percentage of the yield of cassava weeded with herbicides
** The "+" indicates additional weedings
*** UH = until harvest, as needed
**** Alachlor + fluometuron were applied in preemergence, and directed applications with a shielded nozzle were made of paraquat as needed in postemergence.

were conducted to screen commercial and promising experimental herbicides. To determine the margin of selectivity of each product, the recommended rate and two, three or four times this amount were applied. Those herbicides causing serious injury to cassava at the recommended rate were classified as nonselective; those causing injury only at double the recommended rate, moderately selective; and those causing no injury even at 3 or 4 times the recommended rate, highly selective (Table 2).

Eighteen products were found to be highly selective in cassava, and among these the right herbicide or combination of these could be found for almost any weed complex. Those products classified as moderately selective could also be recommended as there is no danger of crop damage if the exact rate for a given soil type is applied; only if an overdose is applied would there be a problem of crop injury. Herbicides in the third group may be harmful even at the normal rate and obviously should not be recommended.

Incorporated herbicides and the planting scheme

One of the hardest weeds to control in the tropics is purple nutsedge (*Cyperus rotundus*). Butylate is the only selective herbicide (Table 2) that controls it, and it must be soil incorporated immediately after application to prevent losses due to its high volatility. This can present a problem when cassava is to be planted in ridges, as is frequently done in relatively flat areas and in heavy textured soils. As the ridges are formed after the herbicide has been incorporated, the herbicide accumulates in the ridge, reducing crop tolerance as well as leaving the area between ridges with less product and therefore poorer weed control

A trial was conducted to study this aspect of three preplant incorporated herbicides: butylate , EPTC and trifluralin. Each was applied at the recommended and double the recommended rate and immediately incorporated. Half of each plot was then ridged while the other half was left non ridged.

More crop damage was observed with EPTC in the ridged than in the non ridged system (Table 3). Butylate gave similar results but was much more selective, verifying the selectivity classification of Table 2. Trifluralin caused no crop injury at either rate in either system. Grass weed control was reduced by the ridging operation, especially between ridges, confirming that less product remains in this zone after ridging. In each system a combination of diuron + alachlor was applied in preemergence after planting cassava and gave excellent weed control in both (Table 3). In conclusion butylate is recommended to control purple nutsedge, and better control is obtained in non ridged systems. Hand or mechanical weedings should be performed as often as needed until the cassava has shaded over since the residual effect of butylate is normally 30 to 40 days only. Trifluralin can also be used in this way (incorporated), especially when the principal weeds are grasses.

Postemergence herbicides

Farmers who do not apply preemergence herbicides often have serious weed infestations and seek solutions with postemergence products. For this reason, several postemergence herbicides commonly applied in other crops were tested on cassava.

Diuron proved to be the most selective product in over the top, broadcast applications; but even then yields were reduced 16 percent

Table 2. Selectivity of preemergence and preplant-incorporated herbicides in cassava.*

Highly selective	Moderately selective	Nonselective
Alachlor	Ametryn	Atrazine
Benthiocarb	Butylate	Bromacil
Bifenox	Chlorbromuron	DPX-3674
Butachlor	Diuron	EPTC
Chloramben	DPX-6774	Karbutilate
Cyanazine	Fluometuron	Tebuthiuron
Dinitramine	Linuron	Vernolate
DNBP	Methabenzithiazuron	
Fluorodifen	Metribuzin	
H-22234	Oxadiazon	
Methazole	Prometryn	
Napropamide	Terbutryn	
Nitrofen		
Norea		
Perfluidone		
Pronamide		
S-2846		
Trifluralin		

* Based on the results of four trials

as compared with hand weeded cassava yields. Amitrol, bentazon, paraquat, dalapon, MSMA, DNBP and glyphosate were totally nonselective; nevertheless, directed applications greatly increased their selectivity. For example, diuron, MSMA and dalapon, applied to the lower half of the plant, did not decrease yields. Paraquat and glyphosate were still injurious to cassava with this system, especially in young plants 40 to 65 days old. These postermergence products should, therefore, be applied only with a shielded nozzle to prevent plant contact.

Recommendations

Based on the foregoing and other research, chemical control recommendations are presented in Table 4. To arrive at these recommendations, the effectiveness, selectivity, availability and cost of each product have been taken into account. As was previously mentioned, rarely will the single application of a herbicide give sufficient weed control until the crop canopy closes; therefore, each

Table 3. Effect of three preplant-incorporated herbicides on percentage of germination, injury rating, grass control and cassava production when cassava is planted in ridged and nonridged soil.

Treatments	Rate (kg a.i./ha)	% germination[1]	Injury rating[2]	Grass control[1] (%)	Fresh root yield[3] (tons/ha)
Cassava planted in ridges					
EPTC (PPI)[4]	4	75	5.2	73	22.0
EPTC (PPI)	8	45	7.7	86	8.4
Butylate (PPI)	4	77	0.7	36	33.0
Butylate (PPI)	8	83	3.5	80	30.8
Trifluralin (PPI)	1.5	94	1.5	62	35.8
Trifluralin (PPI)	3.0	100	0	76	35.6
Diuron + alachlor (PRE)[5]	0.8 + 1.5	96	0.5	100	27.9
Weedy check	-	94	0	0	18.3
Average		83	2.3	64	26.5
Cassava planted on the flat					
EPTC (PPI)	4	92	1.5	98	41.7
EPTC (PPI)	8	64	1.2	100	33.1
Butylate (PPI)	4	98	0	92	34.2
Butylate (PPI)	8	79	1.0	96	39.0
Trifluralin (PPI)	1.5	96	0	88	42.5
Trifluralin (PPI)	3.0	94	0.5	93	42.6
Diuron + alachlor (PRE)	0.8 + 1.5	98	0	100	36.9
Weedy check	-	100	0	0	21.4
Average		90	0.5	83	36.4

1 60 days after planting
2 60 days after planting; 0 = no injury, 10 = completely killed
3 10 months after planting
4 PPI = preplant incorporated
5 PRE = preemergence

Table 4. Chemical weed control recommendations for cassava.

Herbicide[1]	Rate (com. prod./ha)[2]	Time of application	Notes
Fluometuron (Cotoran)	4-5 Kg	Pre[3]	Most annual weeds
Diuron (Karmex)	2-3 Kg	Pre	Most annual weeds
Alachlor (Lazo)	4-6 liters	Pre	Excellent on grasses
Linuron (Afalon or Lorox)	2-3 Kg	Pre	Most annual weeds
Fluometuron + alachlor	2 Kg + 2.5 liters	Pre	Tank mix
Diuron + alachlor	1 Kg + 2.5 liters	Pre	Tank mix
Trifluralin (Treflan)	2.5-3.5 liters	PPI[4]	Excellent on grasses
Butylate (Sutan)	5-6 liters	PPI	Controls grasses and sedges
Dalapon (Dowpon or Basfapon)	8 Kg	Post[5]	Directed application
Paraquat (Gramoxone) + diuron	2 liters + 2 Kg	Post	Tank mix; directed application with a shield

1 Name of commercial product given in parentheses.

2 The lower rate is for lighter soils and the higher one for heavy textured soils.

3 Pre = preemergence, before crops and weeds emerge.

4 PPI = preplant incorporated; ridging after incorporation may reduce weed control

5 Post = postemergence; a surfactant should be added.

field must be observed closely to determine when complementary hand or mechanical weedings should be performed.

Integrated control

In order to develop the best weed control program for each farm, it is not enough to know which herbicides are selective, nor should cassava be considered as a short season crop such as corn or soybeans. Its slow initial growth gives weeds an opportunity to grow vigorously; and even when herbicides are used, the best products control weeds for approximately 60 days and the cassava canopy has not yet closed. Therefore, an experiment was conducted to evaluate how to integrate the various methods of control best. The systems studied were preemergence herbicides followed by postemergence ones, preemergence herbicide applications complemented with a hand weeding, and postemergence applications followed by a hand weeding. These methods were compared to the traditional system of three hand weedings.

The highest yield was obtained with three timely hand weedings (31 tons/ha at ten months); the use of diuron in preemergence, complemented with one hand weeding, was the next best system (27 tons/ha). The lowest yields were from the preemergence treatments alone, emphasizing the need to integrate the use of chemical control with complementary measures.

In general, the hand weeding that follows the preemergence application should be done two to three weeks prior to the canopy's closing (normally 60 to 75 days after planting under conditions at Palmira); but if there is a serious weed problem prior to this time, weedings should be practiced as often as needed to avoid competition with cassava.

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THE MINERAL NUTRITION AND FERTILIZATION OF CASSAVA

Reinhardt H. Howeler

In general cassava is considered a rustic crop that grows relatively well on poor soils without the application of much fertilizers. On the other hand, farmers consider cassava a crop that exhaust the soil, and for that reason prefer to plant it as the last crop in a rotation before returning the plot to bush fallow. Hongsapan (1962) reports that in Thailand yields dropped from 25-36 tons to a level of 12-18 ton/ha due to continuous cassava production. Though cassava extracts large amounts of K from the soil, he considers that among crops like corn, sugarcane, bananas, cabage, cassava is not the most soil depleting crop per ton of food produced. Still, on a per crop basis, cassava extracts more nutrients from the soil than most other tropical crops as shown below (Kanapathy 1974):

Crop and Production	N	P	K	Mg
	Kg/ha			
Cassava (18.6 ton/ha- 6 months)	87	37.6	117	35.1
Oil palm (18 ton/ha)	61	9.9	84	13.6
Rubber (1.13 ton/ha)	9	2.0	11	2.3
Corn (3.4 ton/ha)	82	20.7	69.2	14.7

On peat soils of West Malaysia high yields of continuously grown cassava could be maintained with adequate fertilizer applications (Kanapathy, 1970). Birkinshaw (1926) reports that excellent yields of rubber were obtained after 15 consecutive well-fertilized cassava crops. Thus, due to its high nutrient extraction rate, cassava rapidly exhausts the soil if not fertilized, but with adequate fertilization soil fertility can be maintained.

Besides nutrient extraction by the crop, the fertility of the soil may also deteriorate because of erosion, since cassava tends to enhance soil erosion, especially during seeding and after harvest. Gómez (1975) calculated an erosion index of 9.8 for cassava compared with 1.1 for sugarcane, 1.7 for pineapple, 1.0 for pasture and 11.8 for coffee in a volcanic ash soil with 60 percent slope in Colombia.

Nutrient Removal

To maintain soil fertility it is necessary to fertilize the soil at least with the quantity of nutrients that the crop removes in the harvest. Among tropical crops cassava probably extracts more K than any other crop. According to Prevott (1958) cassava has the highest K/N extraction ratio (Figure 1). Other crops of high K/N ratio are bananas, oil palm, pineapple, coconut and sugarcane, while corn, rice and cotton have a relatively low K/N ratio. The extraction of nutrients per ton of cassava roots harvested, according to different authors is shown in table 1.

Although the data vary considerably among authors due to different soil conditions, cultivars, etc., on the average cassava extracts per ton of roots about 2.14 kg N, 0.46kg P, 3.5 kg K, 0.69 kg Ca, and 0.39 kg Mg, when only roots are removed from the field. Thus an average yield of 25 ton/ha removes 53.5 kg N, 26.3 kg P_2O_5, 105 kg K_2O, 17.2 kg Ca, 9.75 kg Mg. If the whole plant is removed from the field this corresponds to 174 kg N, 72.1 kg P_2O_5, 200.7 kg K_2O, 71.7 kg Ca, and 24.7 kg Mg, thus, cassava extracts a large amount of nutrients from the soil with each crop, but returning stems and leaves to the field considerably reduces soil depletion. Besides K, cassava extracts large amounts of N while the extraction of P, Ca and Mg is relatively low.

Nutrient accumulation in the plant

Sampling and analyzing every two weeks different plant parts, Orioli (1967) in Argentina determined the nutrient accumulation and distribution in the plant up to six months of age, both for plants fertilized and not fertilized. Figure 2A shows dry matter (D.M.) accumulation and distribution during the growth cycle. It can be seen that D.M. production was slow during the first three months, being about 20% of the total accumulation. In the next two months plants accumulated D.M. at about 25 percent per month while during the six months the accumulation slowed down. This reduction in accumulation rate after the fifth month is probably due to the onset of winter in Argentina and is not observed under tropical conditions (see below).

Roots accumulated D.M. at rather constant rate during the entire growth cycle, while the leaves and stems accumulated little during the six month. Although fertilized plants accumulated dry matter in greater quantities than unfertilized plants, Figure 2B shows that the relative accumulation curves were almost identical for both conditions.

Figure 2C shows the accumulation of N in the plant during the growth cycle. Again, the N accumulation rate was slow during the first two months reaching a maximum in the third and fourth months, while the last two months little or no N accumulated, with even some losses for the non-fertilized plants. Although the dry matter is about equally distributed at six months between roots, stems and leaves, Figure 2D shows that N is present mainly in the leaves with relatively little accumulation in the roots and stems. This reflects the high protein content of the leaves and low content of the roots. The N accumulation rate for the leaves was practically constant during the entire growth cycle but for the stems and roots accumulation nearly stopped in the last months.

Accumulation of P and K was similar to that of N, being slow during the first two months, reaching a maximum of about 40 percent per month during the third and fourth month and slowing down to almost zero at six months. Again, most of the P and K was present in leaves; during the last month both leaves and stems lost some P while the roots and stems lost some K.

Calcium accumulation differed from that of NPK in that after the first two months, the rate of accumulation remained nearly constant throughout the growth cycle. Ca accumulation in leaves and roots stopped after three months, while that of stems continued.

The relative nutrient accumulation curves for fertilized and non-fertilized plants was very similar although the fertilized plants absorbed nutrients in greater quantities.

Nyholt (1935) determined dry matter and nutrient accumulation in different plant parts up to 14 months, sampling plants at monthly intervals, using two cultivars grown on an acid lateritic soil in Indonesia. Figure 3 shows the fresh matter accumulation and distribution during the growth cycle. Unlike the Argentina data presented above, under the tropical conditions of Indonesia, D.M. accumulation continued throughout the growth cycle, with only a slight decrease in rate after six months. However, D.M. accumulation stopped after six months in the leaves, and slowed down in the stems, while it continued in the roots.

Figure 4 shows the accumulation and distribution of N,P,K,Ca and Mg during the growth cycle. The amount of N in the plant increased at a nearly constant rate up to six months, then remained constant and actually decreased after eight months. This was due to a loss of leaves after six months. Roots accumulated N only up to eight months, after which the amount remained constant. Though root weight continued to increase up to 14 months, the N content decreased from 1.03 percent at two months to 0.17 percent at 14 months. Only the stems continued to accumulate N throughout the growth cycle.

P,K,Ca and Mg accumulation continued at a rather constant rate throughout the growth cycle, although the amount in the leaves decreased after six months due to leaf fall. K and P accumulated mainly in the roots, and Ca and Mg mainly in the stem.

Nutrient content in the plant

The nutrient content varies considerably among plant parts and also changes during the growth cycle. Table 2 (Nyholt 1935) shows how the concentration of various nutrients varies with time in roots, stems and leaves. N,P and K contents decrease significantly in all three plant parts with the aging of the plant. Ca and Mg contents tend to increase in the leaves, but decrease in stems and roots. Thus, in general, all nutrients contents decrease during the growth cycle, except the Ca and possibly the Mg content of the leaves which increase.

The N content is very high in leaves, much lower in stems and very low in the roots, resulting in a low protein content of the latter. The K contents too are higher in leaves than in stems and roots, but the differences are minor. The P, Ca and Mg contents are also highest in leaves, followed by stems, and then roots, with considerable differences in the contents of various plant parts.

Cours (1961) determined that within the aerial part of the plant considerable differences occured between older and younger parts. Table 3 shows that the young leaves are higher in N P K, but lower in Ca than old leaves. The petioles of young leaves are higher in N P Ca, but lower in K than those of old leaves. The leaves are higher in N P but lower in K and Ca than the petioles. Also, the upper green branches are higher in N,P,K and Ca than the lower green branches, which in turn are higher than the primary branch or the main stem. The pheloderm of the main stem is exceptionally high in K, and Cours (1961) recommend to use this plant part for diagnosing K deficiency. In a more detailed study Cours (1953) determined that the contents of N P K decrease from upper to lower leaves of the primary branch, and from upper to lower branches, while the Ca and Mg contents increase from upper to lower leaves and from upper to lower branches.

Table 4 summarizes nutrient contents in various plant parts reported by several investigators. Even among the same plant parts nutrient contents vary because of differences in soil fertility, cultivars, age of plant, and plant part sampled. For diagnostic purposes it is very important to standardize the part of the plant to be sampled, and the physiological age of the plant at sampling. In general, the uppermost fully expanded leaves, i.e. the 4th or 5th leaf from the top, are used for sampling, analizing only the leaf blade for all elements, or the petioles for K, Ca and Mg. The best physiological age is about three months when the plant reaches it maximum rate of nutrient absorption (see Figure 2). However, if cassava are planted before a dry season, sampling should be postponed untill the onset of the rainy season, when the plants start to grow actively again.

Fox (1975) reports that an N level of 5 percent at 4-5 months corresponds to maximum yield. Figure 5 shows the relation between yield and the P content of leaf blades at five months (3 months physiological age) indicating a critical level of about 0.4 percent P. Roche (1957) suggest a critical K content of 0.6 percent in leaves and 0.5 percent in phelloderm, while that of soil is 0.06 me/100 gm. In Essais de Fumure (1953) it is suggested that leaves with less than 0.7 percent K are indicative of K deficiency. CIAT (1974) obtained highest yields in a pot experiment with a leaf K content of 1.1-1.3 percent. Though critical levels have not been determined exactly and will vary somewhat with the cultivar used, the following levels seem a reasonable approximation i.e. no fertilizer response is very likely if uppermost fully expanded leaf blades contain more than 5.0 percent N, 0.4 percent P, 1.2 percent K, 0.7 percent Ca, 0.3 percent Mg and 0.35 percent S.

Literature on minor element contents is even more scarse as that on major elements. Table 5 summarizes some data from the literature. The great variability of the data probably reflects the luxury uptake of some minor elements in soils that are well supplied with them. CIAT (1975) reports a critical level for Zn of about 60 ppm in the uppermost fully expanded leaves. Zn deficiency symptoms generally appear when the Zn content is below 20 ppm. Since Zn deficiency is quiet common in cassava the proper diagnosis through leaf analyses is very important.

Normal levels of minor elements in the upper leaf blades are approximately 15-40 ppm B, 60-100 ppm Zn, 50-150 ppm Mn, 6-12 ppm Cu, 100-200 ppm Fe(CIAT 1974).

In order to supply the plant with the nutrients needed for maximum production, it is important to know the plant's requirements, to diagnose correctly any deficiency through visual observation or soil and plant analyses, and to know the means to correct the deficiency. Below these points are treated for each element separately.

Nitrogen Fertilization

Nitrogen is a basic component of protein, chlorophyl, enzymes, hormones and vitamins.

N deficiency is most common on sandy soils or very acid soils where toxic levels of Al and/or Mn reduce the microbial decomposition of organic matter.

Nitrogen deficiency is also common in volcanic ash soils, these normally have a high amount of organic matter, but its decomposition is slow and does not contribute much to the N supply.

Plants suffering from N deficiency have light-green colored leaves and generally a stunted growth (Krochmal 1968, Asher 1975, Lozano 1976). The older leaves are affected firts, but the whole plant may become uniformly chlorotic. In nutrient solution trials (Forno, 1977) cassava produced only very mild symptoms at low N concentrations while corn, sorghum, and cotton showed severe symptoms. Cassava growth was markedly reduced. This corresponds with observations at CIAT (Lozano 1976) in which cassava suffering from N deficiency showed stunted growth rather than deficiency symptoms. The critical level of N deficiency is about 5 percent N in the leaf blade (Fox 1975).

Cassava extracts relatively large amounts of N from the soil, especially if leaves and stems are removed with the roots. With 25 ton of roots about 50 Kg of N is removed. If the efficiency of N is estimated to be about 50 percent (43-69 percent according to Fox 1975) about 100 kg of N should be returned to the soil to maintain its fertility. In Madagascar investigators (Essais de Fumure 1953, Le Manioc 1952) recommend incorporation of farm yard manure (FYM) or green manure such as *Mucana utilis*, Vigna or Crotolaria. However, Crotolaria is very susceptible to acid soils and does not produce well at a pH below 5 (CIAT 1974). De Geus (1967) and Kumar (1977) also indicate that cassava responds well to application of FYM, especially when fortified with some chemical NPK fertilizers. In Malaysia, Lambourne (1927) obtained better results with FYM (10 ton/ha) than with chemical fertilizers or green manures (Crotolaria + basic slag).

On Ultisols of Puerto Rico, Fox (1975) reports a response to only 40 Kg N/ha, with no significant response to higher levels up to 200 kg N/ha, with no significant response to higher levels up to 200 kg N/ha. ICA (1971) obtained a positive response to 50-60 kg N/ha in 16 out of 23 trials in farmers fields in Colombia. The greatest response was obtained in the volcanic ash soils near Popayán. In Oxisols of the Llanos of Colombia in the dry season planting, CIAT (1976) obtained a positive response to 100 kg N/ha, which was not significant (Figure 6). Split application was equally effective as a basal application at seeding. On the same soil, but during the wet season, a significant response was observed to 100 kg N/ha as urea and to 200 kg N/ha as sulplur coated urea (SCU) as shown in Figure 7. On similar soils Ngongi (1976) obtained a response to 100 kg N/ha, but only in the presence of 150 kg K_2O/ha, and the application of 200 kg N/ha was detrimental. On volcanic ash soils in Colombia, Rodriguez (1975) obtained highest yields with 145 kg N in combination with 194 kg P_2O_5 and 46 kg K_2O/ha. Many investigators (Vijayan 1969, Acosta 1954, Obigbesan 1976, Fox 1975) have reported a negative response of cassava to high N applications, which produce excessive foliage and little roots. Krochmal (1970) reports a root yield reduction of 41 percent and an increase of top growth of 11 percent by high N application. Vijayan (1969) noted a decrease in the number of tubers and starch content with N applications above 75 kg/ha. Also an increase in HCN content by high N rates were reported by several workers (Vijayan 1969, Muthuswamy 1974, Obigbesan 1976). Apparently, high N application stimulates the formation of nitrogenous products such as protein and HCN and inhibits the synthesis of starch (Dias 1966, Malavolta 1954).

In Costa Rica (Acosta 1974) a yield response was obtained to 50 kg N/ha with a yield depression at higher rates. In Brasil, no response to N was observed (Silva 1968) in Sao Paulo, while for infertile Goias soil Normanha (1960) recommends only 20 kg N/ha top dressed at 3-5 months. In Rio de Janeiro Nunes (1974) obtained a positive response to 30 kg N/ha. In Western Nigeria, Amon (1973) recommends about 25 kg N/ha in combination with 60 kg K_2O, while Obigbesan (1976) obtained high yields of 56 and 64 ton/ha in 15 months applying 50 and 60 kg N/ha. In Ghana, Stephens (1960) obtained a yield response mainly to P, but also a slight response to 25 kg N/ha. In the same country, Takyi (1972) obtained a 50 percent yield increase applying 60 kg N and 45 kg P_2O_5/ha, while no response was observed to K and lime. In Madagascar cassava responded mainly to K, but the application of 30-60 kg N/ha is recommended (Le Manioc 1953, De Geus 1967). In acid lateritic soils of Kerala State in India, Mandal (1971) obtained highest yields with 100 kg N/ha, applied half as a basal and half as a top dressing at two months. On peat soils of Malaysia, Chew (1970) obtained the greatest response to N, applying about 180 kg N/ha. For similar soils Kanapathy (1974) recommends 120 kg N/ha. In Indonesia (Java) cassava responded mainly to K and Den Doop

(1937) did not recommend the application of N.

Most workers (Samuels 1970, Santana 1975) found no significant differences between N sources such as urea, $(NH_4)_2 SO_4$, $Ca(NO_3)_2$ or $NaNO_3$, although in India, $CaNH_4 (NO_3)_3$ was found to be superior, probably because of its Ca content (Trivandrum 1970). SCU was not found to be superior to urea in Colombia (Figure 7) or Puerto Rico (Fox, 1975).

Normanha (1959) obtained poor stands when N and K were applied in the planting row. He recommends lateral placement of the fertilizer at planting with a top dressing of N at three months (Normanha 1968). In Malaysia, Chan (1970) found no significant differences between broadcasting or spot dressing of N at planting. Rodriguez (1975) recommends applying fertilizers all at planting rather than a split application, while Samuels (1970) and Mandal (1971) prefer to apply half of the N at planting and half at 2-2.5 months.

Thus, in general, cassava does not respond to N or responds only to relatively low rates, producing excessive tops and little roots with high application rates. Little differences were observed between N sources; its application is recommended all at seeding or as a split application at seeding and at 2-3 months.

Phosphorus deficiency

Phosphorus is a basic component of nucleo proteins, nucleic acids and phospholipids, and all the exzymes involved in energy transport. P is essential for such processes as phosphorilation, photosynthesis, respiration, decomposition and synthesis of carbohydrates, proteins and fats. Through these processes it affects root growth, flowering and fruit ripening (Lotero 1974, Fassbender 1967). P is essential for the process of phosphorilation in starch synthesis; therefore, a good supply of P will increase root production and starch content. Malavolta (1952) reported a reduction in starch content from 32 to 25 percent when P was eliminated from the nutrient solution. The application of P had no effect on the HCN content of the roots (Muthuswamy 1974).

Although cassava extracts rather small amounts of P from the soil and grows on many soils low in P, Edwards (1977) found that cassava has an extremely high P requirement, producing maximum growth at a P concentration in solution 15-40 times as high as that needed for corn. At a very low P concentration cassava produced 18 percent of maximum, while corn and soybeans produced 21 percent and 34 percent respectively. Deficiency symptoms were produced at a much lower P concentration in cassava tops than in those of corn and soybeans, Thus, cassava requires high P levels for maximum growth, but is able to adjust its growth rate to conditions of low-P (Edwards 1977).

Krochmal (1968) reports that of the three mayor elements, the application of P had most effect on yield, causing a 93 percent increase in tuber production in a sand culture experiment. Krochmal (1968) observed no P deficiency symptoms and only a slight reduction of growth in a zero-P nutrient sand culture. Asher (1975) observed an upward curling and yellowing of the lower levels of P deficient plants. Eventually these leaves fall off and plant growth in seriously stunted. A yield reduction of more than 70 percent was required to produce deficiency symptoms. Figure 8 shows how dry matter production and nutrient content of the plant was affected by various levels of nutrients in solution. Without P in solution plant growth was reduced to about 10 percent of normal, but no deficiency symptoms could be observed. The critical content for P deficiency was about 0.44 percent P in the leaf blade and approximately 15 ppm of P in the soil extracted with Bray II, Olsen, or North Carolina solution.

P deficiency is most common in Oxisols and Ultisols such as those of the Campo Cerrado of Brasil, the Llanos Orientales of Colombia, the Llanos of Venezuela, and a majority of soils in tropical Africa. In Asia Ultisols are common in Malaysia, parts of India and Indonesia. P deficiency and extremely high P fixation are characteristics of many Inceptisols such as those of the Andes mountains (Andosoles), and parts of the Llanos of Colombia, along the Amazone in Brasil, in Hawaii, Cambodia, India and Indonesia.

In Costa Rica, Acosta (1954) did not observe a P response, except in the presence of N. In volcanic ash soils of Colombia Rodriguez (1975) obtained maximum yield at 194 kg P_2O_5/ha. ICA (1971) reports a positive response to 300 kg P_2O_5/ha in 13 out of 14 trials in farmers fields, located principally in acid P-deficient soils of Cauca and Meta in Colombia. They did not find much correlation between the response and the P content of the soil. In Oxisols of the Llanos of Colombia, CIAT (1976) obtained a highly significant response up to 200 kg P_2O_5/ha, and an additional response to 400 kg P_2O_5/ha with the use of the basic slag and simple super phosphate (SSP). The lack of P was the main limiting factor for cassava in these soils. Figure 9 shows that cassava foliage production increased almost linerarly with P application, while root production increased quadratically. Thus, at low P and intermediate P rates the plant had the highest harvest index and was most efficient in root production, while at high rates the plant responded more in foliage than root product. Under Colombian conditions the application of 200 kg/ha was the most economic for most P sources, except basic slag which was more economical at 400 kg P_2O_5 (CIAT 1976).

In Brasil, Normanha (1951) (1960) found that P was the main limiting factor for cassava in Sao Paulo and Goias. He recommended the application of 60-120 kg P_2O_5/ha as bone meal or SSP. On poor sandy soils in the same state, Silva (1968) obtained no P but a significant K response. In Rio de Janeiro, Nunes (1974) reports an 86 percent yield increase with the application of 40 kg P_2O_5/ha, P being the main limiting factor. Most economical was 67 kg P_2O_5/ha. In the Amazone estuary, Albuquerque (1968) obtained maximum yields with 100 kg P_2O_5/ha as SSP.

In Western Nigeria, Amon (1973) did not recommend the use of P while in Ghana, Stephens (1960) and Takyi (1972) obtained highest yields with 24 and 45 kg P_2O_5/ha. Though cassava responded mainly to K in Madagascar, the use 130 kg P_2O_5/ha (De Geus 1967) (Le Manioc 1952) was recommended.

Vijayan (1969) and Trivandrum (1971) in Kerala State of India obtained best yields with 100 kg P_2O_5 in combination with 100 N and 100 K_2O/ha, basic slag being the most economical P source. In the same state, Chadha (1958) reported up to 25 percent yield increase with 80 kg P_2O_5/ha. In Thailand Hongsapan (1962) obtained best yields with 32-48 kg P_2O_5/ha. For Malaysian peat soils, Chew (1970) recommends 50 kg P_2O_5/ha, although Kanapathy (1974) did not observe a P response in these soils.

The most commonly used P sources are single and triple superphosphate. Basic slag is as effective as TSP, especially on acid soils, and where available, this is generally a more economical source (CIAT 1976) (Trivandrum 1971). Figure 10 shows the response of cassava to various P-sources in the Llanos of Colombia. It is clear that TSP was superior to SSP (when hand applied), and that incorporated basic slag and rock phosphate were also highly effective sources. Mixing the rock with elemental sulphur or H_2SO_4 improved considerably its availability. Rock phosphates from different parts of the world vary greatly in P-availability and cassava responds to their application according to their citrate-solubility. Rocks from N. Carolina, Morocco and Peru were among the best sources (CIAT 1976). Figure 10 also indicates the effect of method of application of basic slag; broadcasting was highly superior to band application. For TSP no significant differences were observed between band or broadcast application, although in highly P-fixing soils band application is expected to be superior. Ofori (1970) suggests that broadcasting P on the soil surface once the plant is established, maybe most effective as the actively absorbing roots are present in the top 10 cm of soil; once the roots start functioning as carbohydrate sinks they no longer play and active role in nutrient absorption. Campos (1974) and Sena (1973) report the presence of cassava roots to a depth of 140 cm, but calculated that 86 percent of the roots were present in the top 10 cm of soil. Thus incorporation of fertilizers does not seem to be beneficial.

Potassium deficiency

Potassium is not a basic component of proteins, carbohydrates or fats, but is definitely involved in their metabolism; K is essential for carbohydrate translocation from the tops to the roots (Malavolta 1954). Thus K deficiency will lead to excessive top and little root production. Blin (1905) and Obigbesan (1973) reports that K increases the starch and decreases the HCN content of roots, which is opposite to the effect of N. Muthuswamy (1974) found no effect of P and K on the HCN content of roots, while Payne (1956) reports a higher HCN content of roots in K deficient than K sufficient soils. As mentioned above, cassava extracts more K than any other element from the soil, and an average crop will remove about 100 kg K_2O/ha from the soil.

Potassium deficiency is characterized by reduced plant growth and in very severe cases purple mottling of older leaves, curling up of leaf margins and chlorosis and necrosis of leaf tip and margins (Asher 1975, Krochmal 1968). Older leaves and petioles senescence prematurely and fall off. K-deficiency also results in shorter internodes and reduced plant height. Dias (1966) also reports excessive ramification of K deficient plants. Ngongi (1976) observed that K application increased leaf size, leaf lobe number, leaf retention and plant height. The critical K content of leaves is about 1.2 percent in the leaf blade and 2.5 percent in the petioles.

Potassium deficiency in cassava is common in many soils where other crops do not respond to K. Severely K deficient soils are those of the Llanos Orientales of Colombia. Most of the Adolsols in S. America are reasonably well supplied with K. K deficiency can also be expected on sandy soils.

In Puerto Rico Samuels (1970) obtained, a response to 100 kg K_2O/ha, while Murillo (1962) did not find a K response in lateritic soil of Costa Rica. In Colombia a K response was reported in 11 out of 14 trials (ICA 1971). Ngongi (1976) obtained a significant response to 240 kg K_2O/ha in the Llanos Orientales and to 120 kg K_2O/ha in the Cauca Valley (Figure 11). In the Llanos, K_2SO_4 was superior to KCl since high applications of KCl induced a S deficiency. This could be overcome by applying K_2SO_4 or mixing elemental S with the KCl. High K applications also reduced the Mg content of leaves and petioles, possibly inducing a Mg deficiency. Ngongi (1976) also observed a strong N x K interaction, in which a N response was obtained only in the presence of K. On the same soils CIAT (1976) reports maximum yields with 160 kg K_2O/ha.

In Brasil, Nunes (1974) did not find a significant K responce in Rio de Janeiro, while in Sao Paulo and Goias Normanha (1960) (1961) recommends the application of 30-100 kg K_2O/ha. Silva (1968) obtained a significant K response on poor sandy soils of Sao Paulo. Dias (1966) states that K deficiency is not common in Sao Paulo. In the Amazone estuary Albuquerque (1968) obtained maximum yields with 180 kg K_2O/ha.

In eastern Nigeria, Irving (1947) obtained a K response on light acid soils, while in western Nigeria, Amon (1973) recommends the use 60 kg K_2O/ha. In Ghana Lakyi (1972) found no K response in a forest ochrosol.

In Madagascar K deficiency was the main limiting factor (Roche 1957) and applications of 110 kg K_2O/ha were recommended (DeGeus 1967, Le Manioc 1952, Essais de Fumure 1953). K application significantly increased the K content of the phelloderm (Cours 1961), and decreased the N and P contents. K contents of leaves may increase with increasing K applications without increasing yield (Ngongi 1976).

In India Kumar (1971) and Trivandrum (1969) obtained a significant response to 100 kg K_2O/ha., while Chadha (1958) report increases in yield of up to 75 percent with 160 kg K_2O/ha. He found a strong N x K interaction and recommended the application of N and K_2O in the ratio of 1:1.75. On Malaysian peat soils continuous cassava could be grown with 90 kg K_2O and 120 kg N/ha applications (Kanapathy 1974). Chew (1971) recommended 110-160 kg K_2O/ha for these soils. In Indonesia, both Nyholt (1935) and Den Doop (1937) consider K the main limiting factor. Den Doop (1937) obtained a positive response to 150 kg K_2O/ha in the first planting, and a strong residual effect to application of 300 kg K_2O/ha in the second and third planting (Figure 12). He reports that K application increases the P requirement, and that K availability is reduced during droughts. Kumar (1977) reports best results with the application of half of the K at planting and half at one month. Normanha (1952) and Silva (1968) report that application of KCl in contact with the stake is especially detrimental for germination, and recommended lateral placement of both K and P, and top dressing at three months of N. CIAT (1976) reports no significant difference between methods of application of NPK (10-20-20), including broadcast, band, circle and spot application under the stake.

Calcium and Magnesium deficiency

Calcium plays a major role in the water regulation of the plant, while magnesium is a component of chlorophyl and therefore involved in photosynthesis.

Ca deficiency presents itself mainly as a reduction in root growth without clear leaf symptoms. Forno (1976) found that lack of Ca during mist propagation of cassava resulted in root rot. This could be overcome by the addition of 150 uM Ca to the misting solution (Forno 1976).

Mg deficiency is characterized by intervenal chlorosis of lower leaves starting at the leaf tip and margins, while the veines remain dark green (Asher 1975, Lozano 1976). Mg deficient bottom leaves had Mg levels of 0.05 ppm and normal leaves had 0.26 ppm while the petioles had 0.04 ppm and 0.28 ppm, respectively. In general the petioles are more sensitive to Ca and Mg deficiency than the leaf blades.

Ca and Mg deficiencies are most common on acid infertile Oxisols and Ultisols, while Mg deficiency in cassava has also been observed in low Mg, high K volcanic ash soils of Popayán, Colombia.

Ca deficiency is generally controlled by the application of lime although the more soluble source, gypsum or $CaSO_4$ can also be used, especially if the soil is also low in sulphur. Mg deficiency can be controlled by application of dolomitic lime ($CaCO_3$+ $MgCO_3$), MgO or $MgSO_4$. In the Llanos of Colombia Ngongi (1976) obtained a significant response to the application of 50 kg Mg/ha as $MgSO_4$ or MgO, the $MgSO_4$ being much superior to the MgO, probably due to its S content and greater solubility (Figure 13). Application above 50 kg Mg/ha resulted in a yield decrease probably due to induction of Ca deficiency.

Aluminum and Manganese toxicity and the effect of pH

Many soils in the tropics are unproductive because of extreme soil acidity, which in case of mineral soils generally is accompanied by toxicity of Al and/or Mn. These soils can be made productive by liming, which increases the pH and Ca content and decreases the exchangeable Al and Mn (Figure 14). However, in many areas the cost of lime, including its transport, is prohibitively high, and only relatively small quantities can be applied economically. For these areas the selection of crops that tolerate soil acidity and high levels of Al and Mn is very important. And within the tolerant crop varieties could be selected that are especially tolerant to these adverse conditions. Edwards (1977) showed that among 3 crops tested, cassava was best able to tolerate a low pH of the nutrient solution. In addition, cassava was least affected by high levels of Al and Mn. Figure 15 shows that in field screenings of cultivars of six food crops, cassava and cowpeas produced 54 and 60 percent of their maximum yields without lime, while rice, corn, and beans produced essentially no yield under these conditions. Thus, although all these crops responded positively to liming, cassava and cowpea were most tolerant to acid soils. Large scale screenings are presently under way in the field and in nutrient solutions to identify the most tolerant cassava cultivars.

Aluminum toxicity is characterized by a general lack of vigor and very poor root growth. Lower leaves are ofter yellow and necrotic alghough this can also be due to Mg deficiency which often accompanies Al toxicity in the field. Figure 16 shows that liming the soil may actually decrease yields of cassava due to the induction of Zn deficiency. Only in the presence of sufficient Zn did cassava, like most crops, show a positive response to liming up to 6 ton/ha. Figure 17 shows that the Zn content of the leaves decreased drastically by liming, reaching levels below the critical Zn content of 60 ppm with the application of 6 ton lime/ha. When Zn was applied, the critical level was not reached and plants did not suffer from Zn deficiency even at the high liming rate. Thus, in very infertile soils, liming should be done with caution so as not to induce minor element deficiencies such as those of Zn, Cu, Mn, and B.

In Puerto Rico Samuels (1970) obtained a positive response to the application of 2 tons of lime/ha to a soil of pH 4.5. In Cruz das Almas (Brasil) no lime response was obtained in 3 years of testing (Conceicao 1973). However, Silva (1968) and Normanha (1961) recommend the application and deep incorporation of lime in soils of Sao Paulo. Rodriguez (1976) recommends to apply 1.5 ton lime/ha for each me Al/100 gm., although data from CIAT (1975) indicate that cassava can tolerate reasonably well levels of 2-3 me Al/100 gm. Normanha (1951) recommends the use of 2 ton dolomitic lime if the soil pH is below 5. Also in India Trivandrum (1971) recommended the application of 2 ton lime/ha and found that it increased the P availability.

On peat soils in Malaysia, Manapathy (1970) and Lim (1973) observed that cassava survived without liming in a soil of pH 3.2, while corn and peanuts died. Since the Al content of these soils is very low, this is mainly a direct pH effect. For optimum yields, however, they recommend the use of lime, and suggest that its beneficial effect is mainly that of increasing pH rather than the supplying of Ca.

Although cassava is quite tolerant to acid soils, it does not tolerate an extremely high pH, and is quite sensitive to soil salinity and alkalinity. Figure 18 shows that cassava yields were drastically reduced when the pH was above 7.8, the percentage of Na saturation was above 2.5 percent, or the electrical conductivity was above 0.5-0.7 mmhos/cm. In comparison, bean yields were much less affected by these conditions. Cassava cultivars varied greatly in their tolerance and certain cultivars could be selected for high pH soils. Although the application of 2 ton S/ha was effective in increasing yields under the high pH conditions of the CIAT farm (CIAT 1976), this practice is generally too costly to be recommended. Changing to a different crop or a different cultivar with better salt tolerance is a more practical solution.

Sulphur deficiency

Sulphur is a basic component of various amino acids and is thus involved in protein synthesis. In the absence of sufficient S, plants accumulate excesive amounts of inorganic N, amino acids and amides in the leaves, without the formation of protein (Stewart 1969). Krochmal (1968) and Asher (1975) observed that S deficiency is characterized by a light green to yellow coloring of the upper leaves, similar to that of N deficiency. In the Llanos of Colombia Ngongi (1976) observed that the application of K_2SO_4 was significantly better than that of KCl, but a similar benefical effect could be obtained by mixing elemental S with the HCl. Thus, he concludes, that S was the limiting factor, and that high applications of chlorides may inhibit sulfate uptake and induce an S deficiency.

Minor element deficiencies

For diagnostic minor element deficiencies, leaf and or soil analises are recommended. Levels that can be considered normal are shown at the bottom of table 5. Critical levels of Zn deficiency are about 60 ppm in the leaf blades and 2 ppm in the soil (determined by extraction with 0.25 N H_2SO_4 + 0.05 N HCl); for B deficiency is about 15 ppm in the leaves (Forno 1976) and 0.3-0.6 ppm hot water soluble B in the soil.

Although visual deficiency symptoms of major elements are not very clear in cassava, those of minor elements are quite distinctive and can often diagnose a minor element problem. Lozano (1976) shows color photographs of these symptoms. They can be briefly described as follows (Krochmal 1968, Asher 1975, Lozano 1976):

Zn deficiency:

Intervenal white or yellow mottling of the upper leaves, production of very small, pale green leaves at the growing point. In severe cases completely white to yellow leaves.

Cu deficiency:

Intervenal white mottling, similar to that of Zn deficiency. In extreme cases uniform yellowing of the upper part of the plant, deformation of the growing point, and reduction in root development.

Fe deficiency:

Intervenal chlorosis followed by uniform yellowing or complete loss of color of leaves in the upper part of the plant, without reduction in plant height.

Mn deficiency:

Intervenal chlorosis followed by uniform yellowing of the leaves, similar to Fe deficiency but only paler and with less color contrast between veins and intervenal areas.

B deficiency:

Small chlorotic spots near the tip of young leaves; small leaves and plants; death of root tip and inhibition of lateral root formation.

B toxicity:

Necrotic spots and burn at the leaf tip and along the margins of lower leaves.

Minor element deficiencies are not frequently reported for cassava, but it may be more common to limiting yields than is generally realized. On the peat soils of Malaysia cassava is stunted and the upper part of the plant completely yellow if Cu is not applied to the soil (Kanapathy 1970). Chew (1971) recommends a basal fertilization of 15 kg Cu/ha as $CuSO_4$, which eliminates the problem for several years. Both under the alkaline conditions of the CIAT farm and the extremely acid conditions of the Llanos in Colombia, Zn deficiency symptoms are commonly observed and cassava responds significantly to the application of Zn. In CIAT best results were obtained with a foliar application of 1 percent $ZnSO_4$ or a stake dip in 1 percent $ZnSO_4$ solution just before planting. In the acid soils of the Llanos, soil application of $ZnSO_4$ (10 kg Zn/ha) was the most effective, although a combination of stake dip and foliar application is probably the most economic method of application.

Figure 19 shows that of the minor elements tested in the Llanos, the greatest response was obtained from Zn, followed by Cu and Mn. Deficiency symptoms of Mn and Cu, however, were never observed. Although these soils are low in B, cassava did not respond much to B application. Compared with crops like corn and beans, cassava seems to have a low B requirement; in contrast, its Zn requirement is exceptionally high. The excessive application of one minor element can easily induce a deficiency of another. Minor elements can be extremely important for optimum production, but their application should be done with caution.

SUMMARY AND CONCLUSIONS

Although cassava grows relatively well on acid infertile soils where many crops do not grow at all, it does respond to fertilization and actually has an extremely high P requirement for maximum growth. In three tropical soils, P is generally the element most limiting yield; yields were increased three fold by adequate P fertilization in the Llanos of Colombia.

Cassava extracts large amounts of K from the soil (about 100 kg K_2O for each 25 tons of tubers) and the soil may become exhausted of K if cassava is grown continuously without adequate K fertilization. Under those conditions the crop responds to high rates of applied K.

Compared to many other crops cassava has an equal on lower requirement for N, and generally only low levels of N are recommended; excessive N fertilization leads to excessive top growth with a reduction in starch synthesis. Cassava is very tolerant of acid soils, where other crops suffer from Al on Mn toxicity. It also tolerates a low pH <u>per re</u>, although the optimum pH range is between 5.5 and 7.5. The crop oftentimes responds to low rates of liming, but is susceptible to overliming, which may induce minor element deficiencies. Of the minor elements, Zn deficiency is the most common. It can be overcome by application of $ZnSO_4$ to the soil, as a foliar spray, or a stake dip.

By screening large numbers of cassava cultivars for tolerance to adverse soil conditions, such as acidity or low P availability, it will be possible to select genetic material that is exceptionally well adapted to grow on poor soils with a minimum of fertilizer imput.

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Table 1: The amount of nutrients extracted per ton of harvested cassava roots.

Plant Part	Root Yield Ton/ha	N	P	K	Ca	Mg	Reference
				kg/ha			
Roots	40	1.83	0.37	1.82	0.36	1.08	Dulong (1971)
Roots	52.7	0.72	0.53	5.08	0.65	0.37	Nyholt (1935)
Total Plant	52.7	2.50	0.92	9.04	3.06	0.99	Nyholt (1935)
Roots	64.6	0.70	0.44	4.91	0.79	0.28	Nyholt (1935)
Total Plant	64.6	1.93	0.70	7.53	2.40	0.66	Nyholt (1935)
Roots	6	1.0	0.29	2.64			Hongsapan (1962)
Roots	42	3.64	0.40	4.40	0.60	0.14	Dufournet (1957)
Stems	42	2.38	0.26	1.55	0.40	0.55	Dufournet (1957)
Total	42	6.02	0.67	5.95	1.00	0.69	Dufournet (1957)
Roots	26	6.85	0.77	3.50	1.0	0.12	Dufournet (1957)
Stems	26	4.12	0.62	1.19	1.15	0.35	Dufournet (1957)
Total	26	10.96	1.38	4.69	2.15	0.46	Dufournet (1957)
Roots	25	2.20	0.19	1.60			Diaz (1966)
Roots	50	3.06	0.34	3.70	0.50	0.12	Cours (1953)
Stems	50	2.00	0.22	1.30	0.34	0.46	Cours (1953)
Total	50	5.06	0.56	5.00	0.84	0.58	Cours (1953)
Roots	18.6	1.14	0.50	2.35	0.41	0.53	Kanapathy (1974)
Total Plant	18.6	4.67	2.02	7.33	2.45	1.87	
Roots	2.6	1.49	0.49	2.11			Mejfa Franco (1946)
Roots	-	0.70	0.44	2.8	1.00	0.05	Bonnefoy (1933)
Total plant		20.10	2.40	9.0	9.90	2.20	Bonnefoy (1933)
Roots	-	2.02	0.43	3.02			Kanapathy (1970)
Total plant		6.28	1.89	6.53			
Roots		3.00	0.50	3.5	0.60	0.10	Cours (1953)
Stems		2.00	0.30	1.5	0.60	0.40	Cours (1953)
Total		5.00	0.80	5.0	1.20	0.50	Cours (1953)
Roots		1.82	0.36	1.77	0.34	1.08	Velly (1969)
Roots	30	2.0	0.71	7.05			De Geus (1967)
Roots	40	2.12	0.66	5.74	1.32		De Geus (1967)
<u>Average</u>							
Roots		2.14	0.46	3.50	0.69	0.39	
Total Plant		6.95	1.26	6.67	2.87	0.99	

TABLE 2.- Nutrient content of leaves, stems and roots at various ages of the cassava plant (adapted from Nyholt 1935)

Month	Leaves-% of D.M					Stems-% of D.M					Roots-% of D.M				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg
2	3.28	0.29	2.21	1.13	0.33	0.80	0.27	1.96	1.07	0.30	1.03	0.19	2.13	0.48	0.16
4	3.41	0.27	2.05	1.38	0.23	0.81	0.21	1.69	1.03	0.27	0.45	0.11	1.47	0.22	0.07
6	3.06	0.24	2.11	1.37	0.27	0.64	0.13	1.53	0.78	0.20	0.36	0.11	1.41	0.16	0.06
8	3.20	0.24	2.16	1.43	0.28	0.49	0.12	1.52	0.69	0.15	0.28	0.09	1.18	0.13	0.05
10	2.79	0.22	2.00	1.39	0.23	0.40	0.12	1.53	0.73	0.17	0.22	0.10	1.07	0.15	0.07
12	2.47	0.23	1.61	1.48	0.29	0.44	0.12	1.30	0.70	0.15	0.13	0.09	1.14	0.16	0.06
14	2.24	0.23	1.33	1.61	0.35	0.40	0.12	1.26	0.72	0.17	0.17	0.11	1.19	0.19	0.07

TABLE 3.- Nutrient content of different leaves, petiols and stem of cassava (Cours 1961)

Plant part	N	P	K	Ca
	% of D.M.			
Top leaf	3.84	0.23	0.80	0.45
Bottom leaf	2.48	0.18	0.72	0.81
Petiol top leaf	1.68	0.17	1.04	1.13
Petiol bottom leaf	1.40	0.08	1.15	1.02
Upper part young branch	1.36	0.16	0.49	1.40
Lower part young branch	1.28	0.06	0.40	0.45
Primary branch	1.00	0.05	0.51	0.37
Pheloderm of main	1.12	0.06	1.81	0.85
Wood of main stem	0.76	0.07	0.40	trace

TABLE 4.- Nutrient content of different plant parts of cassava as reported by various investigators

Plant part	N	P	K	Ca	Mg	S	Reference
Young leaves	5.5	0.4	1.2	0.7	0.3		Cours (1953)
Old leaves	5.0	0.3	0.7	1.4	0.4		
Stake	0.95	0.39	2.47	0.42			Orioli (1967)
Leaves	2.80	0.25	1.27	2.23	0.55		Krochmal (1970)
Petioles	0.86	0.24	1.56	5.86	1.23		
Stems	0.60	0.36	1.92	0.83	0.17		
Roots	0.27	0.11	0.59	0.10	0.13		Kanapathy (1970)
Leaves	4.31-4.82	0.33-0.37	0.58-0.92				Roche (1957)
Leaves	3.54-6.17	0.22-0.37	0.78-1.05	0.27-0.93	0.24-0.44		Cours (1953)
Leaves		0.19		1.29			Barrios (1967)
Roots		0.10		0.04			Barrios
Roots		0.10		0.12			Barrios
Leaves + twigs	3.18	0.33	1.33	1.08	0.64		Kanapathy (1970)
Stems	0.61	0.49	1.13	0.52	0.36		
Roots	0.23	0.12	0.57	0.10	0.14		
Leaves	4.65	0.18	1.14	1.07	0.42	0.16	CIAT (1974)
Leaf blades	4.78	0.22	1.65	0.60	0.22		Ngongi (1976)
Petioles	1.59	0.11	2.80	1.48	0.22		" "
Roots (peeled)	0.70	0.07	0.73	0.04	0.03		" "
Leaf blades	5.0		1.74			0.37	" "
Petioles	1.6		2.35				" "
Roots (peeled)	0.47		0.80			0.06	" "
Leaf blades	4.9	0.22	1.48	0.66	0.23		" "
Petioles	1.52	0.11	1.88	1.52	0.30		" "
Roots (peeled)	0.35	0.05	0.67	0.04	0.05		" "
Leaf blades	4.5-6.5	0.2-0.5	1.0-2.0	0.75-1.5	0.25-1.0		CIAT (1974)
Leaf blades	4.9-5.6	0.25-0.27	1.5-1.8	0.6-0.7	0.22-0.23	0.34-0.37	CIAT (1975)
Petioles	1.4-1.6	0.12-0.13	2.2-3.3	1.2-1.5	0.30-0.41	0.13-0.14	" "

TABLE 5.- Minor element contents of various plant parts of cassava reported by different investigators

	ppm					
Plant part	B	Zn	Mn	Cu	Fe	Reference
Roots		10.5-63.2	4.2-10	2.1-8.4	13.2-74.2	
Roots		28.2	6.1	3.3	34.2	Muthuswami (1974)
Roots (peeled)		204	273	20	152	Albuquerque (1968)
Leaves + twigs			262		72	Kanapathy (1970)
Stems			65		45	" "
Roots			10		17	" "
Roots (whole)					274	Barrios (1967)
Roots (peeled)					592	" "
Roots (whole)					443	" "
Roots (peeled)					729	" "
Leaves					505	" "
Leaves			150		140	Pages (1955)
Leaves	15-40	40-100	50-150	6-12	100-200	CIAT (1974)
Shoots	15-150*					Forno (1977)

* Range from B-deficiency to B toxicity

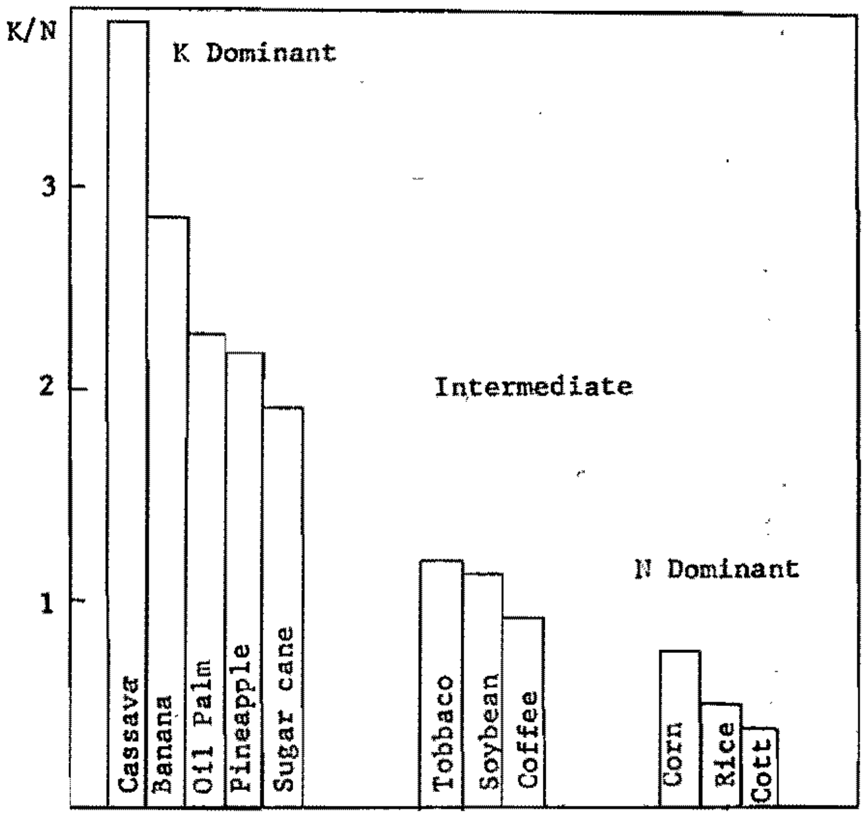

Figure 1.- The K/N extraction ratio of several tropical crops (Prevott 1958)

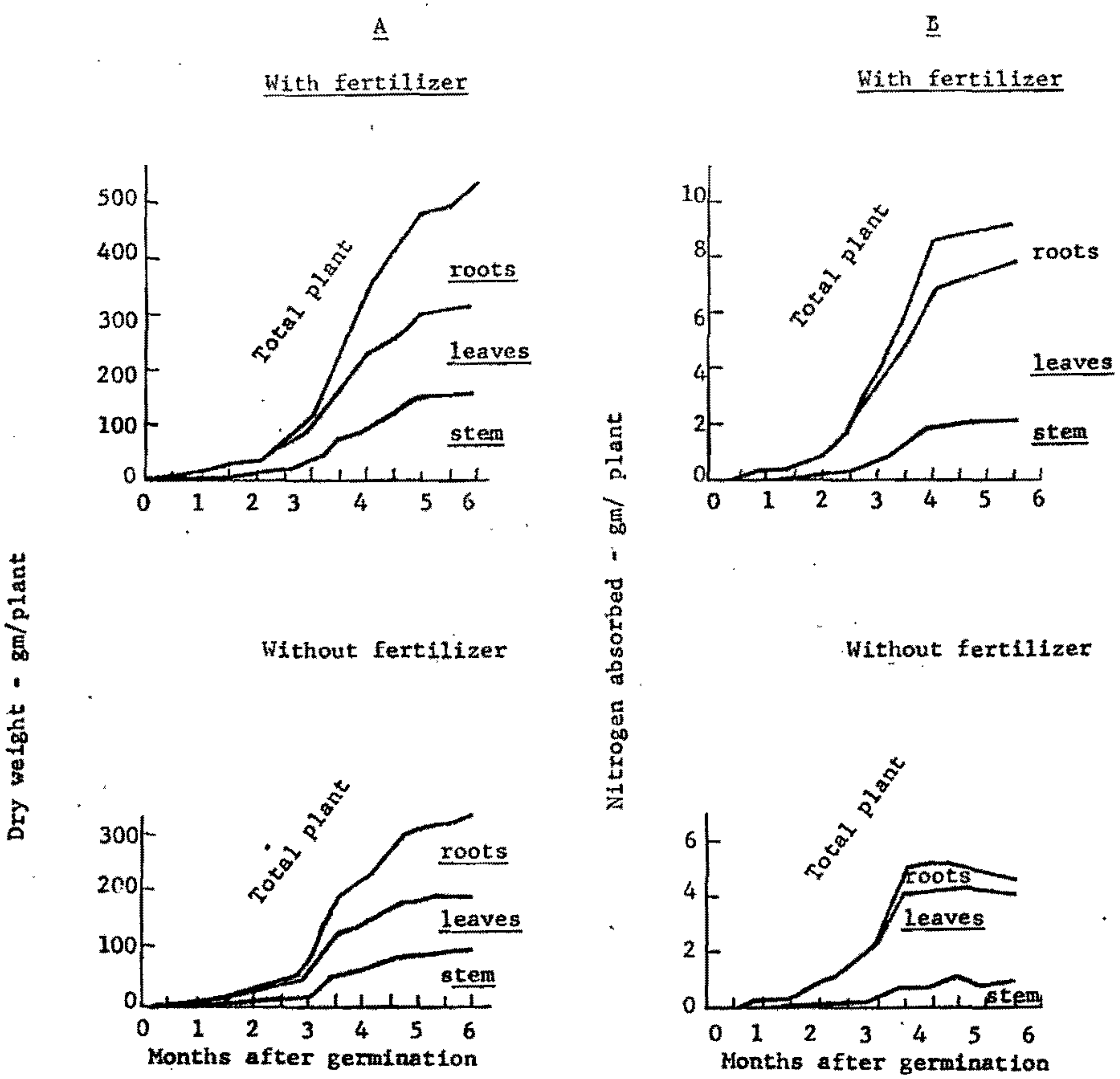

Figure 2.- The accumulation and distribution of dry matter (A) and nitrogen (B) during six months of growth of cassava in Argentina (Orioli 1967).

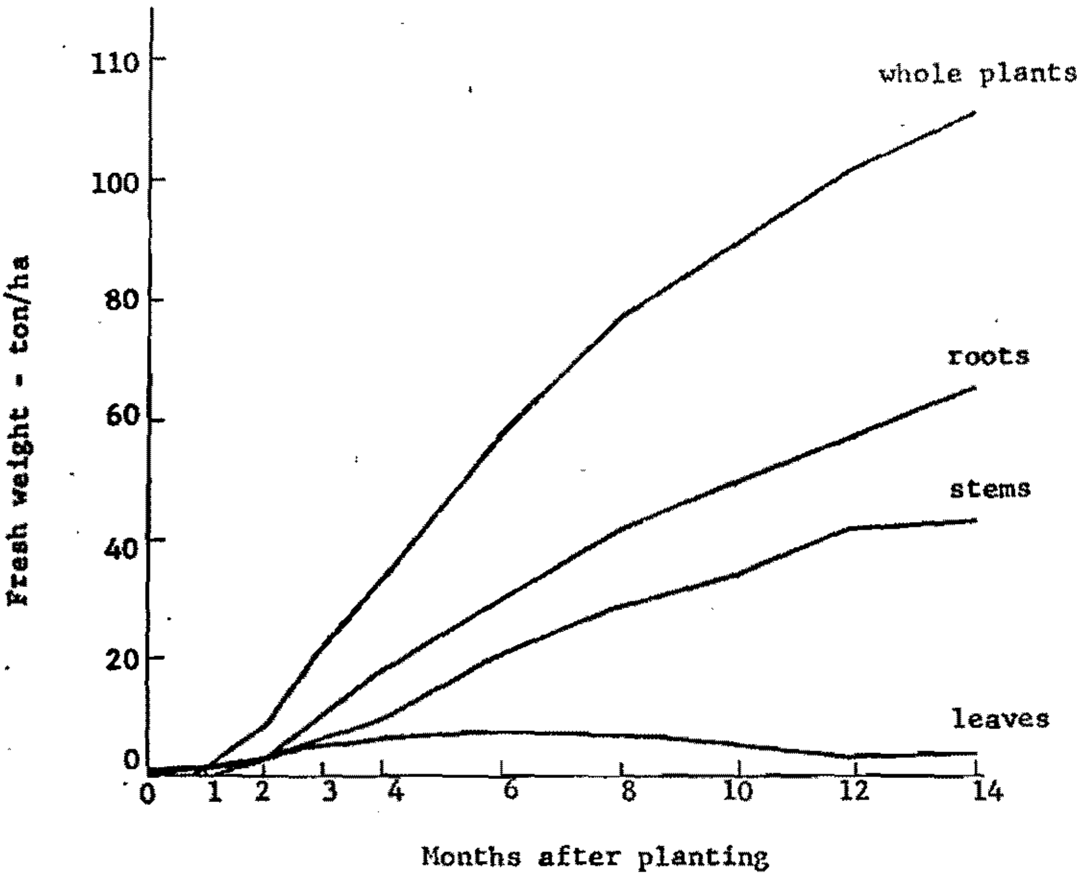

Figure 3.- The accumulation and distribution of fresh matter during a 14 months growth cycle of cassava in Indonesia (Nyholt 1935)

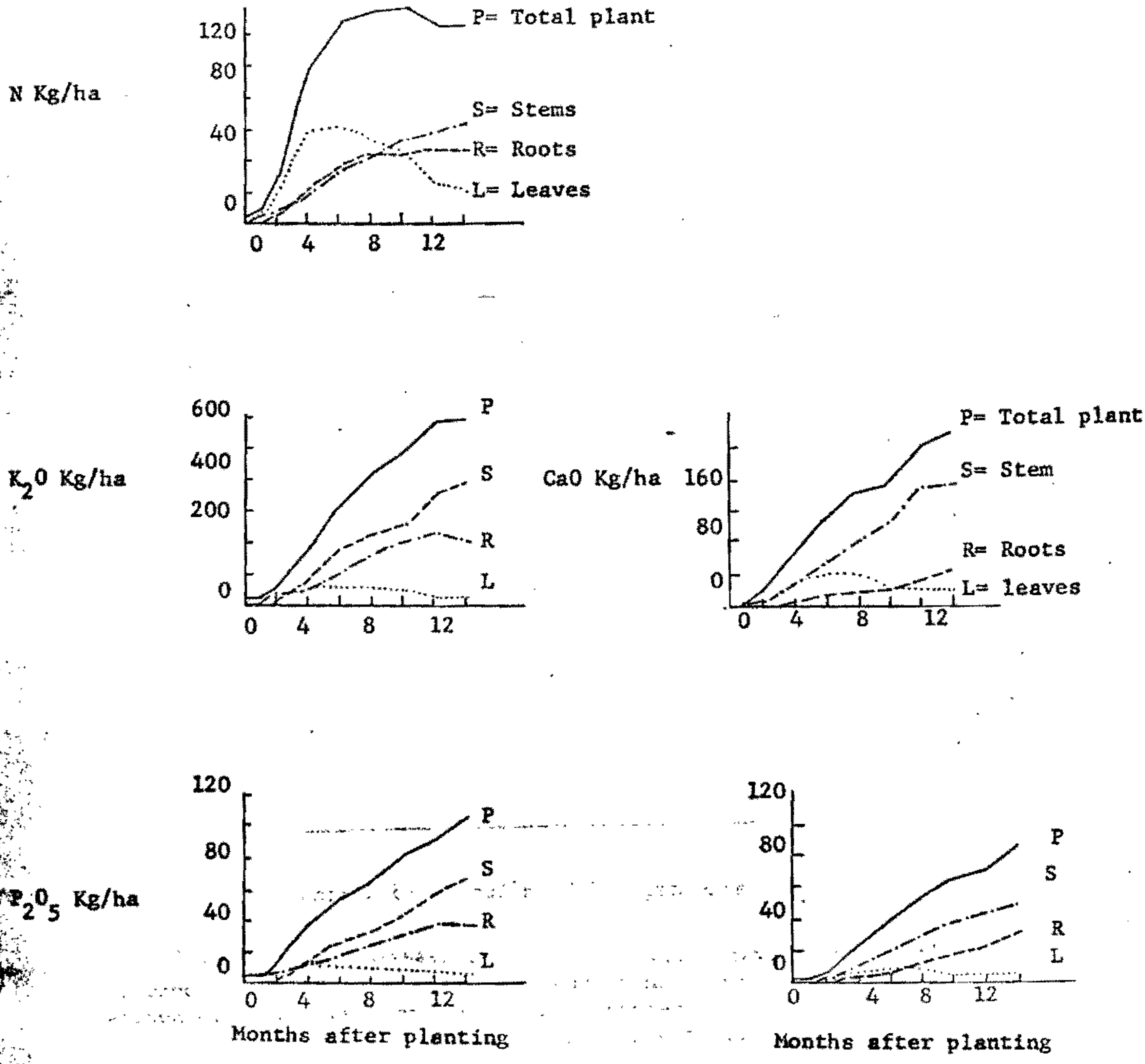

Figure 4.- The accumulation and distribution of N, P, K, Ca and Mg during a 14 months growth cycle of cassava in Indonesia (Nyholt 1935)

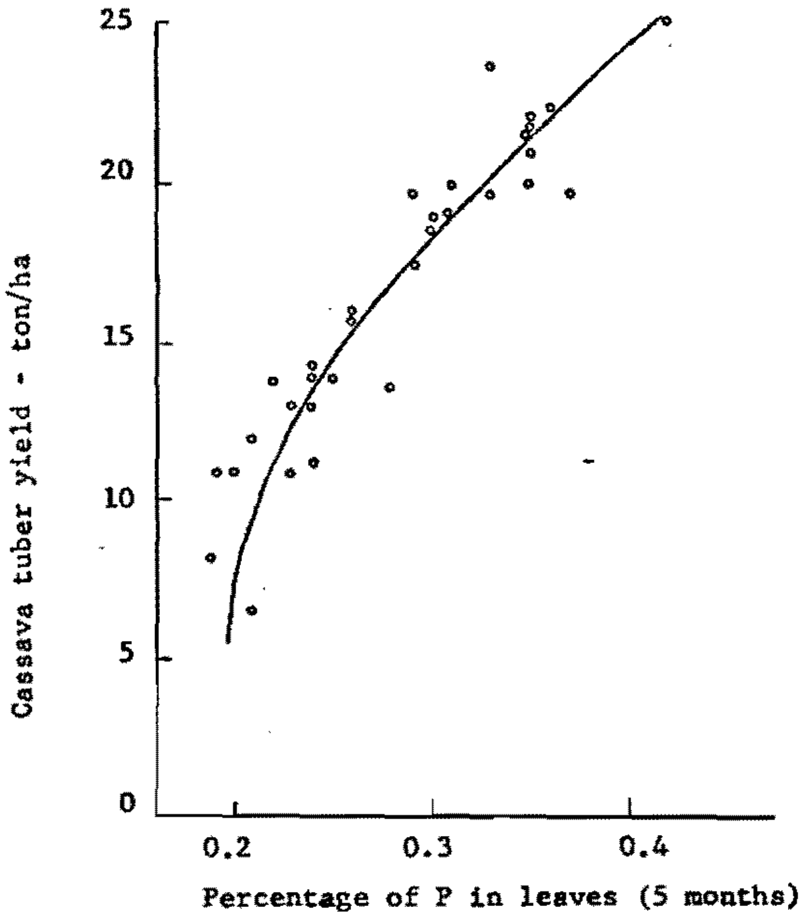

Figure 5.- Relation between cassava yield and the P content of uppermost fully expanded leaves at five months after planting.

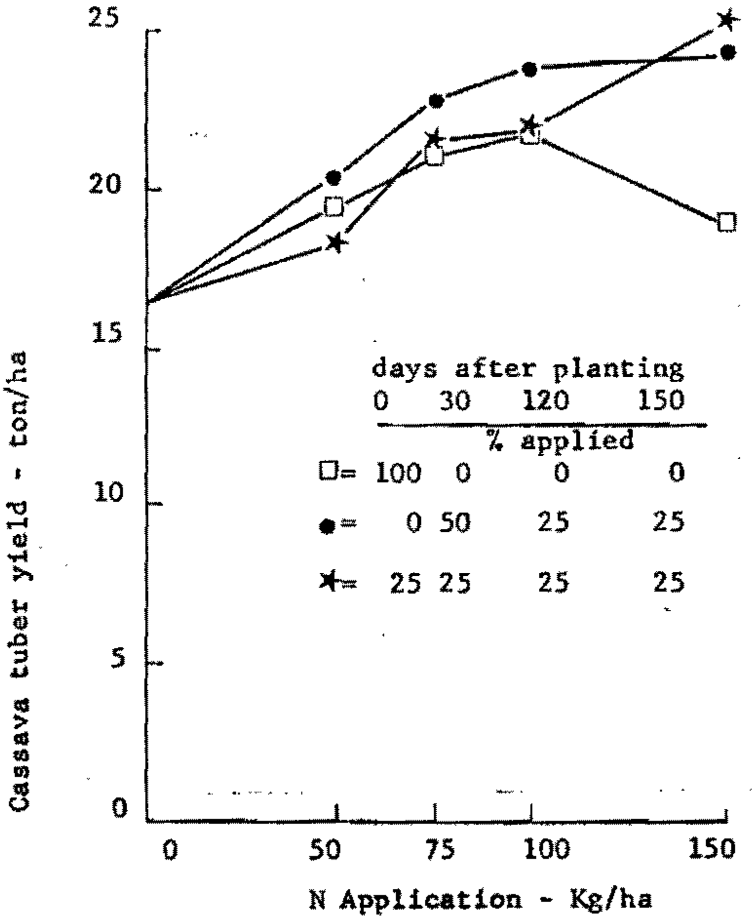

Figure 6.- Cassava response to various levels and times of application of urea-nitrogen at Carimagua.

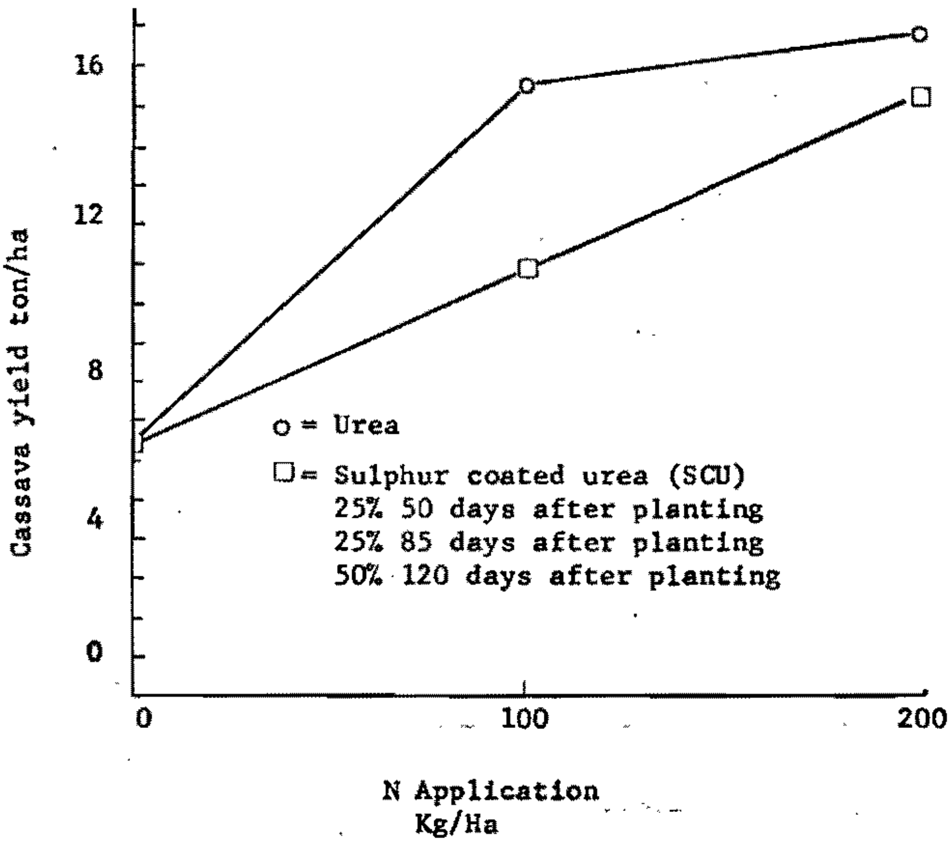

Figure 7.- The response of cassava to three levels of N, applied as urea and sulphur-coated urea at Carimagua.

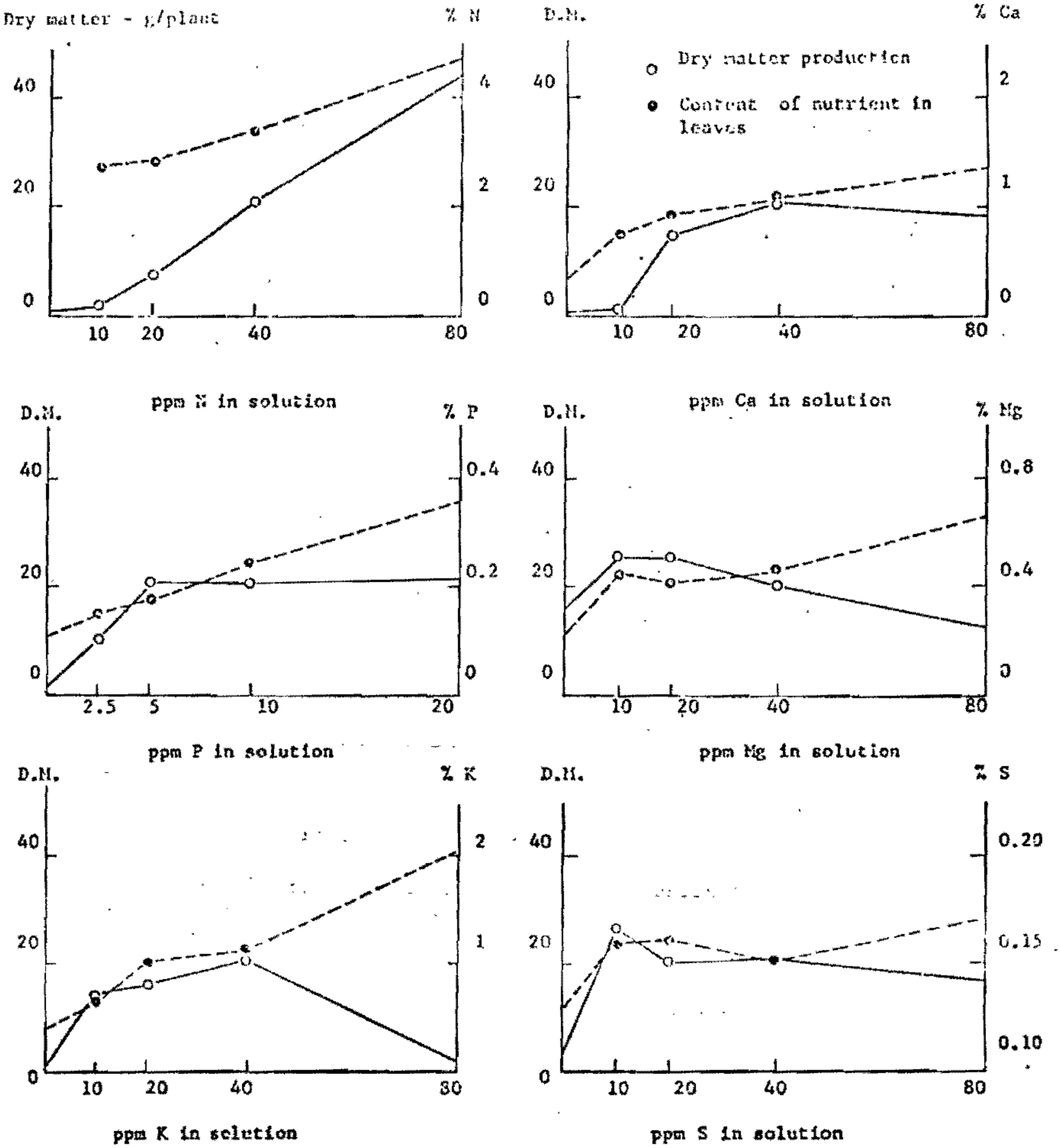

Figure 8.- Total dry matter production and nutrient content of cassava leaves at 3 1/2 months, as affected by different levels of N, P, K, Ca, Mg and S, in a nutrient-solution-sand culture.

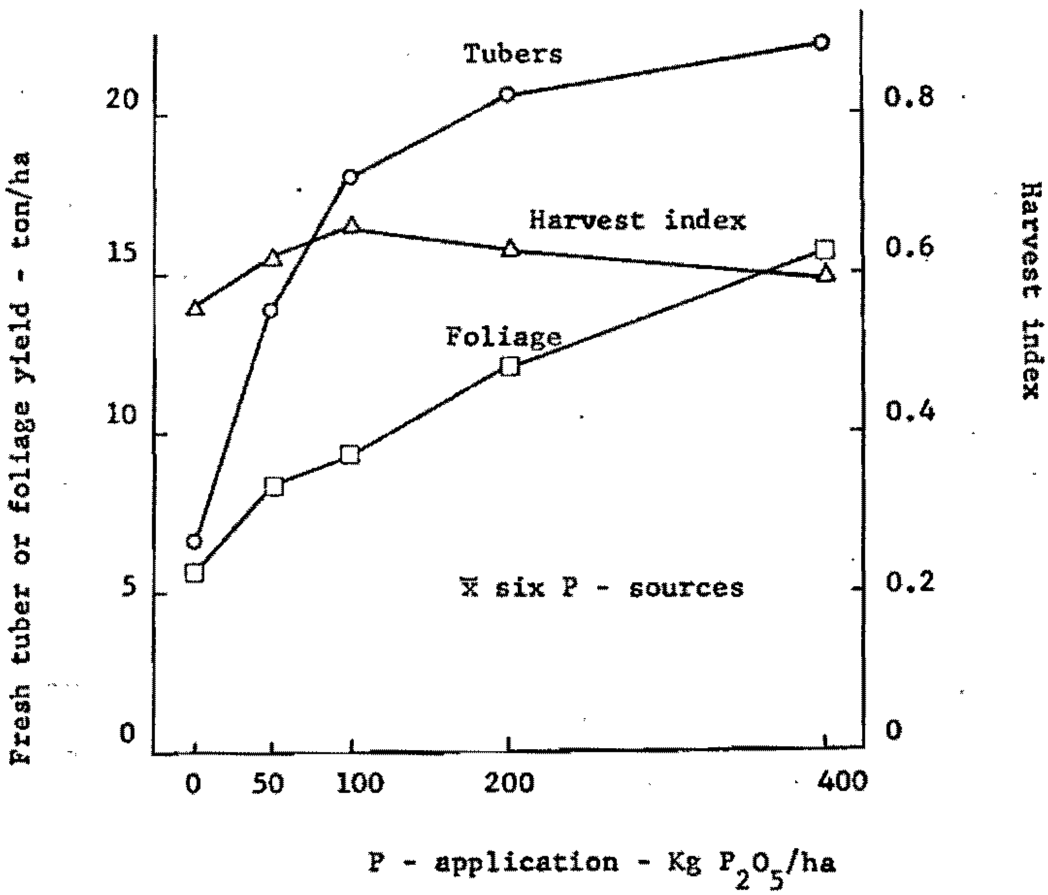

Figure 9.- The effect of P-applications (average of six sources) on the yield of fresh tubers and foliage and on the harvest index of cassava.

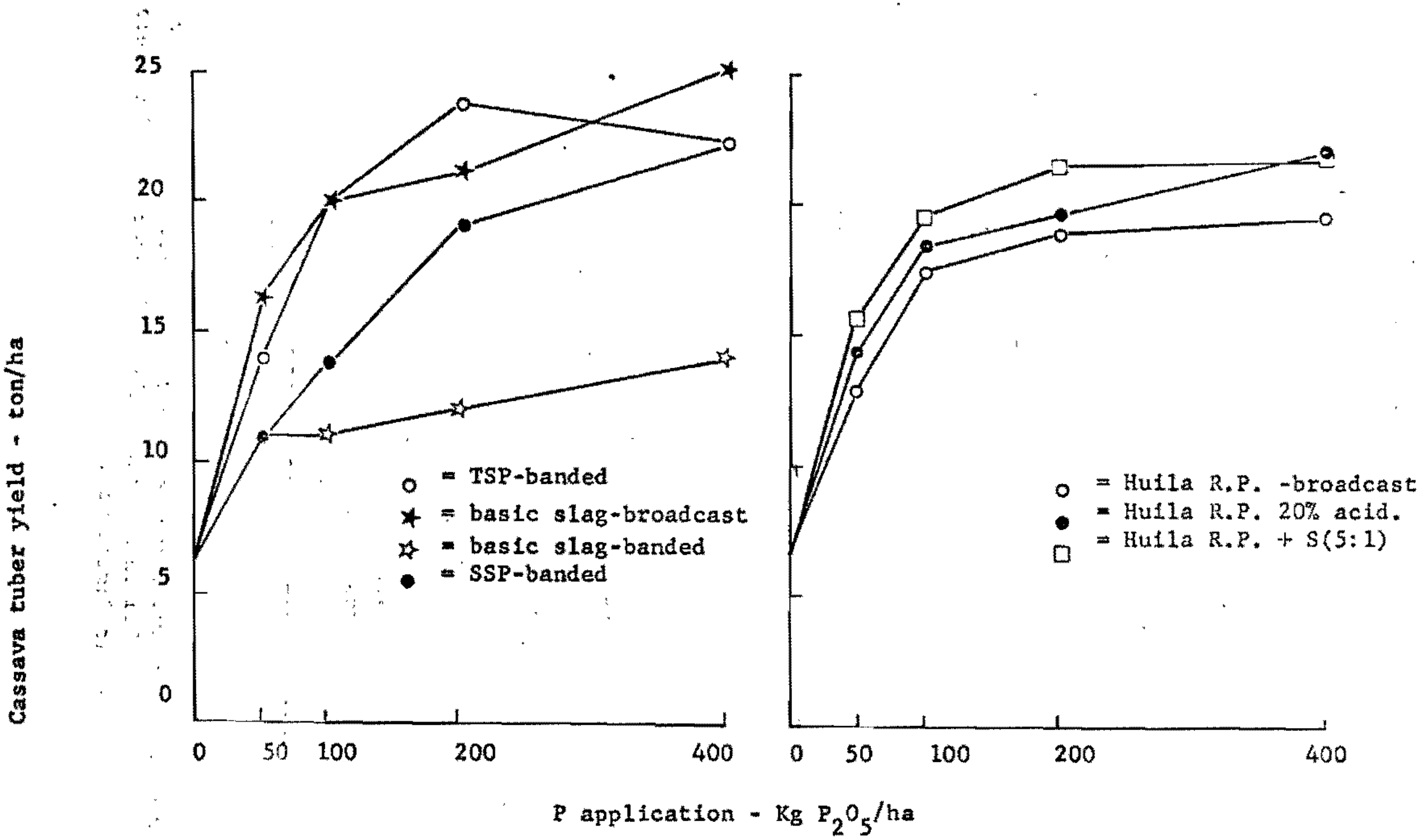

Figure 10.- Cassava response to various levels and sources of P, applied either banded or broadcast at Carimagua.

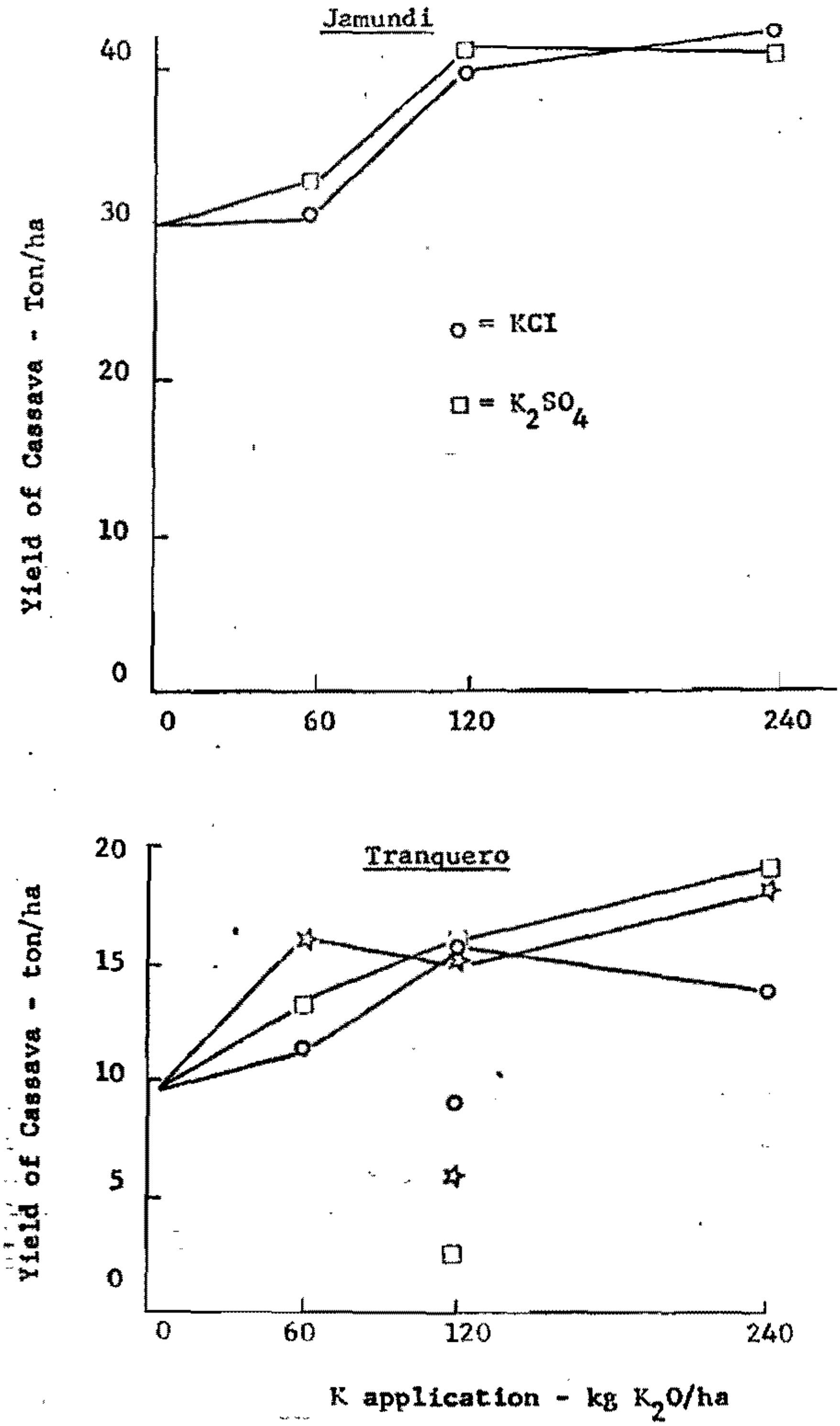

Figure 11.- Cassava response to various levels and sources of K, applied in Jamundi (Valle del Cauca) and Tranquero (near Carimagua).

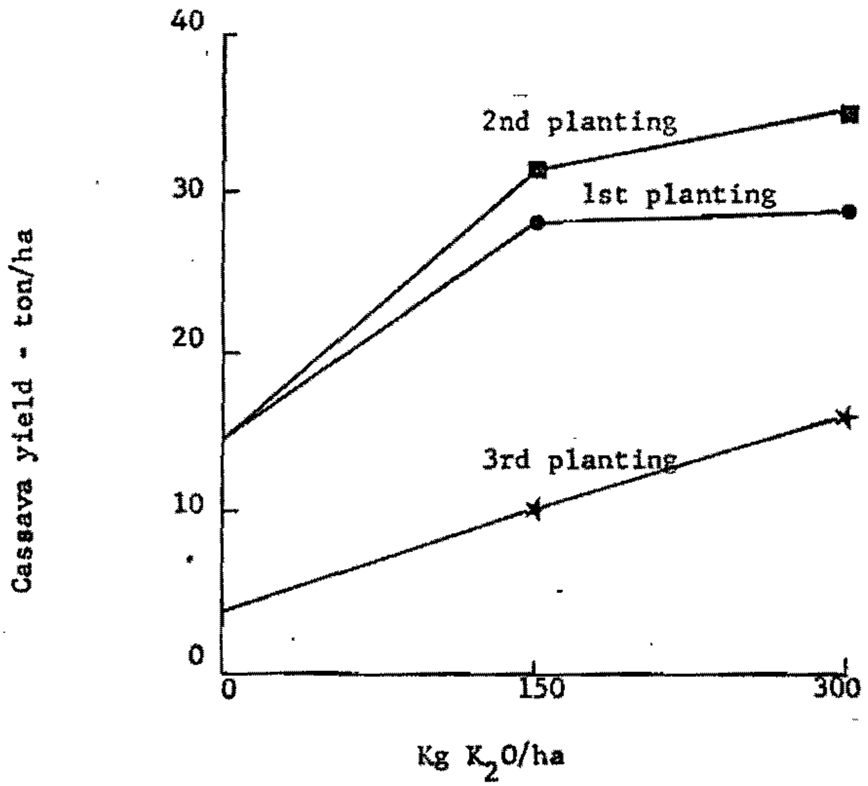

Figure 12.- The response of three cassava plantings to various levels of K, applied before the first planting (Den Doop 1937).

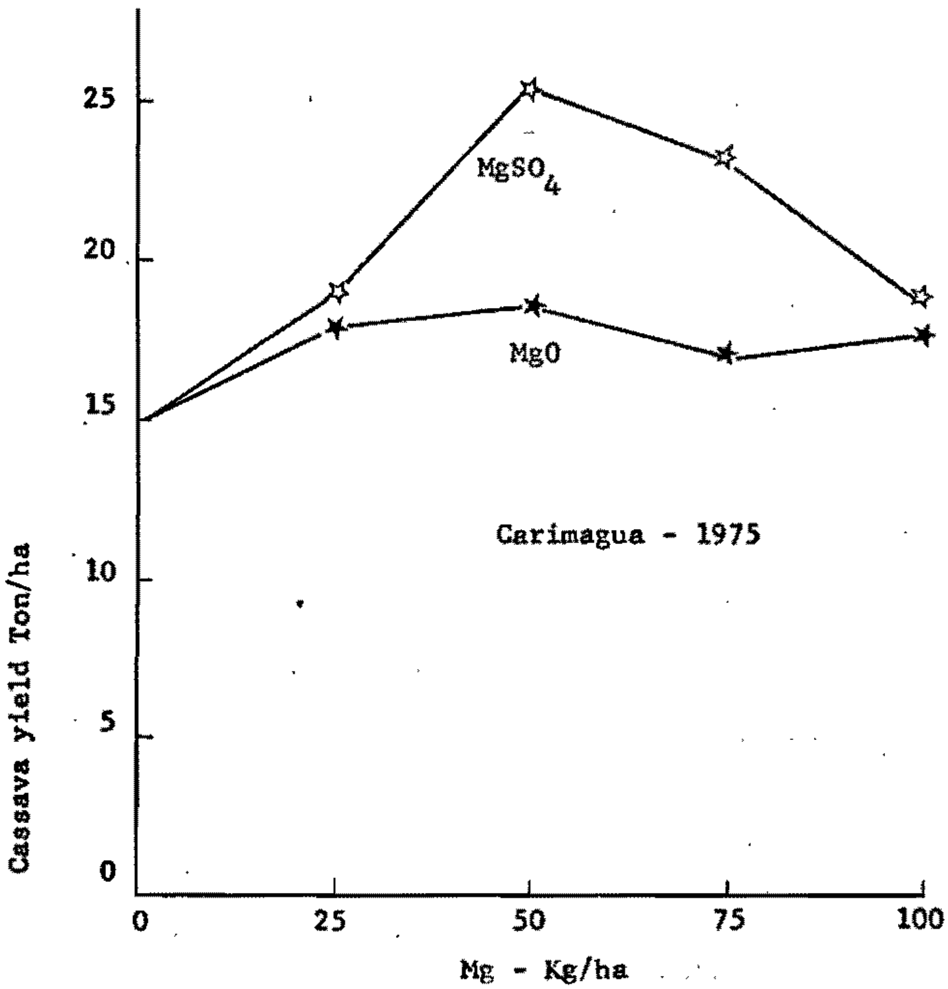

Figure 13.- Cassava response to various levels of Mg applied as MgO_4 and mgO at Tranquero (near Carimagua).

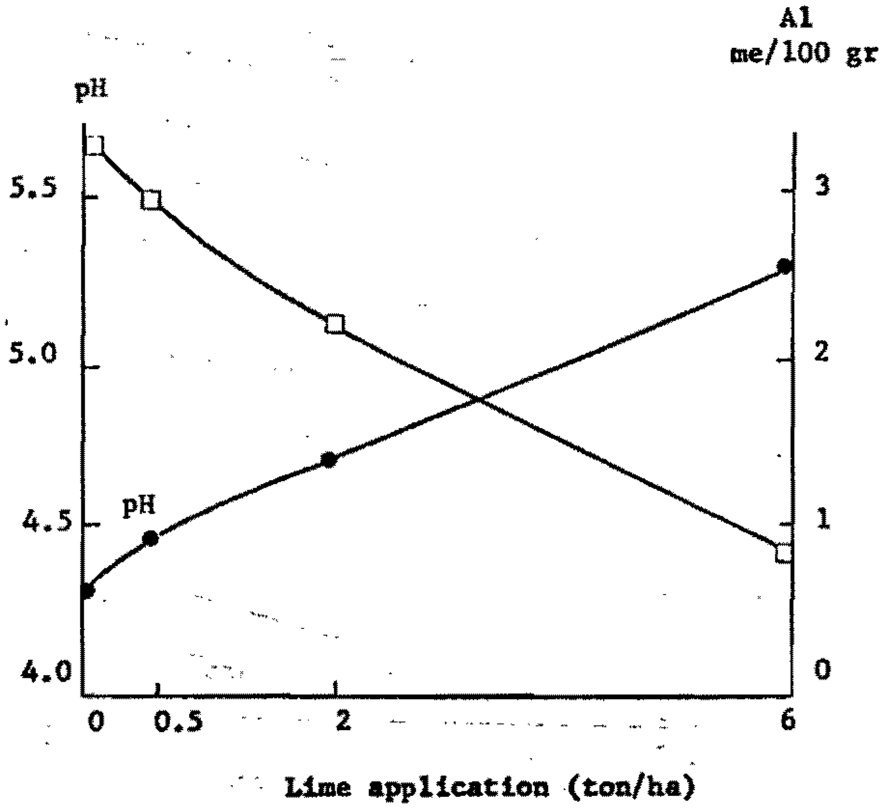

Figure 14.- The effect of liming on soil pH and exchangeable aluminum at Carimagua.

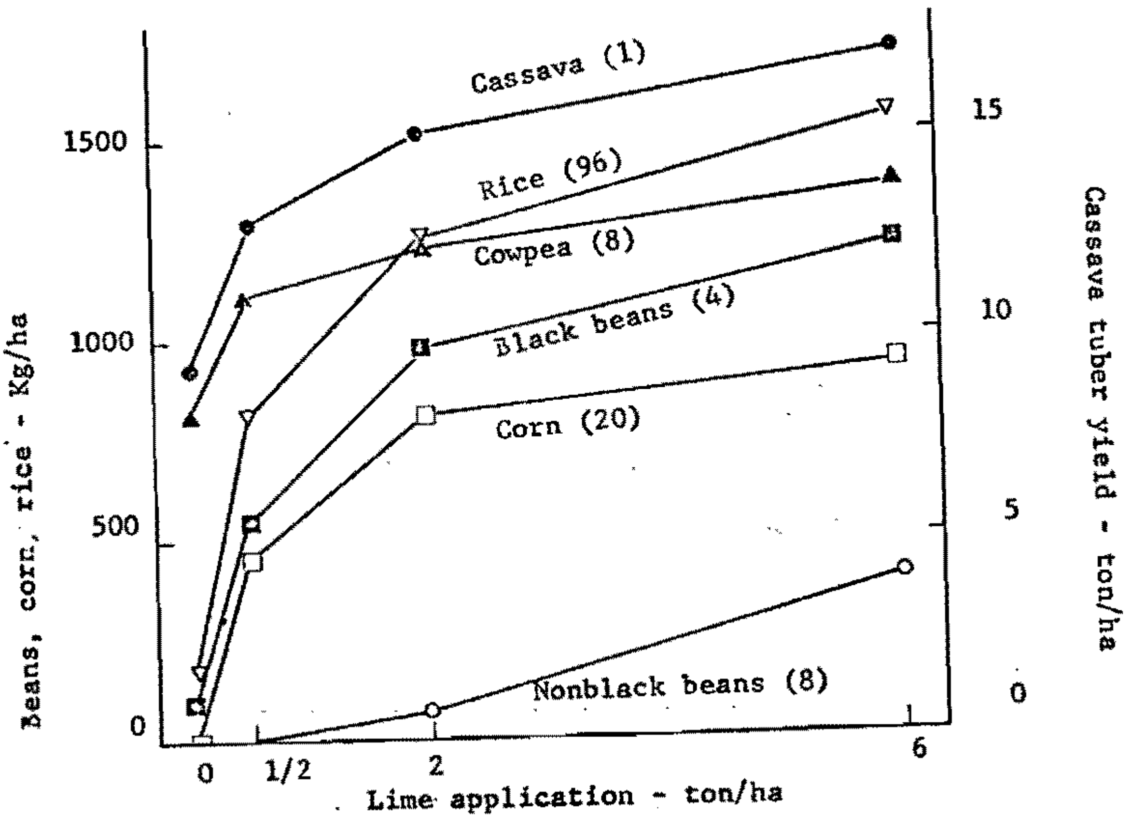

Figure 15.- The response of six food crops to the application of lime at Carimagua. Numbers in parenthesis indicate the number of cultivars tested.

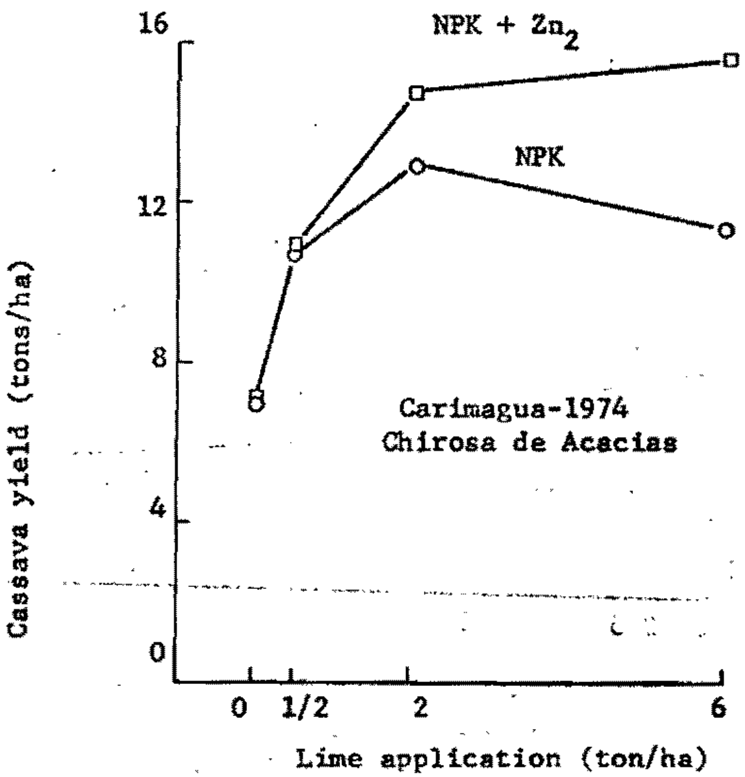

Figure 16.- Cassava response to liming, with and without the application of 20 Kg Zn/ha at Carimagua.

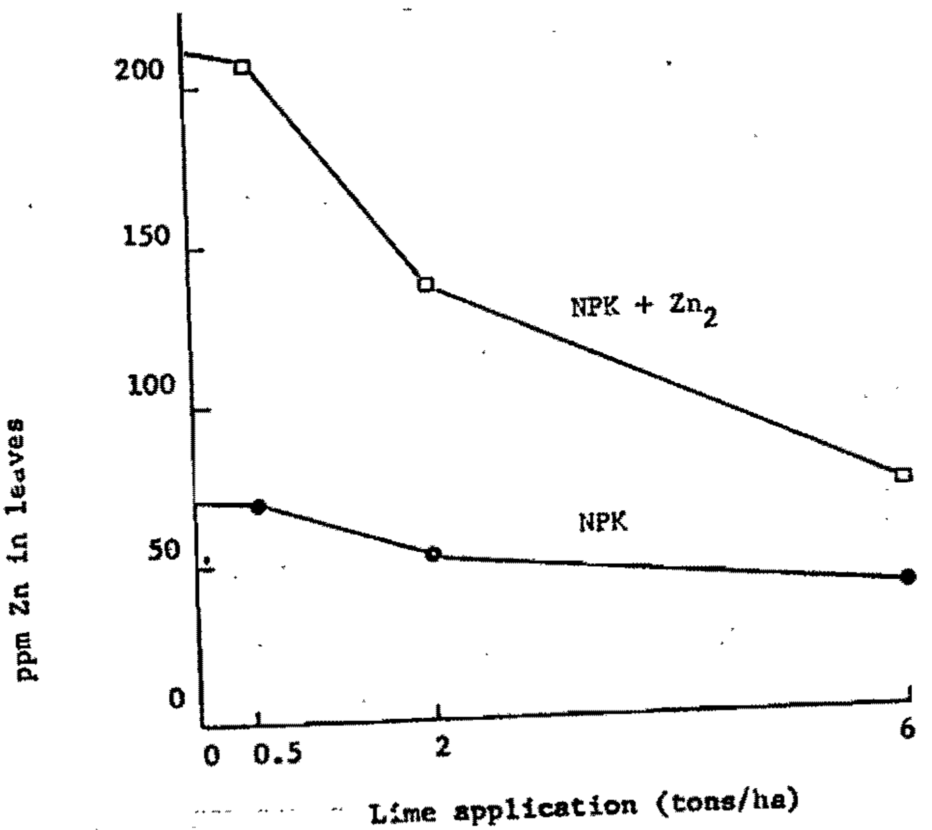

Figure 17.- The effect of liming on the Zn content of upper leaves of cassava in the absence and presence of soil applied Zn.

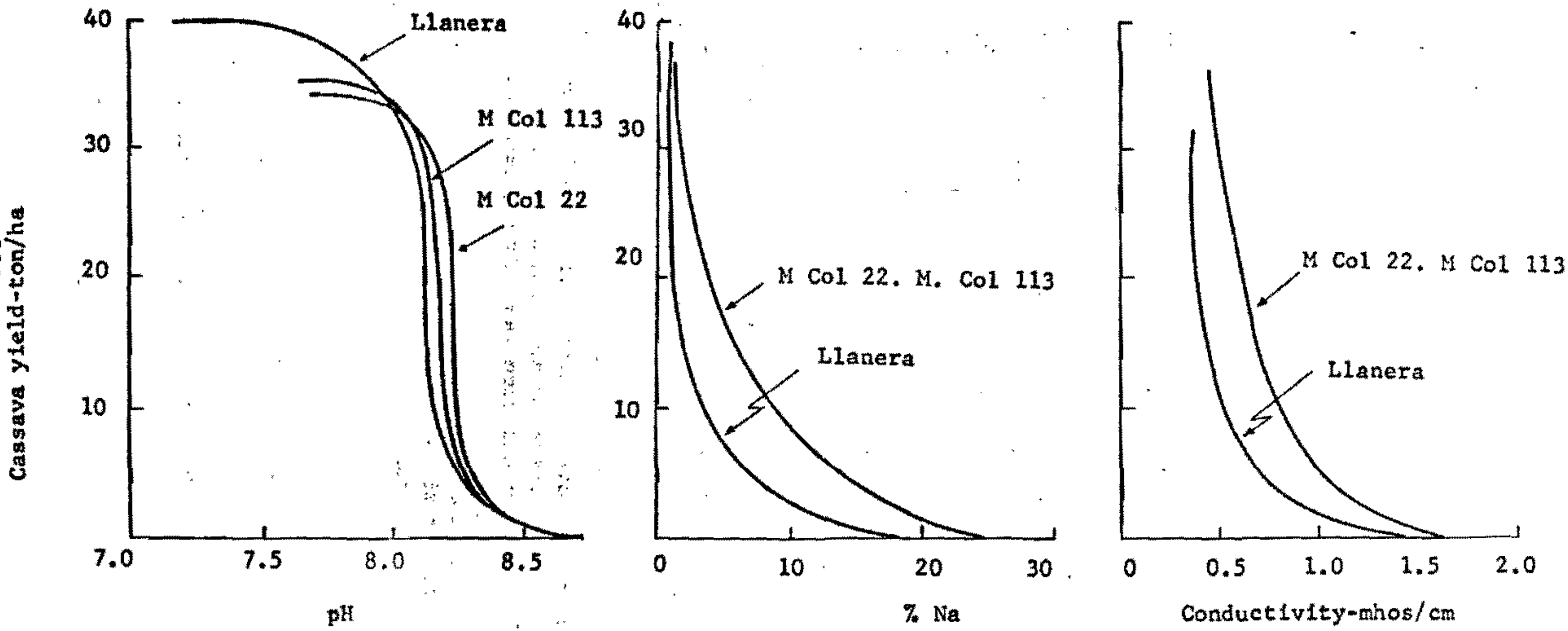

Figure 18.- The effect of soil pH, per cent sodim saturation and electrical conductivity on the yield of three cassava cultivars at CIAT, Palmira.

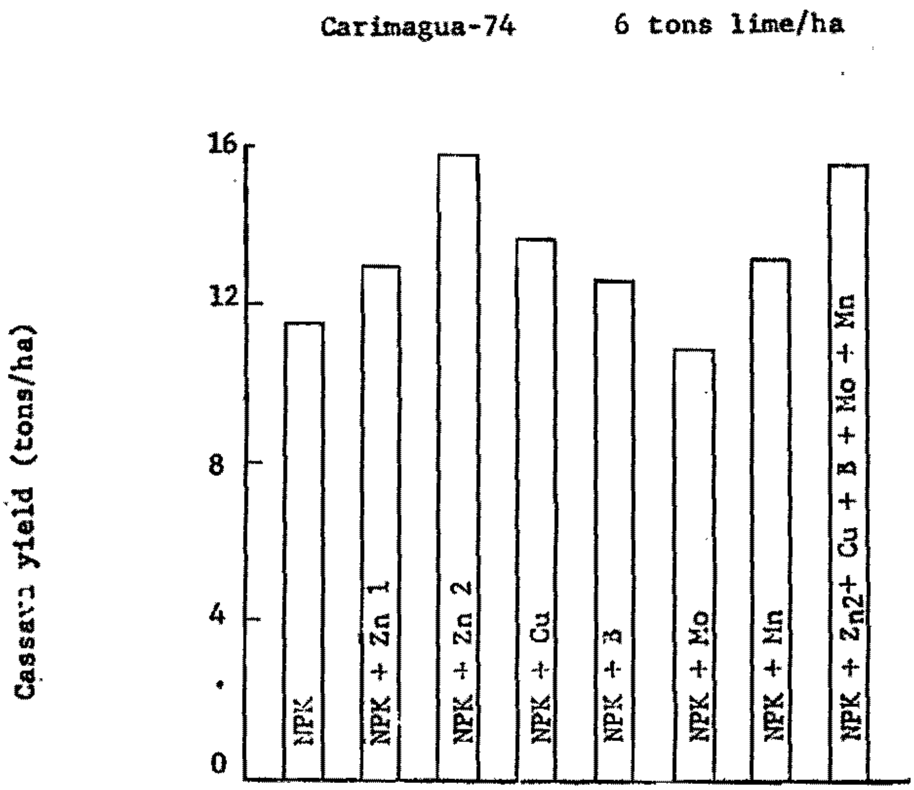

Figure 19.- Cassava response to the application of several minor elements in soil which had received 6 ton lime/ha at Carimagua

MULTIPLE CROPPING INVOLVING CASSAVA AS THE MAIN CROP [1]

M Thung and J.H. Cock *

I- Introduction

Multiple cropping or growing of more than one crop on the same land at the same time, is commonly practiced by the farmers in the tropics and subtropics. This technique, which is labor intensive and often uses low input to maximize land productivity per unit area per season by utilizing the natural resources,-light,water and nutrients- has persisted for centuries. The yield of each component in multiple cropping is lower than the yield in monoculture, but this system tends to give relatively stable, risk free production. This kind of cropping system produces a large proportion of the food for human consumption in the tropics. In Colombia 70 percent of the food consumed is produced on farms where multiple cropping is practiced (Pinchinat 1976). Most of the beans produced in Latin America are grown with multiple cropping systems. Scobie *et al* 1974 found that the contribution from beans produced by intercropping system is 85 percent in Colombia, 50 percent in El Salvador, 50 percent in Mexico and 80 percent in Brazil.

Multiple cropping systems are also suggested as one of the future forms of agriculture to meet the future demand of food (Martin 1970 and Sánchez 1976), because established food crops production in monoculture with one harvest per season per unit area, has not shown sufficient potential to meet the future demand. Exploring old and new crops with genetic high yielding potential, for example cassava. Recently cassava is emerging from its obscurity in the tropics and is marching toward the future as to be an universal crop. It may replace to some extent yams, aroids, and sweet potatoes, (Martin 1970). Still the cassava cultivars have not reached their genetic ceiling potential (de Vries 1967, Cock 1976). Cassava as an efficient starch producer has rather low protein content and vitamins. To balance the human diet in regions where cassava is highly consumed, legumes may be a good alternative.

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1 Cassava multiple-cropping is carried on by the cassava physiology program at CIAT.

* Physiologists, Post doctoral fellow and cassava program leader.

II- The emphasis of the cassava physiology program at CIAT in studying multiple cropping system.

It is well known that in multiple cropping systems the yield of each component will be lower but the total yield of the components may be greater than in monoculture. This is the result of the inter-specific interactions between the crops during the growth cycle. By understanding the crop to crop interaction we can obtain the basic information of the multiple cropping system and with this data we will be able to define a better cropping system .

III- Definitions

According to Ruttenberg 1971, modified by Sánchez 1976

Multiple cropping

The intensification of cropping in time and space dimensions. Growing two or more crops on the same field in a year.

a. Intercropping. Growing two or more crops simultaneously on the same field. Crop intensification is in both time and space dimensions. There is intercrop competition during all or a part of crop growth. Farmers manage more than one crop at the same time in the same field.

Mixed intercropping. Growing two or more crops simultaneously with no distinct row arrangement.

Row intercropping. Growing two or more crops simultaneously where one or more crops are planted in rows.

Strip intercropping. Growing two or more crops simultaneously in different strips wide enough to permit independent cultivation but narrow enough for the crops to interact agronomically.

Relay intercropping. Growing two or more crops simultaneously during part of the life cycle of each. A second crop is planted after the first stage of growth but before it is ready for harvest.

Sequential cropping. Growing two or more crops in sequence on the same field per year. The succeeding crop is planted after the preceding crop has been harvested. Crop intensification is only in time dimension. There is no intercrop competition; farmers manage only one crop at a time in the same field.

Cropping pattern.

The yearly sequence and spatial arrangement of crop or of crops and follow on a given area.

Cropping system.

The cropping patterns used on a farm and their interaction with farm resources, other farm enterprises and available technology which determine their make-up.

Monoculture.

The repetitive growing of the same sole crop on the same land.

Crop rotation.

The repetitive cultivation of an ordered succession of crops (or crops and fallow) on the same land. One cycle often takes several years to complete.

Land equivalent ratio: LER

Land equivalent ratio is the area of that would be required for total monoculture production to be equivalent to that of one hectare of intercropped production at a given level of technology (without paying any attention at the time and price factors).

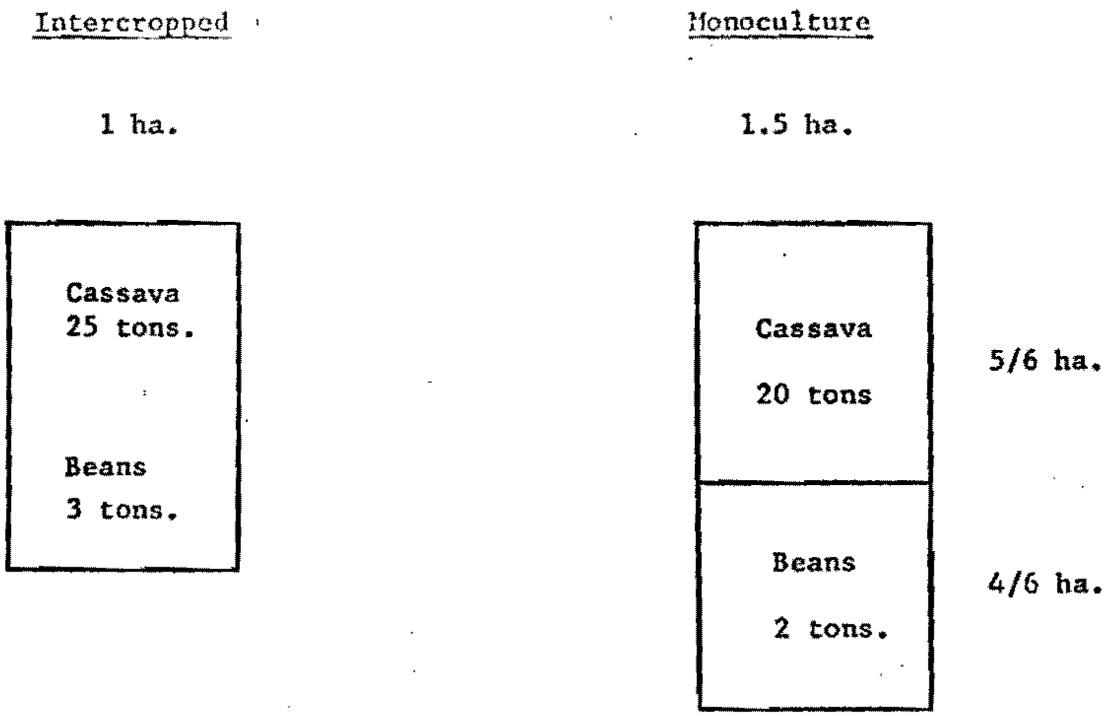
$$LER = \frac{X1}{Y1} + \frac{X2}{Y2} + \dots\dots\dots = \sum_{=1}^{m} \frac{Xi}{Yi}$$

Where X is intercropped yields of each crop and
Y is monoculture yield of the same crop.

Example: Intercropping cassava with beans. The monoculture of cassava is 30 tons/ha and the beans 3 tons/ha. In intercropping system the cassava yielded only 25 tons/ha and the beans only 2 tons/ha.

The LER is calculated as follow:

$$LER = \sum_{1=1}^{2} \frac{Xi}{Yi} = \frac{25}{30} + \frac{2}{3} = \frac{25}{30} + \frac{20}{30} = \frac{45}{30} = 1.5$$



IV- Phylosophy of Multiple cropping.

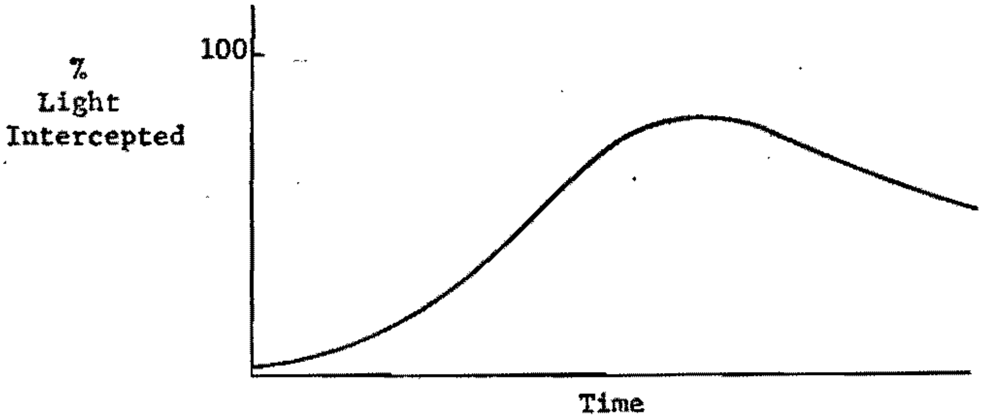
Plants can grow all year round in the tropics because of the abundance of solar energy available. The natural ecosystem in these regions consist of an enormous amount of plant species which build up a complex biological unit. The agro-ecosystem of the tropics is like its surrounding nature. This system was characterized by Harris (1972) as having "Diverse assemblages of crops in polycultural pattern of structural and functional interdependence", as opposed to the temperate regions agro-ecosystem, which is relatively simple and tends toward monoculture, Holdridge (1959) suggested that a potential, successfull tropical agro-ecosystem strategy is to plant "a polyculture simulating the natural vegetation" as closely as possible. Multiple cropping systems can be defined as a symplified polyculture ecosystem of the tropics.

Introducing the monoculture system into the complex ecosystem of the tropics will change the stability of this system; continuous pest susceptibility has been observed (Pimentel 1961, Nickel 1973 and van Sneider *et al* 1974), more air born disease is evident (Soria *et al* 1975) and the weed community changes to favor the more aggresive weed (Bantilan *et al* 1973) and a higher total weed biomas (Soria 75) which means a greater nutrient water and light competition for the crops.

Intercropping the cassava with beans may bring them a step back to-wards their origin and it might help to restore the upset ecosystem and give a favorable pest-predator balance, less disease and also weed problems.

V- Physiology of intercropping cassava with beans.

Cassava usually planted in wide spacing arrangement and has a slow buildup of canopy at the early stage. The canopy buildup can be slower if it grows in unfavorable conditions. This can be seen in simplified form of the light interception curve of cassava.



In the early stage cassava does not utilize much light but neither does it tolerate shade and competition (Doll 76). Hence much light apparently is not utilized. The available light could be utilized more efficiently if LAI of the stand were increased rapidly. There are 2 ways to increase the LAI within a short period:

1. Increasing the cassava density increases LAI rapidly lub. There is a limit of plant density beyond which the cassava can not develop to its fullest due to the severe intra-specific competition, and the crop growth rate remains constant. **(Cock and Yoshida, 1973).**

2. Intercropping the cassava with another crop should allow this crop to build up its full canopy in a short time before the cassava covers the ground.

From 6 months onwards cassava tends to drop its leaves. Again sufficient light is available beneath the cassava canopy. In this case climbing beans could be intercropped with the maturing cassava by using cassava stem as support. An advantage of this method of growing climbing beans is that there is no need to try expensive artificial supports.

VI- Competition problems in intercropping system.

Plants require the growth factors: Light, carbondioxide, water and nutrients. Light and CO_2 are absorbed by the leaves, water and nutrients mainly by the roots. Competition between plants for these resources

resources occur in all crops planted at agricultural density. But in intercropping system it may occur somewhat earlier than in monoculture system.

Light and CO_2

Even though in the tropics there is abundant of solar energy available it may be a critical factor in intercropping system. When the photosynthetic canopy of the component are at the same height and have the same Leaf area index (LAI), competition for light may occur very soon at the early stage. When the photosynthetic canopy of a component is higher than the other the higher intercepts the greater share of light. In this case the shorter component is in an unfavorable condition.

The intercropping system of cassava with beans shows an ideal canopy stratification in order to utilize efficiently the solar energy. The young cassava plant which still has a low LAI always stands at the same height or slightly above the beans' canopy. This ideal condition can be obtained by manipulating the planting date of one crop relative to the other.

Competition for light may occur within the plant itself when one leaf shades another leaf. This intra-plant competition happens only for light because light is basically not redistributed like the other resources such as nutrients. An example for this can be shown in wheat. Wheat with a local application of concentrated fertilizers to a few of its roots, as when fertilizer is drilled, will do better than plants with a less concentrated fertilizer on the whole root.

If the soil conditions are not limiting and the crops are still in vegetative phase, the photosynthesis and growth rate of their canopies are nearly proportional to the radiation which they intercept (Stern and Donald 1962).

During the critical phase of growth, shading may be crucial for yield production. Beans critical phase is during the flowering time. If shading occurs during this period a yield reduction of 20% is expected. (CIAT 76), while shading the cassava during the first two months of growth reduced cassava yield is 50 percent (Doll 1976).

Competition between components for CO_2 play a minimum role in an open stand although theoretically possible. The turbulence within the canopy is usually so great that it seems unlikely to occur (de Witt 1965). Furthermore the respirated CO_2 during photosynthesis can be utilized again by the plant for reassimilation. (Cock and Yoshida 1972).

Water and nutrients

Roots take up water and nutrients from the soil. When both crops are at seedling stage, roots will be far enough from each other. Since the surface area of the root system may be over 100 times greater than that the of shoot area (Dittmer 1937), the soil soon becomes crowded and competition may begin. Thus competition by roots can occur earlier than the upper part of the plant. Water and nitrate ions in the soil are more mobil than potassium and phosphate (Bray 1954). Thus they are taken up at faster rates, hence the depletion zones of water and nitrate grows faster than potassium and phosphate. This means competition begins when an overlapping of depletion zones of certain elements takes place. Although competition between individual roots and root system of one component may begin much earlier. The degree of overlapping between the root system of the components determines the intensity of competition effect.

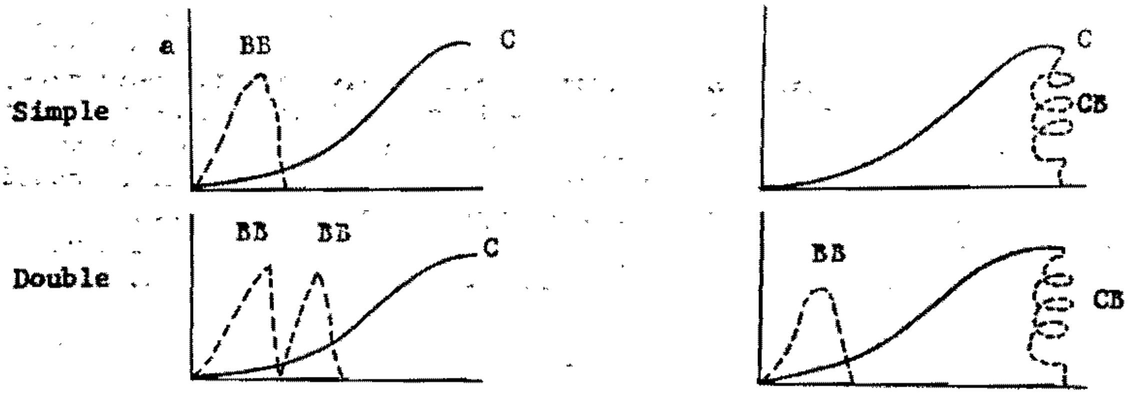
If the nutrient is present in a range of chemical and physical forms, the competitive ability of different species may be determined by their capacity to make use of each of these forms. (For example clover takes up better Potassium than grass in mixed pasture. Cassava needs a greater amount of Potassium than other crops and beans need phosphorus more than the cassava does. This crop requires different nutritive elements for their bulk need during their growth. It would be unwise to intercrop species with high a requirement of the same nutrient, for example cassava and sweet potatoes, without adding Potassium heavily, because these crops need a large amount of K for their growth.

A good knowledge of the distribution, density pattern of the roots and the metrical requirement of nutritive element of the intercrop components is very important in order to get a successful intercropping system.

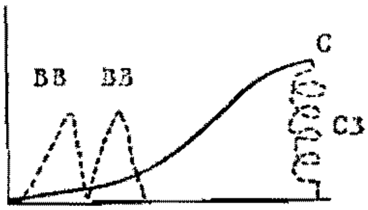
VII- Approaches to understand the cassava-bean intercropping system

Systematic investigations to understand the cassava-bean intercropping system is being carried out by the cassava physiology program since 1976.

1. Time of planting are relative to the other.
2. Optimum density combination of the two components.
3. Genotypes influence in intercropping system.
4. Light competition versus nutrient competition.
5. Intercropping cassava with beans, where beans are in sequencial cropping.



Triple



The main objective is to test how intercropping cassava with beans can be achieved, without reducing the yields severely.

VIII. Cultural practice problems in intercropping cassava with beans.

A. Soil Type and Fertility.

It is recommended to plant cassava with beans on ridges, because cassava as well as beans do not tolerate excessive water. A deep drainable soild would be the best for both crops. Seedbed preparation should be done more delicately than for the cassava alone. The recycling ot nutrients from the bean residues may improve the nitrogen status of the soils.

B. Water.

Where there is no irrigation facility, like most of the small farm fields, planting date is determined by the onset of the rainy season. Michel (1973) found that the multiple cropping system uses available water more efficiently than monoculture. The process is probably the same for fertilizer utilization. The total water use may be higher but efficiency in terms of quantity of water used per unit production will be lower.

C. Planting Material.

Cassava: A high germination rate of the cassava stake is desirable because replanting is too difficult in intercropped fields without disturbing the bean plants.

A late branched cassava cultivar is preferable for this purpose such as M Mex 11, M Mex 17, M Pan 70, because it gives less space competition and makes the bean harvest easier. Heavy foliated cassava cultivars will also give too much shadow to the beans. High yielding varieties should be used because there is not too much competition by the beans, even though it is difficult to predict, whether the cassava plant will manifest its high yielding potential in the intercropping system, genotype selection is urgently needed.

Beans: Shade tolerant beans should be choosen when it will be intercropped with cassava. The critical period to shading in beans is during its flowering time. When shade occurs during this period yield decreased 20 percent (CIAT 76), at this moment the cassava is somewhat taller than the beans and it will certainly shade the beans within a certain limit. P 30 2 seems to be the best type for this purpose, but unfortunately this line is very suceptible to other problems.

Beans have more pest and disease problems than the cassava. Therefore, susceptible bean cultivars to common insects and diseases should be avoided. For example nematods, will affect beans first, then cassava in a later phase.

D. Weed Control.

Keeping cassava or beans weed free until a closed canopy is formed is critical for achieving maximum yield. Cassava monoculture needs 2.5-3.5 months to cover the ground (CIAT 1974).

Introducing the beans between the cassava rows increase the ability to cover the ground more rapidly, hence increase the ability of the crops to compete with the weeds. Not only the weeds will be suppressed by this increasing speed of coverage, but also light utilization is higher.

Weeding in the intercropping system will be very difficult because two crops are on the field instead of one. To avoid postemergence weeding, during the time between germination to a closed crop canopy is formed, preemergence application is essential. Herbicides for this purpose should be selected carefully, because very seldom herbicides are selective enough to two crops. Lazo (alaclor) or Karmex (Diuron) is excellent post planting herbicides on cassava, but is harmfull for beans. Soil texture may influence the selectivity of a certain herbicide.

A selective herbicide, good enough for two crops have to be evaluated. Good experience at CIAT conditions have been derived from using a mixture of:

Afalon (Linuron) 1 kg plus Preforan (Flourodifen) 7 L. mixing with 200 litres of water, will be enough to spray one hectare of land. For lighter soils it is recommended to use Treflan (Trifluralina) with a dosis of 3 l/ha because the above mixture might be phytotoxic to beans if heavy rain follows the application of the mixture on light soils.

E. Insect Control.

Because the cassava growth cycle is longer (one year or more) than the beans, it has the ability to recover from pest attack, when climatic conditions are favorable during the rainy season. Hence cassava pest is not as critical as for beans. Visual observations show that in intercropping system has less insect infestation than in monoculture, because of a much better insect balance.

Random or unwise insecticide applications may completely upset the natural equilibrium of insect population and the natural pest control mechanism. Insect infestation in beans is higher than in cassava, especially during the dry season. Thus our main observation of insect population should be stressed on the bean canopy. Some important insects emphatized in beans are:

1. Empoasca Kraemeri. Can be controlled by Azcdrin 300-400 cc/ha.

2. Little green bugs. Can be controlled by Diostops 400-600 cc/ha.

3. Red and green mite. Kelthane or Tamaron according the dosis recommended.

A common insect, which attack both crops Empoasca has not been observed till now. Empoasca produce severe damage only to the beans but harmless to cassava.

F. Disease Control.

Cassava and beans are attacked by common diseases and the attack can be disastrous during the rainy season. Intercropping system might favor the disease buildup on one of the crops by changing the plant environment or microclimate. Beans are more suceptible to diseases than cassava, espbcially during the rainy season.

1. Bacterial blight. (Xanthomonas Phaseoli). The attack of bacterial blight may be severe during the rainy season. Koccide 101 can be applied with a dosis of 1 kg/ha as a preventive application or 2 kg/ha when the attack is heavy. This application will not only prevent the beans against bacterial blight, but also protect the cassava against superelongation (Spaceloma manihoticola) disease as well.

2. Nematode (Meloidogyne). Both plants may be infestated by nematods. There are products to eradicate this disease but still to costly and this beyond the farmers reach.

The best way to prevent it is by crop rotation. Some other diseases which may attack cassava and beans as well are: Rhirodomo spp, Sclerotium rofsin, Sclerotinira Scleroteotum. The importance of these diseases have still to be evaluated in the multiple cropping system.

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CASSAVA HARVESTING METHODS

Julio Cesar Toro *
Ernesto Celis **
Gustavo Jaramillo **

Introduction

Harvesting represents 30 percent of production costs, according to economic studies conducted at 300 Colombian Farms by Diaz (5). This is greately due to the fact that this operation is generally done following rudimentary manual methods which are often inefficient.

Why mechanical harvesting

The above consideration indicates that there is plenty to be done in this area of cassava harvesting. An increase in the harvesting efficiency by any method or mechanic device would greately reduce production costs, as well as reducing man efforts and energy spent with this operation.

Intervening forces at harvesting

According to Briceño (4) the most important forces acting during cassava harvesting are of two types:

1. Vibration
2. Pulling

When only traction is exerted the stem will probably break and the roots will rest buried in the soil. It is necessary to combine both forces to obtain good results.

MANUAL SYSTEM

This method comprises 2 stages : first, branches and foliage are cut leaving a portion of the main stem which is used to size and apply the two forces. The stripping of the plant is done generally with a machete.

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During the second stage, after removing the material from which seed is later selected, the extraction of the roots takes place, usually accompained by cleaning and packing operation. The length of the stem portion left attached to the roots may vary from 20 to 40 cm and is used to size and pull the roots.

Modalities

1.1 By hand

In light or sandy soils roots can be pulled easily without the aid of an instrument or aditional lever action.

1.2 Drawbar

In somewhat heavy soils, in order to harvest the roots intact, a sharp implement is introduced under the roots and used as a lever. This implement is generally a drawbar.

1.3 Belt

In the coffee zone of Colombia where soils are mostly medium in texture, a belt is very commonly used. The farmer will wrap the belt around his back and over his shoulder tying the other end to the stem. The portion tied to the stem can be a strong rope or a chain depending on the preference of the farmer. This way the hands are used to grip and vibrate, and the body serves as a lever. This is a one-man operation.

1.4 Lever

In areas where soils are compact the operation is done by the use of a lever. This tool consists of a 2.50 - 3.0 m long wood or bamboo pole straight and firm enough to execute the leverage.

This operation needs two men: one to tye the stem to the pole and to vibrate the plant and another to exert the leverage force.

1.5 Modified lever

A modified lever system is possible by modifying the fulcrum and simplyfying the grip. This method could save much energy as well as increase the efficiency of the operation.

MECANIC-MANUAL SYSTEM

Most of the cassava harvesting methods which include mechanic devices or animal traction can be called semi mechanic and work by adaptation of the existing machinery.

In this case the harvesting is mostly mechanic but must be complemented by hand labor.

Modalities

2.1 Furrowing

When there is enough space in between the cassava rows a furrow is opened at each side of the plant. The roots will then grow in loose soil thus, making harvest easier. Production costs can be greately reduced with this system. Its only disadvantageous that some roots get broken which causes preservation and marketing problems.

The above consideration is important under Colombian conditions because according to Booth (3) the roots must be harvested intact to prevent the entrance of pathogens which can cause root rots.

This consideration is not as important in countries like Brazil where most of the cassava goes to processing less than 24 hours after harvest.

2.2. Moldboard plow

A moldboard plow has been used successfully in Sao Paulo, Brazil and Filippines. The angle and curvature of the plow will uncover the roots turning over the soil. The roots are then grouped by the farmer and picked up later by a tractor or wagon.

MECHANIC METHOD

Root harvesting, without any doubt is the most difficult to mechanize of all cropping operations. Besides the irregular size, shape, depth and distribution of the roots, the problem is agravated by the dirt, stones and plant material which must be removed from the roots without causing injuries.

The difficulty of designing an efficient and complete harvesting machine is clear. The varieties available so far have been selected for yield insect and disease resistance without consideration of a future need for mechanical harvesting.

Varieties with its roots grouped in a semi conical shape not too deeply settled and with a short root system are already in mind.

The problems of cassava harvesting due to hard soils, size, and distribution of roots, etc, suggest the use of an implement coupled to a colter or chipper whose vibration reduces the traction and the operation manageable by a medium or big tractor. It is a technical reality that the vibratory principle applied to mechanical harvesting facilitates the extraction of the roots (2).

However, it must be kept in mind that the characteristics of the ground influence greately the power requirements from the tractor because cassava is a deep crop. Because mechanical harvesting requires big tractors, it is necessary to undertake comparative cost studies on manual harvesting, in order to determine the most profitable farm size for mechanical harvest. Distance between cassava rows must be considered at crop planning stage so that machinery can be properly utilized.

THE FACTIBILITY OF THE USE OF MACHINERY IN CASSAVA HARVESTING

Usually, a root crop harvester machine is composed of a blade to cut the plant material, an element that will remove the soil, i.e. a blade or furrower, and finally a system which will remove and separate the soil adhered to the roots.

Modalities

3.1 A manual shaker excavator and a hay packer could provide a solution for cassava planted in ridges in friable soils. A reduction in the suction could be accomplished by the propellers. A test with and without elevator is suggested in order to make comparisons for tuber deterioration and accordingly with these results introduce the vibratory principle.

Roots could be considerably damaged by the cleaning or elevator mechanizm of some root harvesters. Because of the size of the cassava roots the cleaning system should possibly be eliminated from the harvest procedure to perform this task after harvesting.

3.2 The root extraction could be faciliated with little damages, by a highly vibrating system operated continously by a tractor.

3.3. Bates (1) suggests the possibility of modifying a potato planter which would work behind the tractor attached to the power-take-off, carrying a pulling mechanizm instead of an excavator one, lifting the tubers over the surface. It should also be possible to build a root puller at the front end of this harvester.

The pulling of the tubers by the stems can be done by a couple of resistant and modified bands, placed in inclined position like those used for sugar beets.

3.4 Briceño and Larzon (4) developed a implement to be used with a tractor strong enough to pull the roots from the soil. It consists of a blade that cuts into the soil and a series of tubes that extract the roots and separate the soil. Some of the characteristics of the design of this implement are : three point hitch; cutting width of 0.95 m; 40 cm depth and operation speed of 2-3 km/hour. It has a field capacity of 0.29 ha/day. It requires a tractor with a pulling force larger than 4.000 kg at the indicated operational speed. This is equivalent to 80 H.P. at the power take-off.

General considerations

For any device used as an aid in harvesting the following factors must be kept in mind.

1. Planting methods

If planting is done in ridges or beds, harvesting tends to be easier than in level planting.

2. Soil type

In loose or sandy soils harvesting is easier than in clay or heavy soils, regardless of the system used.

3. Soil moisture

In any case harvesting is easier when the soil is moist than when it is dry.

Finally, the type of method used for harvesting is determined by economic considerations. In small scale farming, manual harvesting can be efficient, but other methods must be thought of in cases like Curvelo Minas Gerais Brazil, where 1.000 hectare plantations are common. All these considerations are according to the processing capacity or to the marketing flow.

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NEW DEVELOPMENTS IN CASSAVA STORAGE

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J. Castaño*

Abstract

Cassava roots deteriorate rapidly after harvest. Deterioration is either physiological or microbial, but the former generally occurs within 48 hours of harvesting. Experimental results show that physiological deterioration can be prevented either by pruning the plants two to three weeks before harvest or by packing the roots in polyethylene-lined paper bags after harvest. Microbial deterioration can be prevented by dip-treating the roots with broad spectrum fungicides such as Manzate.

Introduction

The cassava root is highly perishable, often showing cortical necrosis (physiological) deterioration as rapidly as 24 hours after harvest; five to seven days afterwards, microbial rotting occurs (Booth, 1976).

Some progress has been made in searching for varietal ressistance to both types of deterioration (Kawano, personal communication). Nevertheless, ressistance to physiological deterioration apperars to be positively correlated with moisture content (CIAT 1976, Kawano, personal communication). Although this correlation is not particularily close, it does suggest that it may be difficult to breed for high dry matter content, a desirable character, and for ressistance to physiological deterioration at the same time. Furthermore, most lines apparently ressistant to this type of deterioration eventually suffer microbial deterioration after about ten days. It is a moot point whether ressistance to deterioration for such a short period would resolve many of the problems associated with cassava perishability.

In their comprehensive review on cassava storage, Ingram and Humphries (1972) mentioned various traditional methods such as packing in mud and structures similar to potato clamps used in Europe. Booth (1977) refined the potato clamp method and developed a storage system using boxes filled with moistened sawdust. These systems are somewhat costly and difficult to manage and have not, up to present, been adopted on a commercial scale. Oudit (1976) suggested that fresh cassava could be stored for up to one month in polyethylene bags with no extra treatment.

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During visits to cassava-growing areas, the authors and other members of the CIAT cassava production systems team observed that in many local markets the cassava roots were sold while still attached to the stem. The vendors claimed that the roots deteriorated much more slowly under these conditions than when removed from the stem.

Booth (1976) showed that roots kept under conditions of high humidity "cured" and physiological deterioration was prevented; however, as temperature increased microbial deterioration occurred rapidly.

We have attempted to develop simple methods that may readily be adopted to control both physiological and microbial deterioration of harvested cassava roots. In the former case both maintenance of high humidity and leaving roots attached to the stems have been the basis, whereas in the latter case, use of protectants and sterilants were evaluated for preventing microbial rotting.

MATERIAL AND METHODS

The symptomatological definition of the two reported types of deterioration in cassava roots (Booth, 1976) was determined by general observations on stored roots of different varieties. The severity of these two types of deterioration was evaluated by following Booth's scale of deterioration (CIAT, 1972), considering 0 as healthy roots and 4 as the most affected.

Physiological deterioration

The control of physiological deterioration was investigated by (1) pruning the aboveground part of the plants before harvesting and (2) by using different packing systems.

1. Pruning. One-year-old plants of two varieties susceptible to physiological deterioration (M. Colombia 22 and M. Colombia 1802) were used in the first trial. Plants were pruned back to 20 cm above ground and harvested 7, 14 and 21 days after pruning. Half of the roots were stored without the stem and the others with the stem section attached. Roots were stored in the field under an open-sided palm hut and readings taken every five days. Deterioration was determined on 20 roots/variety/time of storage. A second trial included six varieties (M. Colombia 45, M. Colombia 1807, CMC 29, CMC 92, M. Mexico 59 and Popayán), which had in previous trials showed different degrees of deterioration.

To determine the effects of temperature and humidity on deterioration, M. Colombia 22 was pruned 14 or 21 days before harvest. Roots were detached from the stems at harvest; half were sliced at both ends and half were left whole. These roots were stored at 35 and 45°C and 20, 40, 60, 80 percent relative humidity for 0, 6, 12 and 24 hours Deterioration was evaluated daily on 10 roots per treatment for 20 days.

2. Packing systems. Twenty fresh, recently harvested one-year-old M. Colombia 113 roots were packed in burlap sacks, paper, polyethylene-lined paper or transparent polyethylene bags. Bags were stored in an open-sided palm hut, and every five days the root deterioration of 3 bags per treatment type was recorded as previously. The same trial was later repeated with freshly harvested roots of Llanera and M. Mexico 23.

Microbial deterioration

To control microbial deterioration Sodium hydrochlorite and Manzate (Manganous ethylenebisdithiocarbamate) were used to treat the roots; the first because of its sterilizing effect whithout leaving toxic residues, and the second because of its protectant effect with low reported toxicity (Rohm and Haas Co., 1976) as well as its availability on the market. These products were suspended in water at increasing-decreasing mixtural concentrations of 5×10^2, 1×10^3, 2×10^3, 3×10^3 and 4×10^3 ppm a.i. of Manzate and 5×10^3, 1×10^4, 1.5×10^4, 2×10^4 and 2.5×10^4 ppm a.i. of Sodium-hypochloride. Roots were treated by immersion into the suspension for a period of 3 to 5 minutes before packing them in paper-lined polyethylene bags. Readings on deterioration were taken, as above, every five days.

In order to determine whether light had any effect on chemical degradation after treatment, leading to microbial deterioration during storage, roots of Llanera, M. Colombia 113 and M. Mexico 23 were packed in transparent, red, green and black polyethylene and polyethylene-lined and paper bags after treating the roots with 3×10^3 ppm a.i. of Manzate and 1×10^4 ppm a.i. of Sodium-hypochloride. Readings were also taken as above every 5 days.

RESULTS

Physiological deterioration is characterized by a dry brown to dark necrosis, normally appearing in the form of rings around the periphery of the cortex. This deterioration appears within the first 48 hours of harvesting, depending on varietal susceptibility. Microbial deterioration commonly initiates as vascular streadking, followed by soft rot, fermentation and maceration of the root tissues. This type of deterioration which does not occur in any special order, is normally noticeable 5 to 8 days after harvesting, depending on the soil microbial flora able to metabolize cassava roots and on the intensity of damage to roots at harvest (Fig. 1).

Pruning

When plants were pruned before the harvest, the percentage of deterioration decreased with the time from pruning to harvest up to 14-21 days; leaving more time between pruning and harvest had little effect (Fig. 2). Roots left attached to the stem piece always deteriorated more slowly than those without the stem (Fig. 2). Varieties without any treatment differed in susceptibility to deterioration (Fig. 3); for example, M. Colombia 1807 and M. Colombia 22 were more susceptible whereas M. Colombia 1802 and M. Mexico 59 were moderately resistant. However, after 21 days of pruning the first two varieties showed less deterioration than the last two that were more resistant without treatment. Hence the reaction of varieties to the pruning treatment varies and resistance without treatment is not related to resistance with treatment.

Damaged roots generally deteriorate more rapidly than undamaged roots (Booth, 1976). However, after the pruning treatment roots that were cut to simulate damage deteriorated at the same rate as undamaged controls even when held at low humidity to prevent curing. High or low relative humidities did not increase deterioration of roots taken from pruned plants (Fig. 4).

When roots were stored after pruning, the physiological deterioration which normally occurs during the first two days of storage, was prevented; however, after ten days microbial rotting occurred (Fig. 5), but this was prevented by using a dip of Manzate and Sodium hypochlorite (4×10^3 and 2.5×10^4 ppm a.i., respectively).

Storage in bags

Storage in burlap and paper bags improved the number of undeteriorated roots when compared with controls (Fig. 6), but treatments still gave a high percentage of both microbial and physiological deterioration even five days after storage. Paper bags lined with polyethylene, on the other hand, prevented physiological deterioration. There was, however, a tendency for microbial deterioration to occur after about ten days, in a manner very similar to that found with the pruning treatments. This tendency was partially prevented by treating the roots with Sodium hypochlorite (2.5×10^4 ppm a.i.) and completely prevented by a treatment with 4×10^4 ppm a.i. of Manzate (Fig. 7). Further trials showed that this concentration of Manzate allowed some microbial rot and that at concentrations of 8×10^4 ppm a.i., excellent control was always obtained (Fig. 8). Preliminary studies on quality showed that HCN levels were apparently reduced during storage and that eating quality was improved by time of storage if physiological deterioration is avoided.

It appears that light does not influence the protectant effect of the chemicals used. All roots kept in polyethylene bags with different colors deteriorated at the same rate.

GENERAL DISCUSSION

Our results on the definition of the two types of cassava root deterioration were in agreement with those reported by Booth (1976), but vascular streaking appears to be a common sympton. Physiological deterioration develops as a dry rot which ended in light brown to dark discoloration, always found as a ring around the outermost part of the cortex. Vascular streaking, which is also associated with physiological deterioration, is commonly present at the initiation of microbial deterioration as the result of microbial invasion and degradation. This vascular streaking did not have any sympthomatological pattern and always ended in tissue maceration, fermentation and discoloration. Microbial activity was always detected.

It appears that physiological deterioration can be prevented both by pruning the plants two to three weeks before harvest and by packing the roots in polyethylene bags. If pruning is done and new shoots are allowed to develop before harvest, its effect on physiological deterioration decreases. This suggests that the leaves produce some principle that is translocated to the roots, inducing the initiation of physiological deterioration. Booth (1975) reported that this deterioration is associated with mechanical damage to the roots; however, in the pruning system, wounded roots did not show signs of physiological deterioration. It appears that the principle is somehow eliminated or minimized in the roots after pruning; this view is supported by the decline of this type of deterioration when the time from pruning to harvest is extended.

When roots are stored under humid conditions, curing apparently takes place (Booth, 1975) and the consequent healing of wounds prevents physiological rotting. Recent work done by John Marriot while at CIAT suggests that there is a further factor involved related to water loss. When water loss was reduced by artifitial means, physiological deterioration was delayed (Marriot, personal communication). This interesting result may explain why high moisture content is loosely correlated with resistance to this type of deterioration. This physiological process may initiate only when a critical low moisture content is reached; varieties whose roots have a low moisture content may reach this level more rapidly. Furthermore, when roots are placed in polyethylene bags, the high humidity environment may not only favor root curing and healing but also reduce water loss sufficiently to prevent physiological deterioration.

Deterioration due to microbial activity is a separate entity, distinct from physiological deterioration. It is induced by a complex of microorganisms able to degrade root tissues. The use of surface sterilants alone is apparently uneffective, probably because sterilization is difficult and also because there is always an opportunity for reinfections. On the other hand, protectants such as Manzate, etc. can be used to prevent reinfections.

Hence, it seems that protectants can be used to prevent microbial rotting, and either pruning or high humidity conditions, to prevent physiological deterioration. The pruning treatment has come adverse effects on the quality of cassava for fresh consumption. The roots become slightly harder and dry matter content increases slightly, which means that cooking has to be prolonged. On the other hand, cassava drying or starch extraction are facilitated by high dry matter content which reduces transport costs and makes processing easier. Thus, it appears that cassava for industrial use can be conserved and its quality improved by the pruning method.

Although Oudit (1976) suggested that storage in polyethylene bags with no further treatment gave no deterioration after 20 days, we always had microbial rotting 7 to 10 days after harvest. However, polyethylene-lined paper bags, used in conjunction with protectants, allowed cassava to be stored safely for up to three weeks after harvest with no change in cooking quality. The problems of toxicity from the surface protectants are minimal because the roots are always peeled before cooking. Further investigation on the use of several chemicals and their translocation in the roots will be investigated.

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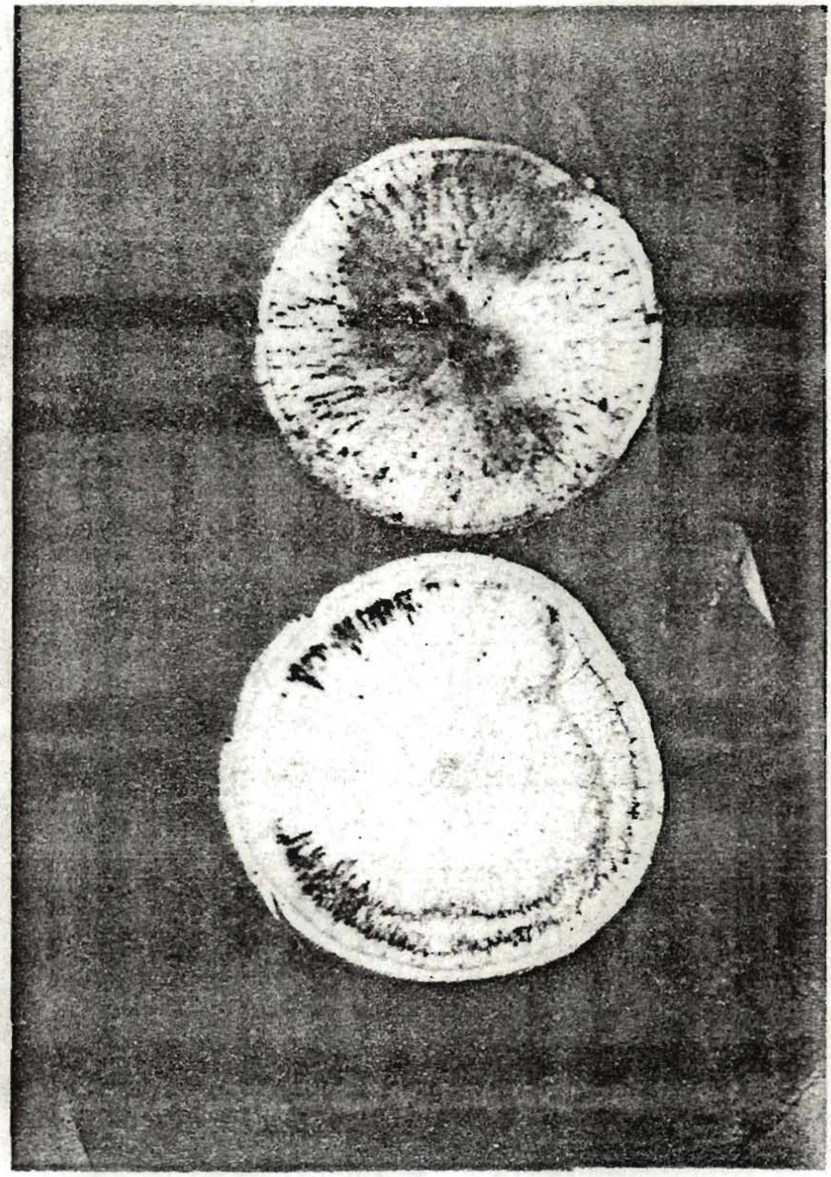

Fig. 1. Deteriorations of harvested cassava roots: Physiological (above) dry brown-dark necrosis in the form of rings around the periphery of the cortex; microbial (below) soft rotting, with fermentation and maceration of the root tissues.

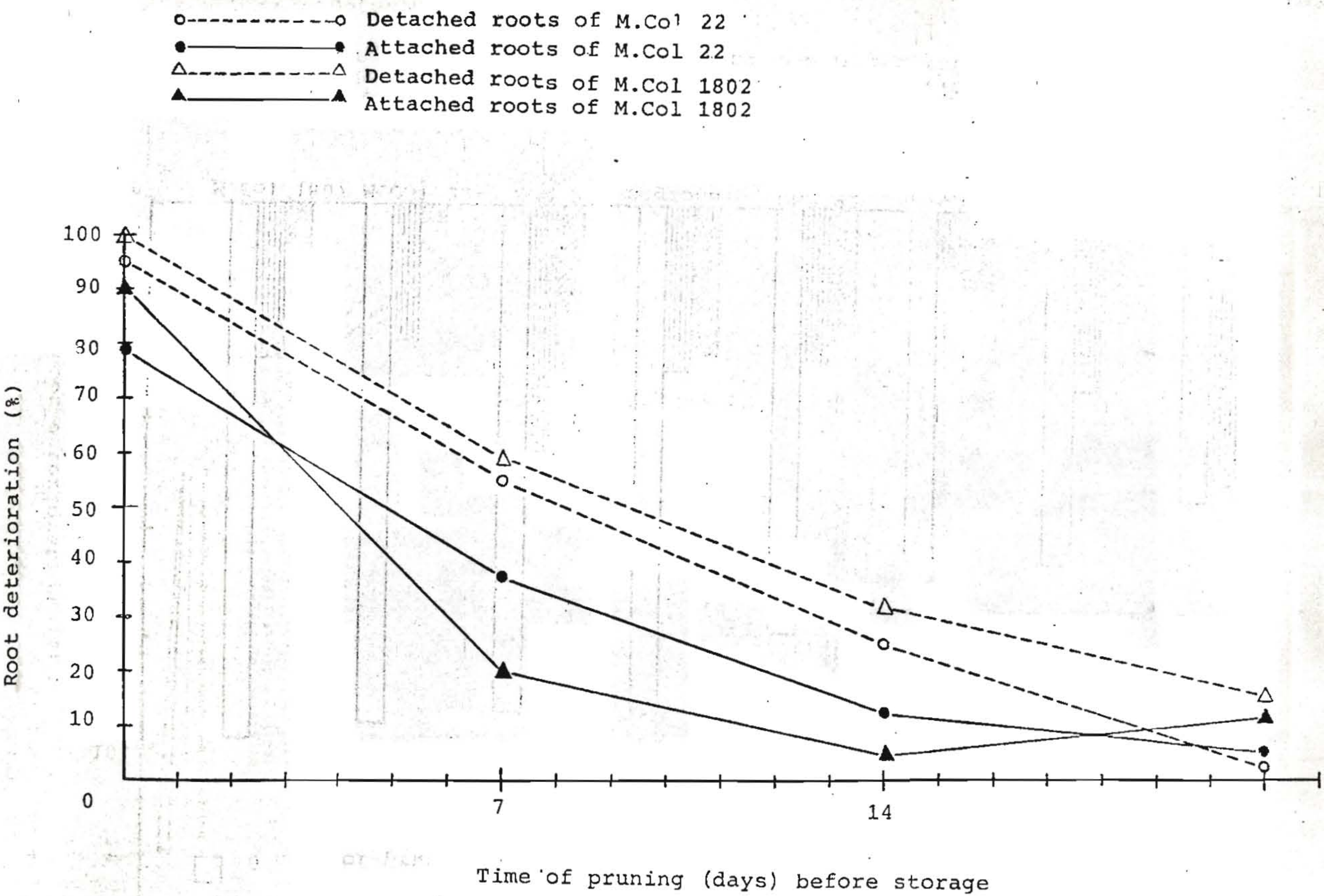

Fig. 2 Pruning effect on cassava root deterioration after 20 days of storage

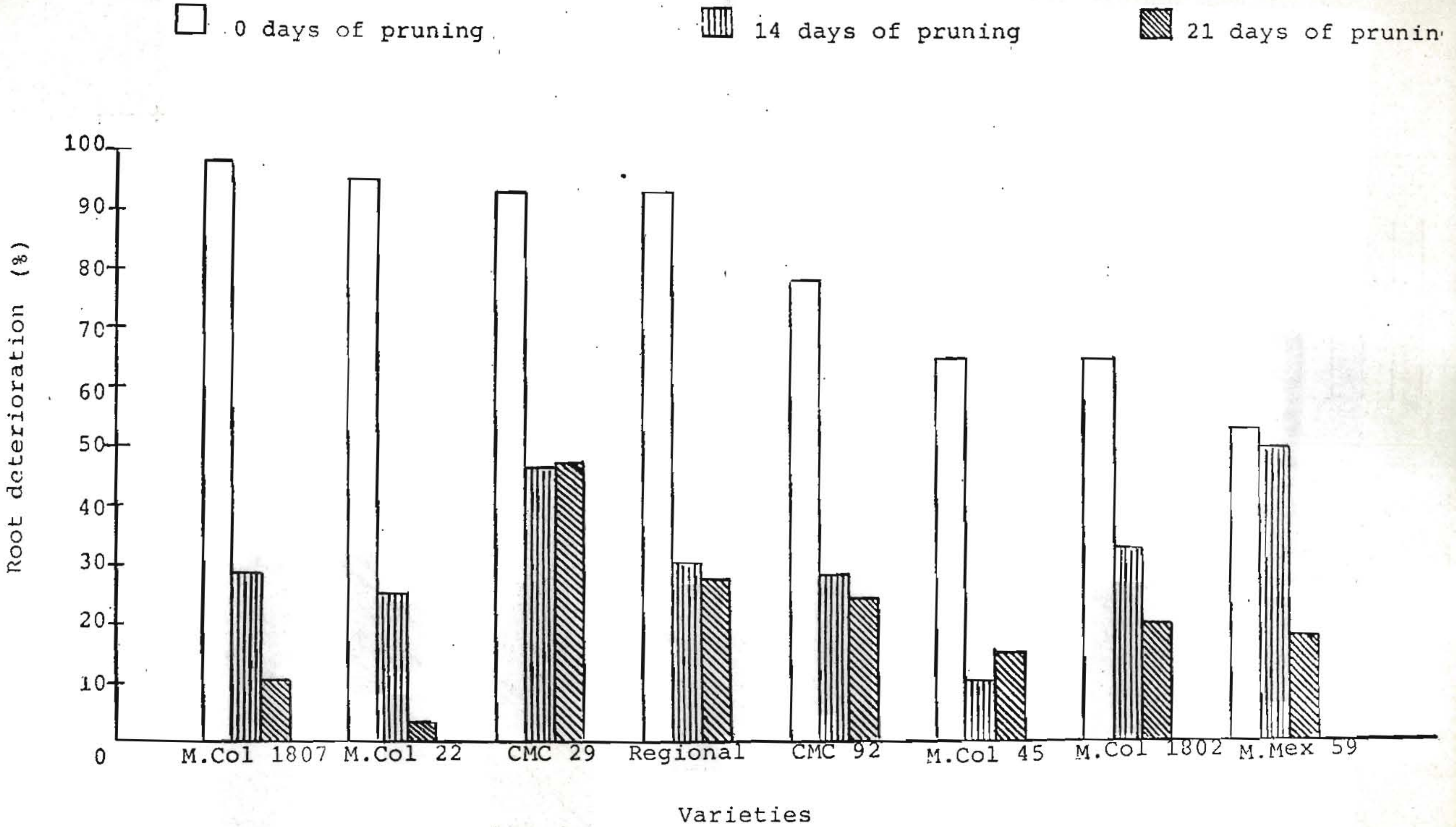

Fig. 3 Root deterioration of eight cassava varieties pruned 0, 14 and 21 days before harvesting and stored for 20 days.

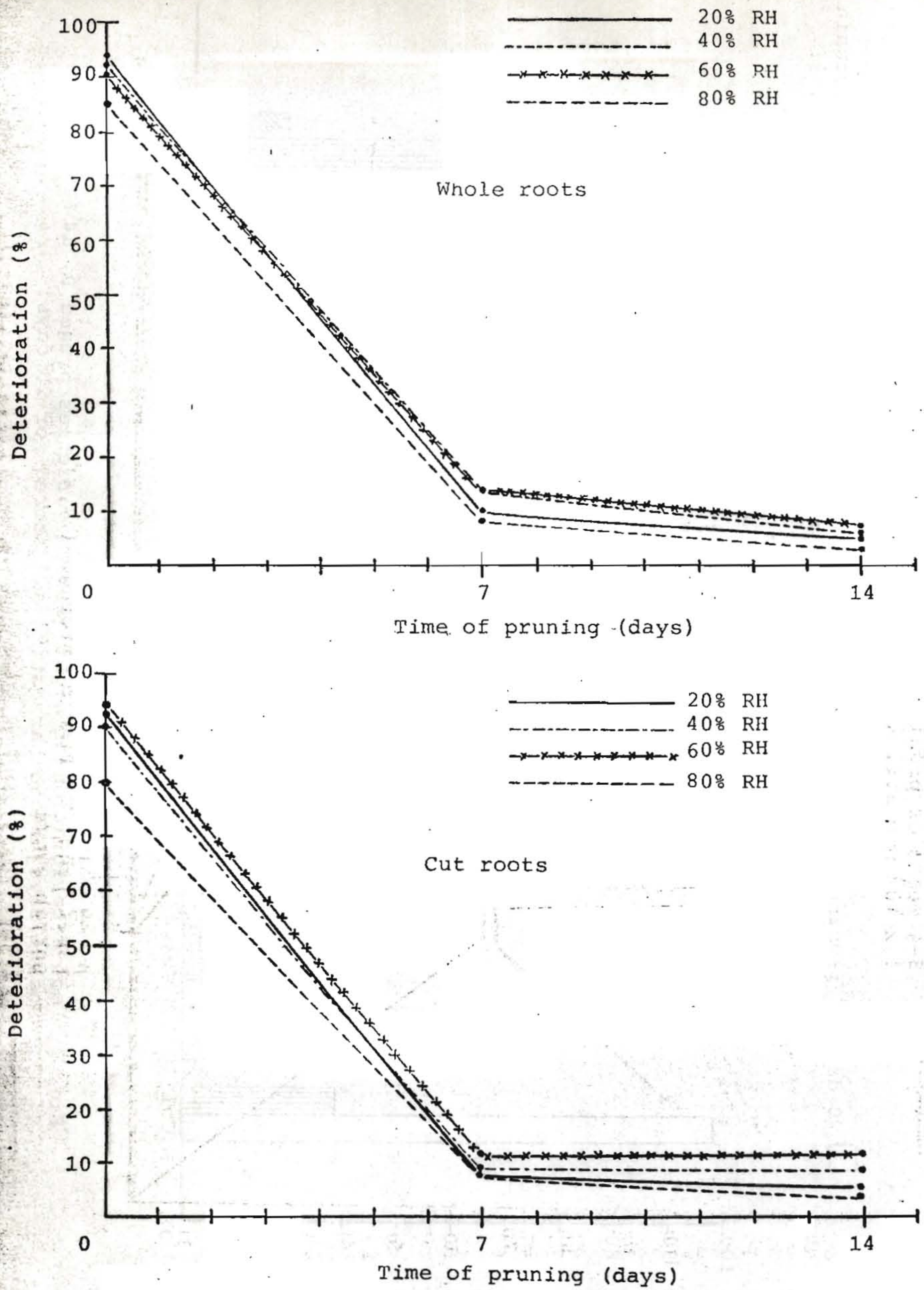

Fig. 4 Deterioration of M. Colombia 22 roots in relation to plant pruning after 20 days storage at 35°C and 20, 40, 60 or 80% relative humidity for 12 hours.

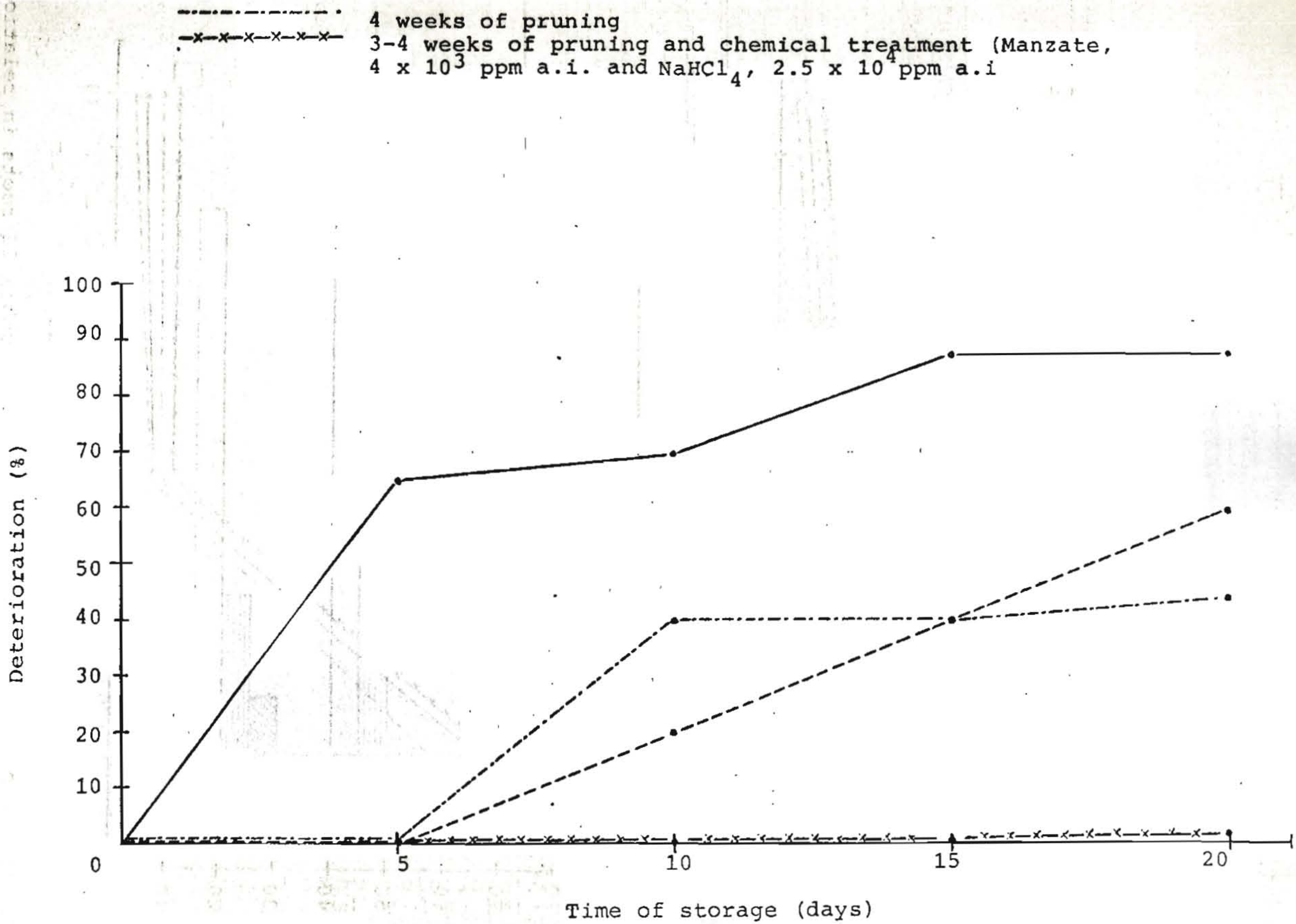

Fig. 5 Effect of plant pruning and chemical treatment on root deterioration (var. M. Colombia 113).

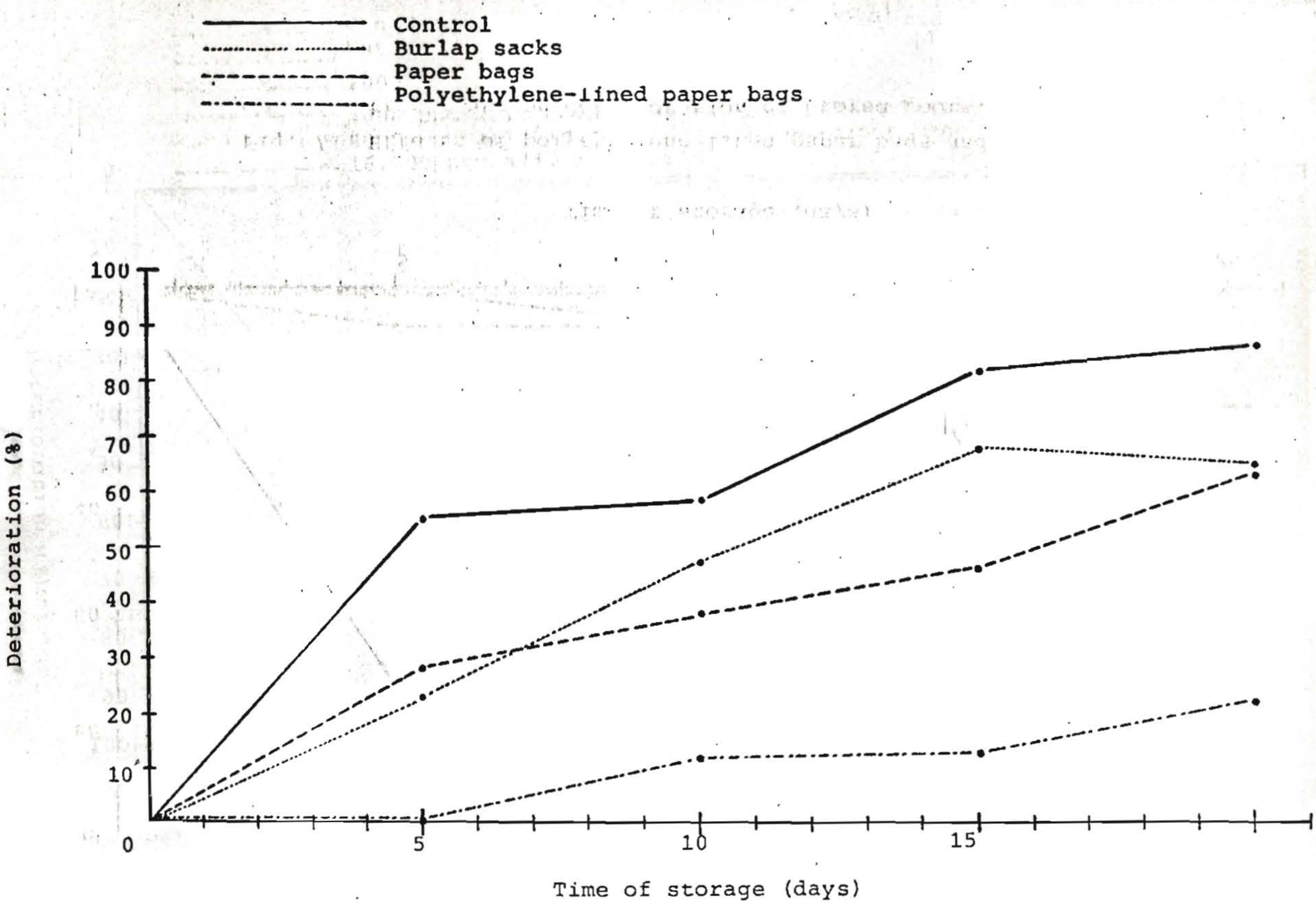

Fig. 6 Effect of storage in bags on cassava (var. M.Col 113) root deterioration.

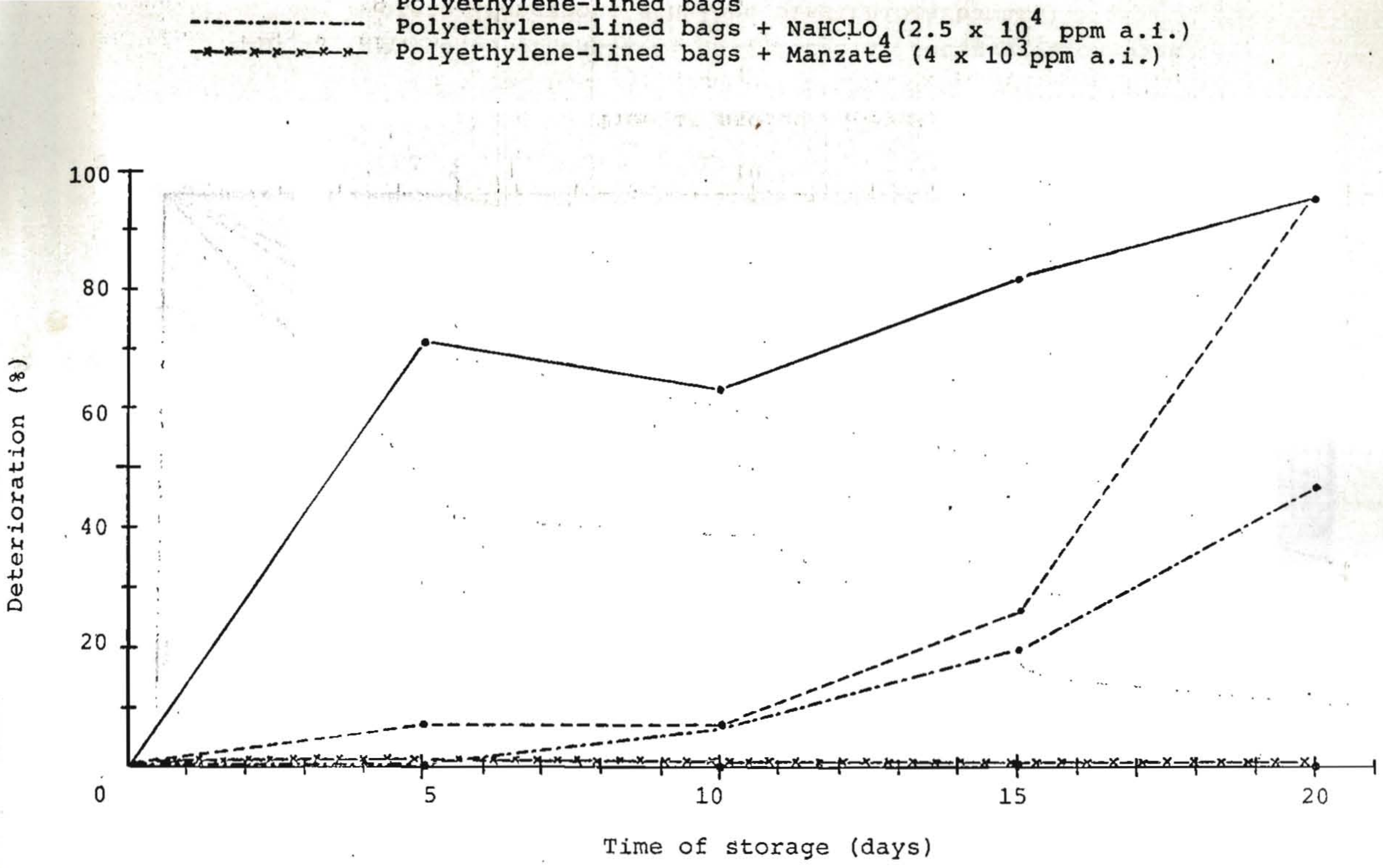

Fig. 7 Effects of polyethylene-lined paper bags and chemical treatments on deterioration of stored roots.

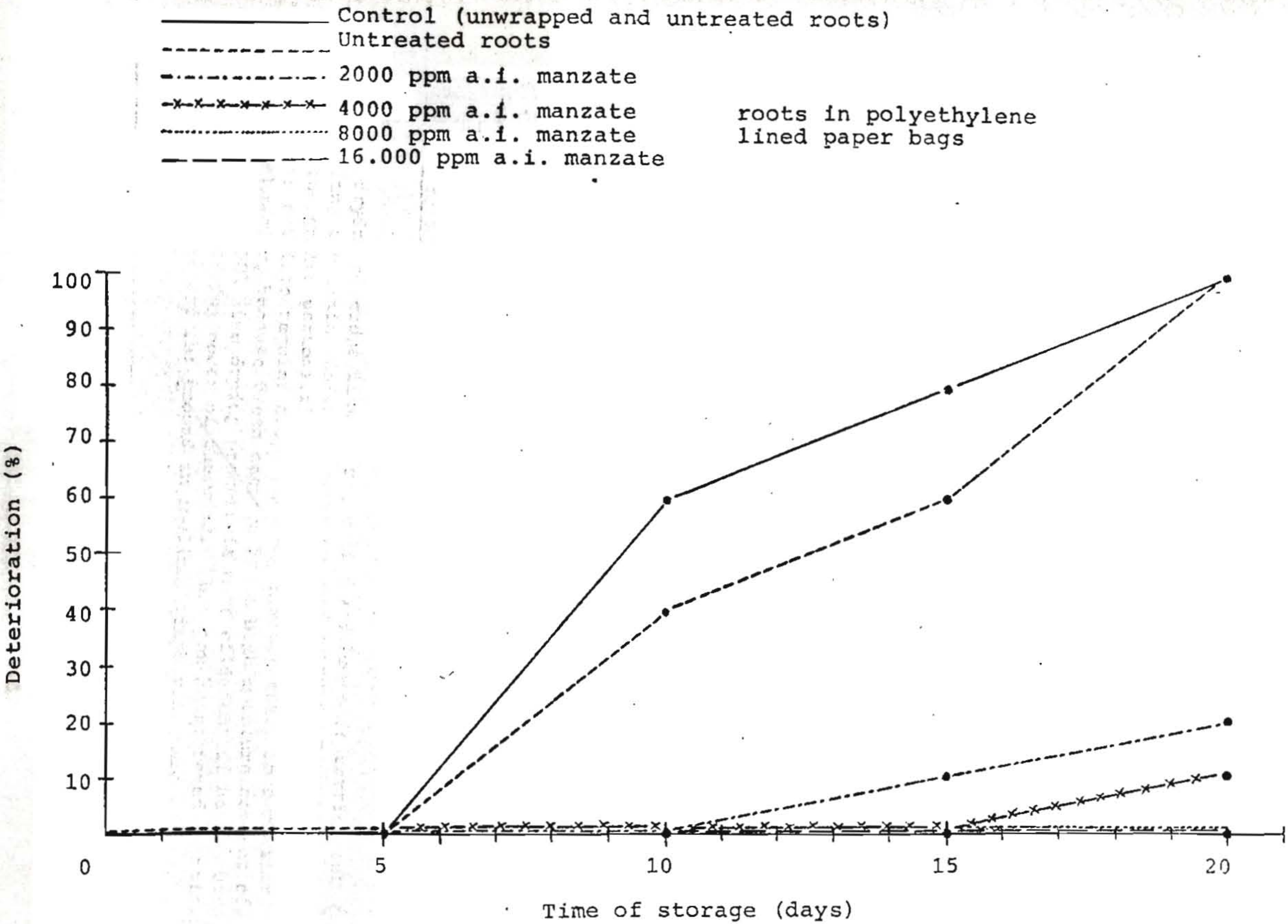

Fig. 8 Prevension of cassava root microbial deterioration with manzate (Manganous ethylene bisdithiocarbamate).

CASSAVA DRYING

Rupert Best*

Introduction

The use of good cultural practices and the introduction of improved varieties have shown that cassava yields may be increased two to five times over those obtained previously. This potential increase in production presents new problems both in terms of marketing and utilization of a crop which is grown principally by subsistence farmers.

Once harvested, cassava tubers are highly perishable and therefore they are usually left in the ground until required for consumption. The fresh tubers can be stored in earth clamps or packed in boxes filled with moist sawdust, but these methods are suitable only for small quantities and short periods of time up to six months. To ensure safe storage over a much longer time, without the risk of losses through rotting, the tubers must be dried. In many tropical and subtropical regions drying can be carried out naturally by utilising the sun and the wind.

Dry cassava is used both as a human and an animal food. Traditional methods exist in many countries for the home preparation of dry cassava based foods while the technology has been developed for the part substitution of wheat flour by cassava flour in breadmaking. Equally, dry cassava is fed as a source of carbohydrate to both pigs and poultry.

Cassava Drying

Sun drying of crops like maize, coffee and beans is carried out by spreading the grains in thin layers on wooden trays or concrete patios and turning the grains periodically to give uniform drying. If cassava tubers are cut into regular chips they may also be dried in a similar manner. However, because fresh cassava has a high moisture content of between 60 and 70%, the drying process is more efficient if better use is made of the drying power of the wind. This can be achieved by raising the cassava chips off the ground in inclined trays with mesh bottoms, Fig. 1.

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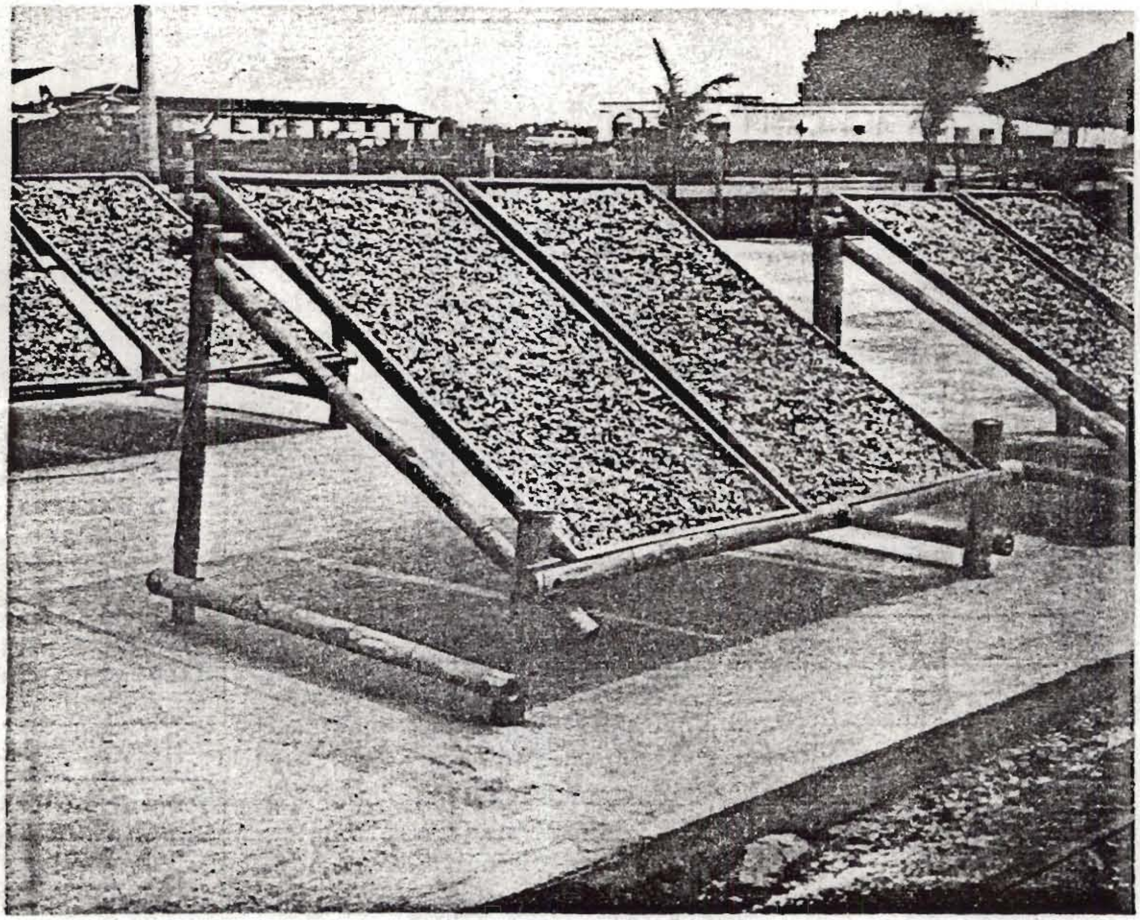


Fig. 1. Cassava drying in inclined mesh trays.

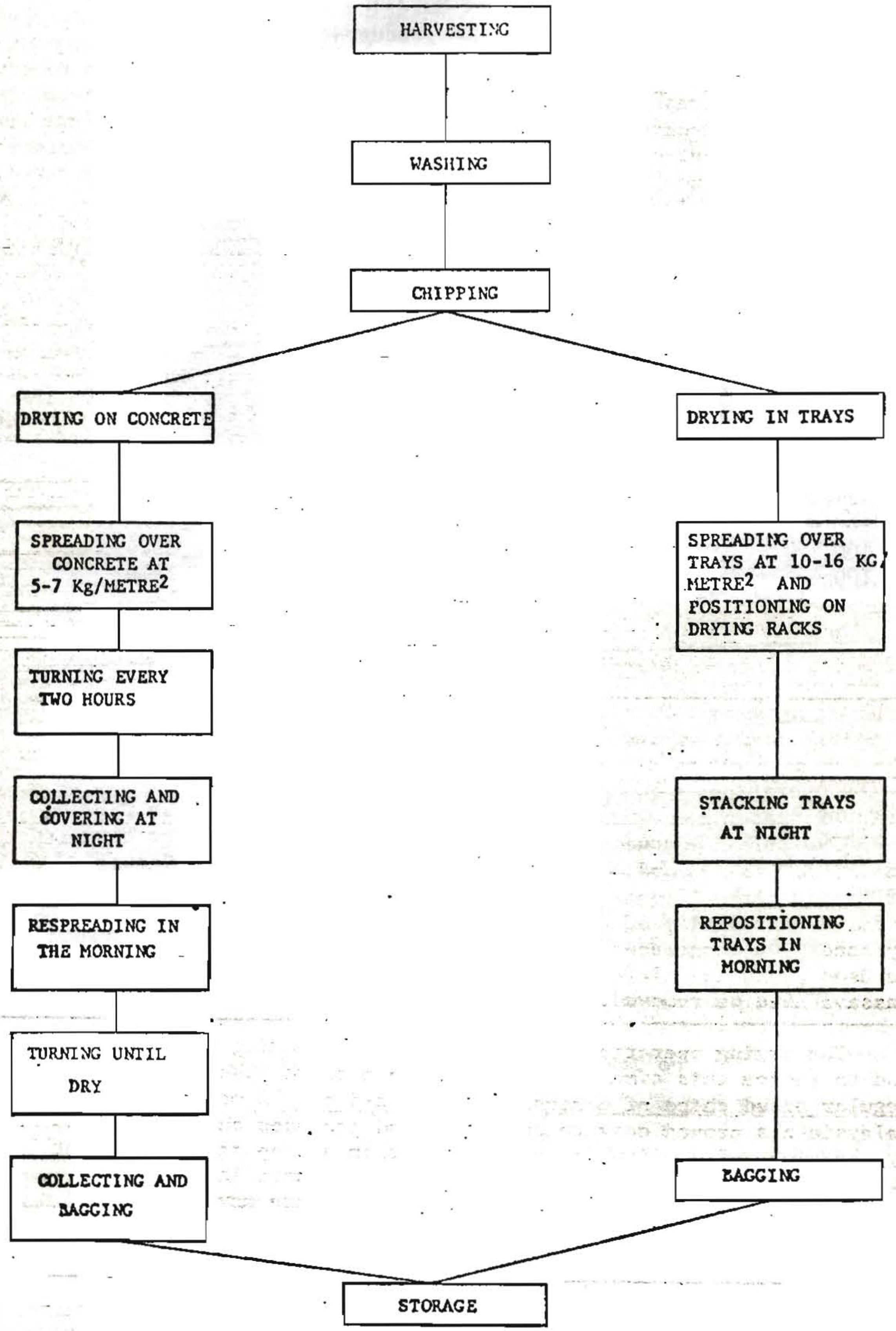


Fig. 2 - Flow diagram of cassava drying

For safe storage cassava must be dried to below 14% moisture content. The quantity of dry cassava produced will depend on the moisture content of the fresh tubers, the higher the moisture content the lower the yield of dry cassava (Table 1) thus 100 kilos of fresh cassava with a moisture content of 70% gives 11 kilos less product than fresh cassava with a moisture content of 60%. Hence it is important to select cassava varieties with a low moisture content.

TABLE 1 : YIELD OF DRY CASSAVA WITH THE VARYING MOISTURE CONTENT OF FRESH CASSAVA.

Weight of fresh cassava, kg.	% moisture content	Theoretical yield of dry cassava at 14% moisture content, kg.	Yield allowing for 5% processing losses, kg.
100	70	34.9	33.4
100	65	40.7	39.0
100	60	46.5	44.5

The drying process

The operations necessary for drying cassava are shown in Fig. 2. In the wet season and on heavy soils the tubers carry a large quantity of earth which, if not removed, is detrimental to both the visual and nutritional quality of the final product. Washing can be carried out by hand in a large concrete tank, Fig. 3. If the dry cassava is to be used as an animal feed neither the outer skin nor the peel of the cassava need be removed.

The drying operation is the most time consuming part of the process and to reduce this time to a minimum the cassava tubers are cut into regular sized chips of dimensions 1 x 1 x 5 cm. A machine developed in Malaysia has proved easy to construct and produces chips of approximately the right size, Fig. 4; the construction and operation of the chipper are given in Appendix 1. Once chipped the cassava is dried either on concrete patios or in inclined mesh trays. There may be situations where areas of concrete are already available and therefore both methods of drying will be described in the following section. Provided that the moisture content is reduced to 50 percent on the first day, cassava will not deteriorate for three days after chipping. However, cassava chips are always whitest when the drying time has been short.

Cassava chips are sufficiently dry for storage when they break easily and are chalky white throughout their cross section; the peel often takes longer to dry than the root itself. The brittle nature of dry cassava chips leads to abrasion and the production of a fine flour on handling, so to reduce losses in storage, sacks with a close weave should be chosen. Precautions must be taken to avoid damage by rodents and insects although poisons and insecticides should be used with extreme care in the vicinity of feeding stuffs. If the chips have to undergo prolonged storage it is advisable to examine them for moisture uptake and the formation of mould; further drying may be necessary.

Standards for dry cassava chips

Companies buying dried crops for incorporation into compound animal feeds often impose standards to maintain the quality of their product. The value of the crop will depend on whether these standards are met. Table 2 gives a range of specifications for the principal constituents of dried cassava. The moisture content is the most important factor and depends on efficient drying. The variety and age of the cassava will determine the starch content although high percentages of ash and fibre will reduce the percentage of starch. Dirty cassava will result in high ash contents, while the fibre content will be above the limit if foreign material like maize husks and cassava stalks are added to the product.

TABLE 2 : RANGE OF SPECIFICATIONS FOR CASSAVA CHIPS

Constituent	Percent	Dependent on
Moisture	10 - 14	Efficient drying
Starch	70 - 82	Variaty, age, ash and fibre content
Total ash	1.8 - 3.0	Clean roots
Crude fibre	2.1 - 5.0	No foreign fibrous material

Cassava drying on concrete

On many farms there are concrete patios which may be used for drying cassava. The chips are spread evenly over the surface of the concrete using the type of wooden rake shown in Fig. 5. Turning the chips is important to ensure uniform drying, especially in the initial stages when the cassava is losing large quantities of moisture, and should be carried out at intervals of two hours. The turning rake, (Fig. 6) forms rows of chips leaving strips of bare concrete between the rows which absorb solar radiation and heat up. Absorption of solar radiation may be made more efficient by painting the concrete black or, when a new patio is putdown, by adding a black pigment to the final cement layer. On rough patios the cracks fill up with white cassava dust which obscures the back surface and therefore drying patios should have as smooth a finish as possible.

A single layer of cassava chips is equivalent to between 5 and 7 kg/m^2 of fresh cassava per square metre. It is possible to put down thicker layers, but above 7 kg/m^2 the effect of a black surface is reduced and, above 10 kg/m^2 turning is difficult and must be carried out more often.

At night and before rain the cassava chips are swept up with wooden boards, (Fig. 7) and covered by sheets of plastic or canvas. Subsequent respreading is made easier if a number of small heaps are formed rather than one large one.

Concrete drying can make a product of high quality if the weather is fine, but under poor conditions repeated sweeping up and extending of the chips increases the formation of fines which are lost if the patio is not carefully swept after use.

Cassava drying in trays

Inclined trays should be employed where large quantities of cassava are to be dried or where the weather conditions are such that shorter drying times are necessary. The cassava chips are spread on trays which are wooden framed with bases of 1" chicken wire and fine plastic mosquito netting, Fig. 8. The trays are then placed at an angle by supporting them on a bamboo frame of posts and rails which is positioned so as to utilise to maximun advantage the direction of the prevailing wind, Fig. 9. The improved air circulation around the cassava chips results in faster drying without the need for turning the chips. The trays are positioned at the angle of repose of dry cassava chips which lies between 25 and 30°. The maximum angle should be employed, but in places with high wind speeds this may have to be reduced to prevent the cassava from sliding down the trays when the chips are dry.

The dimensions of the trays should be chosen to make best use of the materials available. For example, the trays in Fig. 10 are 0.90 m x 1.85 m with a depth of 5.5 cm and are robust and easy to handle.

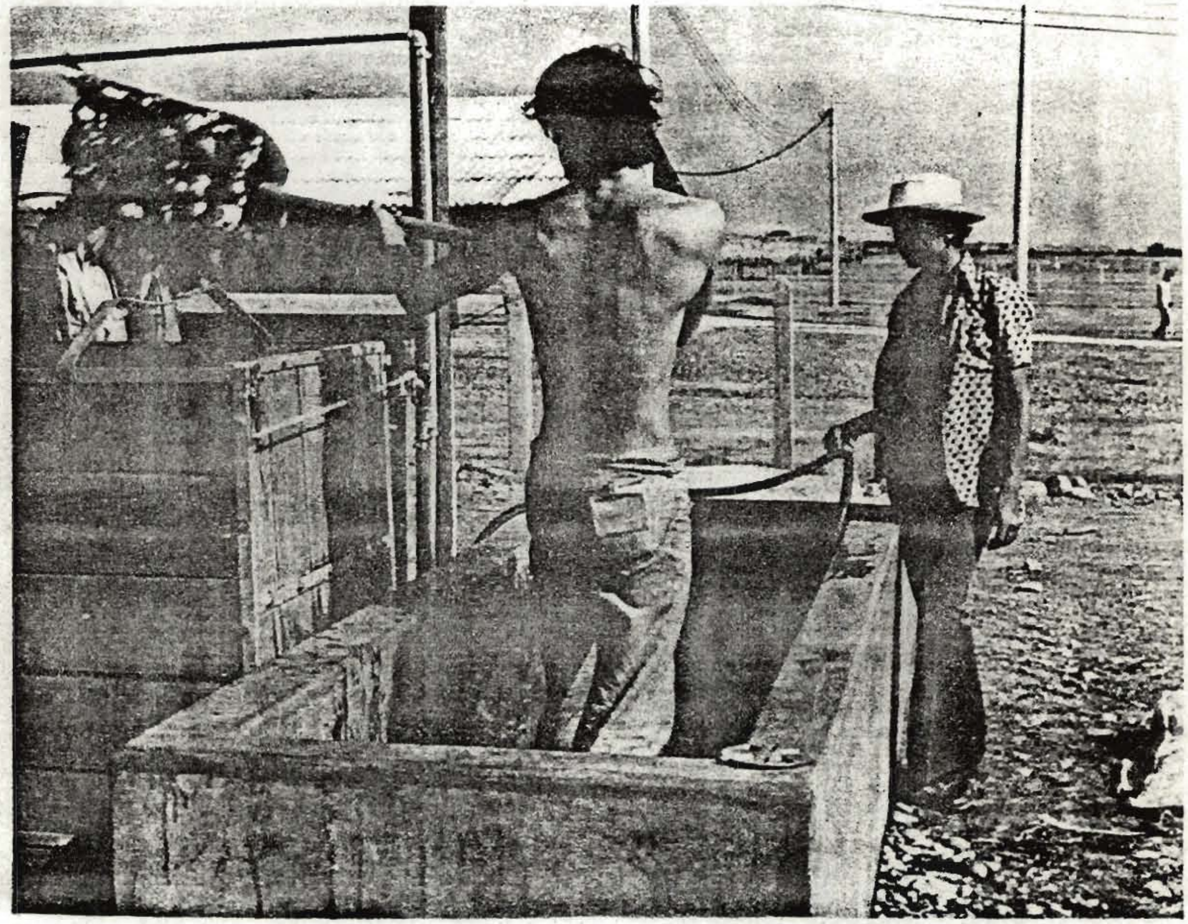


Fig. 3. Washing tank.

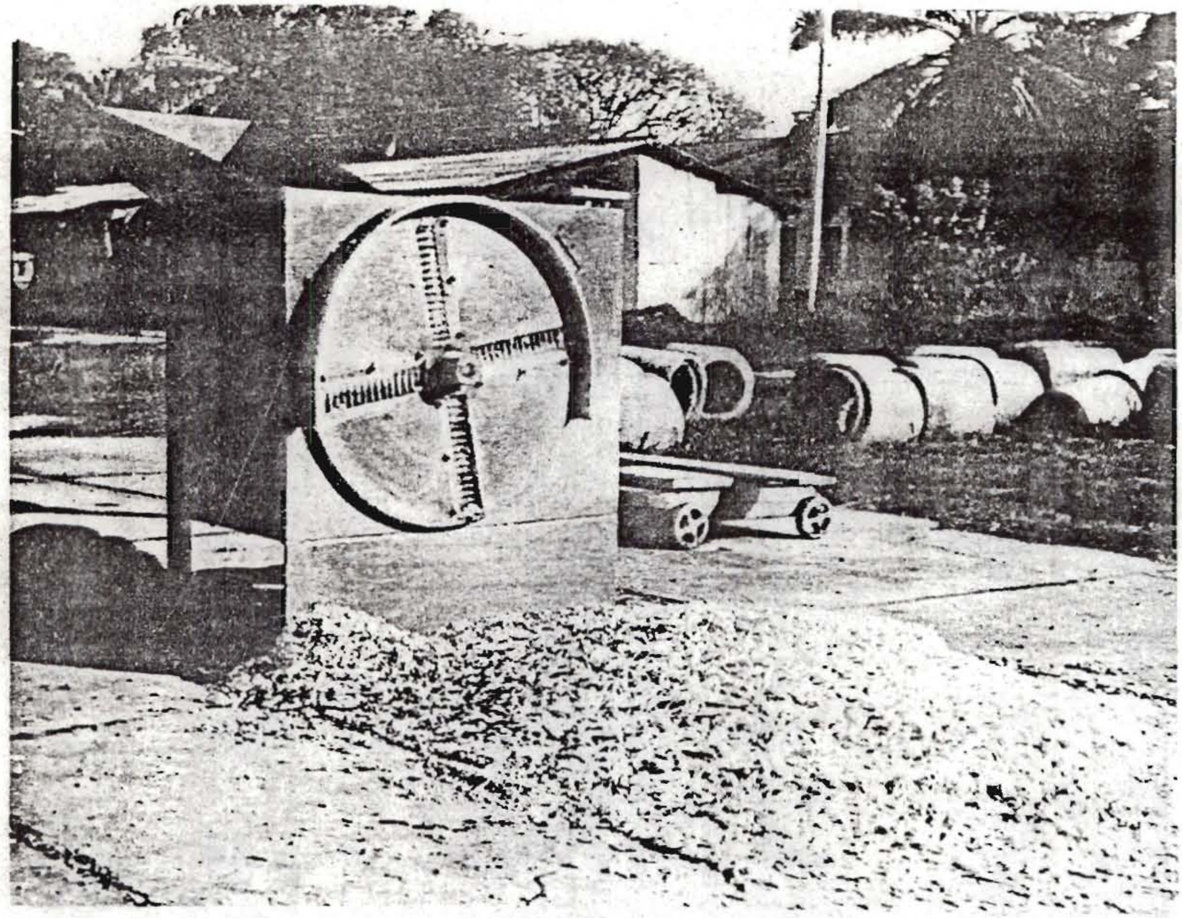


Fig. 4. Malaysian type chipping machine

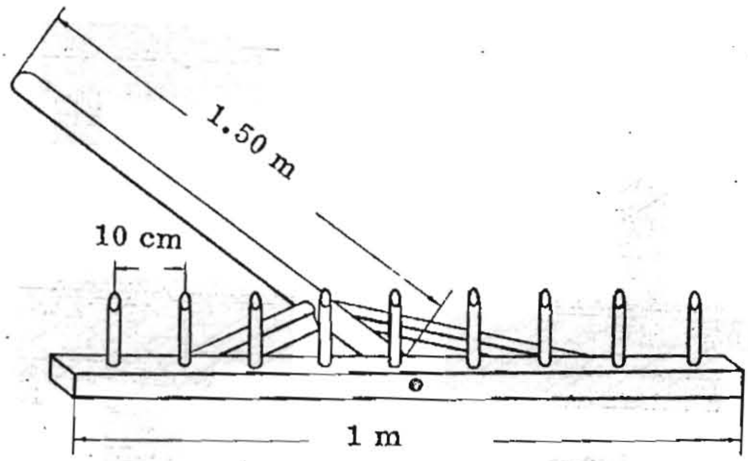


Fig. 5 - Wooden rake for spreading cassava chips on concrete

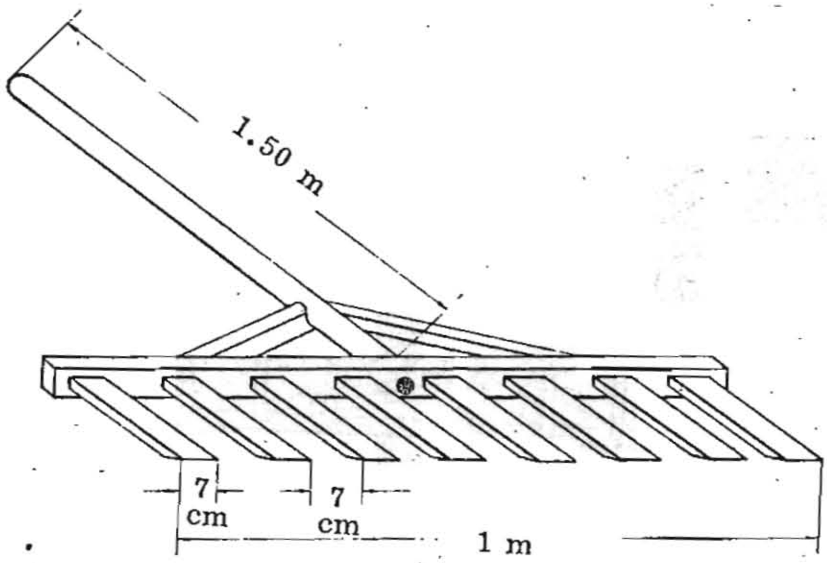


Fig. 6 - Wooden rake for turning cassava chips on concrete

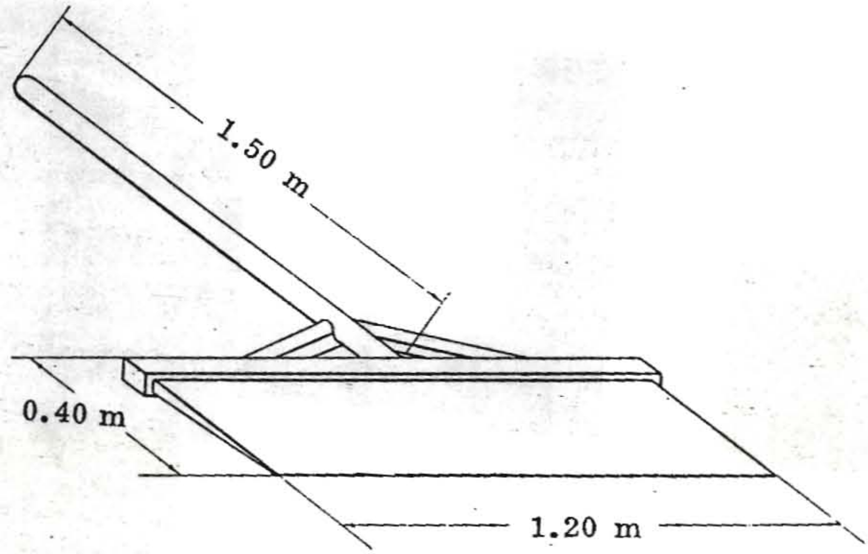


Fig. 7 - Wooden boards for collecting cassava chips at night or before rain.

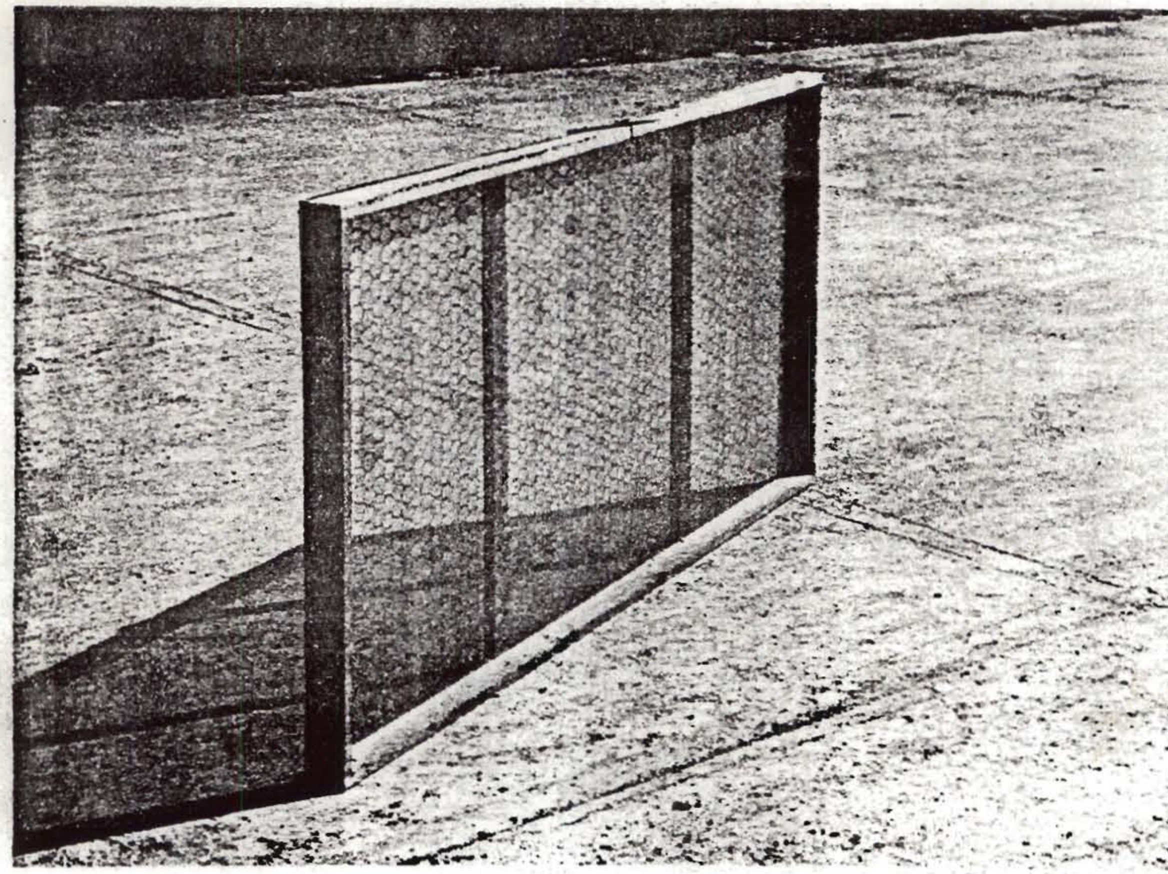


Fig. 8. Wooden framed drying tray.

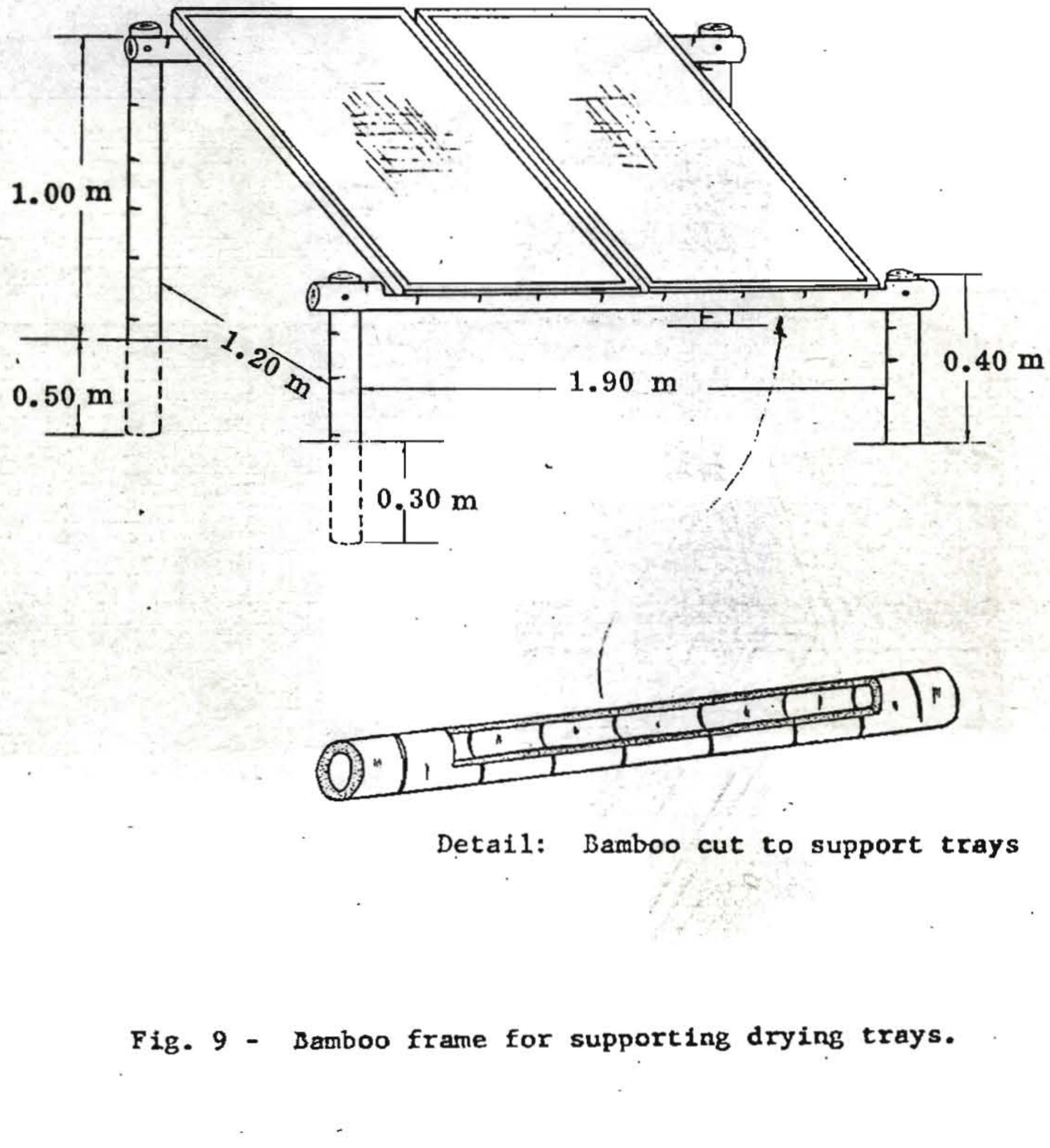


Fig. 9 - Bamboo frame for supporting drying trays.

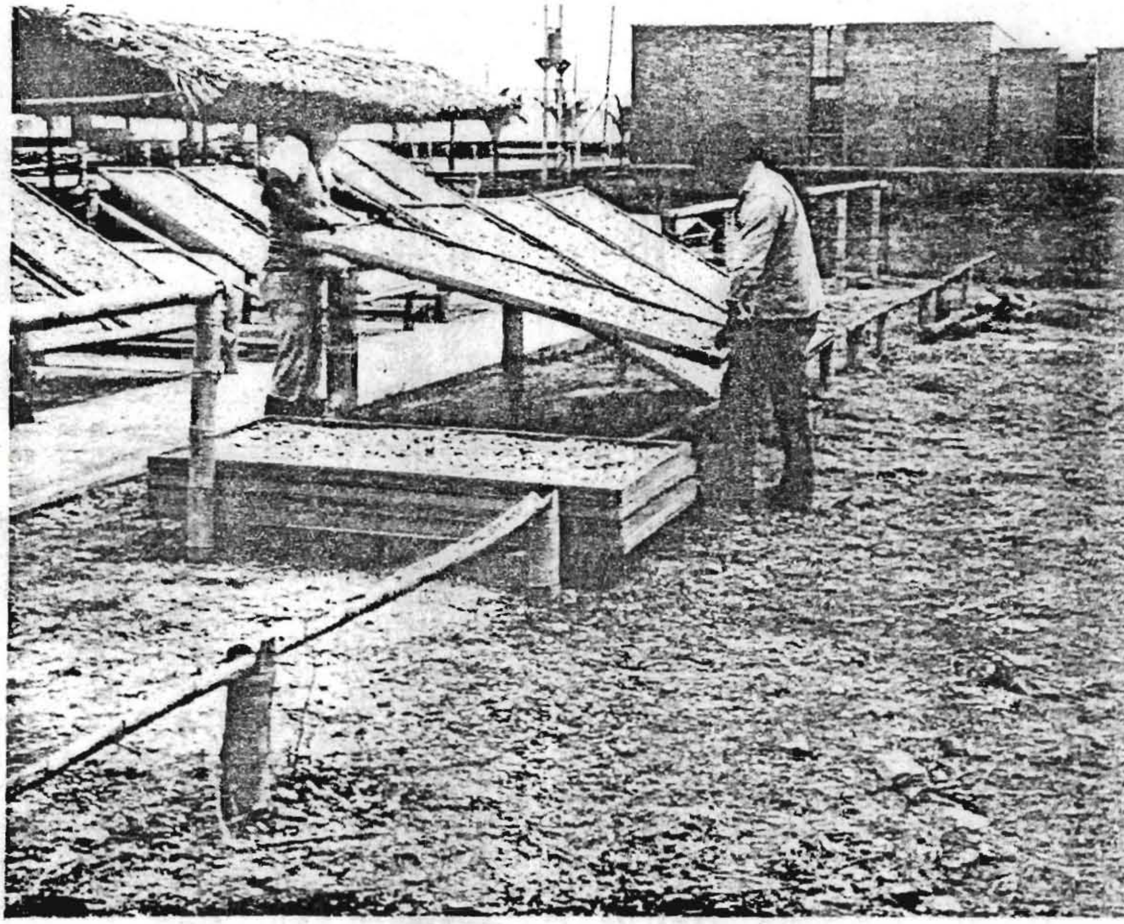


Fig. 11. Stacking trays at night or before rain.

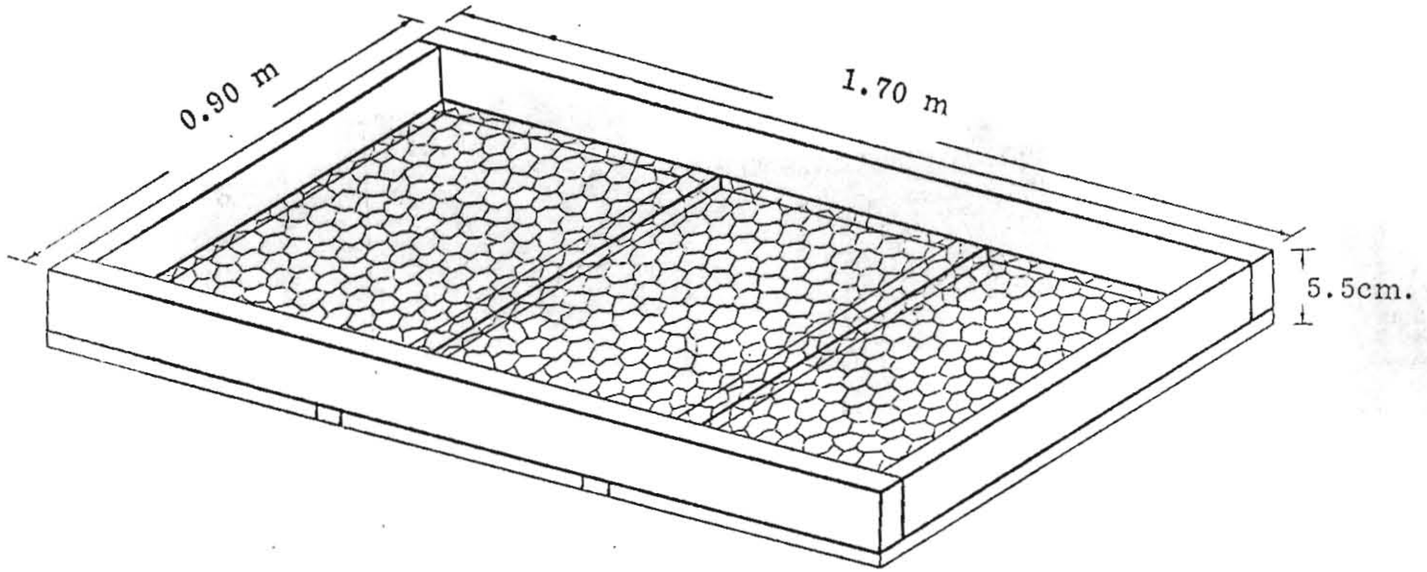


Fig. 10 - Wooden framed tray with bases of chicken wire and plastic mosquito netting.

The width corresponds to the width of the rolls of chicken wire and mosquito netting and the length is chosen to minimise the waste of wood. The wooden cross pieces and the chicken wire serve to support the mosquito netting. Wooden battens are then nailed around the bottom edge to secure the chicken wire firmly in place.

Any materials that are locally available can be used to construct the trays, although an alternative to mosquito netting with a larger mesh will result in losses of cassava through the holes. Losses using mosquito netting (35 holes/cm^2) represent less than 5% of the dry cassava whereas using hessian with approximately 3 holes/cm^2 losses increase to 15% .

The quantity of chips spread on each tray depends on the wind speed, at higher speeds thicker layers can be used without having to turn the chips. Table 3 gives typical loading rates for different wind speeds. The weight per tray need not be exact but it is important that each tray contains equal quantities of cassava. This may be ensured by first filling a container which holds the required amount per tray; using shovels alone to load trays is usually inaccurate. For trays of different dimensions the loading may be found by multiplying the tray area by the appropriate figure in column 4 of table 3 (tray loading in kilograms/$metre^2$). The thicker the layer the more difficult it is to spread the chips evenly and some respreading may be necessary.

Before rain, the trays are stacked horizontally one on top of each other with canvas or a sheet of corrigated iron covering the uppermost tray, (Fig. 11). The bottom trays is supported on two bamboo posts to keep it raised off ground. The trays need only be stacked at night if it is going to rain.

TABLE 3 : FRESH CASSAVA CHIP LOADING FOR TRAYS OF DIMENSIONS 0.90 x 1.85 METRES, AREA 1.67 $METRES^2$

Wind speed		Tray loading	
conditions	metres/second	kilograms/tray	kilograms/$metre^2$
Calm-light breeze	up to 1	17	Up to 10
Constant breeze	1 - 2	22	10 - 13
Steady wind	over 2	27	13 - 16

Time taken to dry cassava

The process of cassava drying can be divided into two stages:

1. an initial stage during which the fresh chips loose moisture rapidly and air movement in the form of wind is more important than the temperature or humidity of the air. Provided that there is sufficient wind speed this stage can be completed under cloudy conditions or even at night. Therefore in the seasons when rain is unlikely to fall, an appreciable quantity of moisture can be lost by leaving the trays on the drying racks overnight (Fig. 12). To make best use of this period the cassava should be chipped in the late afternoon and Table 4 illustrates the effect of the wind speed on the amount of water removed. In comparison, fresh chips left spread on concrete overnight lose only a small amount of moisture because of the inability to turn them and the low wind speed at ground level.

2. In the final drying stage, when the moisture content of the cassava has fallen to about 30% the removal of water is very slow, Fig. 13, and the lower humidities of midday are required to complete the drying process. During this stage the relative humidity of the air must fall below 65% for the moisture content of the cassava to reach a safe storage value. On some days, particularly in the rainy season, the relative humidity remains above 65% and the drying time is prolonged until the weather improves. Provided that the initial drying stage has been completed the cassava, will not deteriorate for two or three days.

A number of trials were carried out at different locations to determine the drying time under varying climatic conditions. The results are shown in Table 5 and illustrate the following points:

a. Drying usually takes more than 10 hours (one day) but less than 20 hours (two days). Only under exceptional weather conditions will cassava dry in less than one day. However, where there are low wind speeds and low solar radiation drying may extend into a third day as happened occasionally at location 2.

b. Approximately the same number of hours are required to dry twice the quantity of chips per metre^2 in trays compared with concrete.

c. In areas with high humidities (locations 1, 2 and 5) cassava dries more quickly if there is high wind speed.

Fig. 12 - Cassava tray drying curve.
Drying started at 5 p.m. and continued at night.

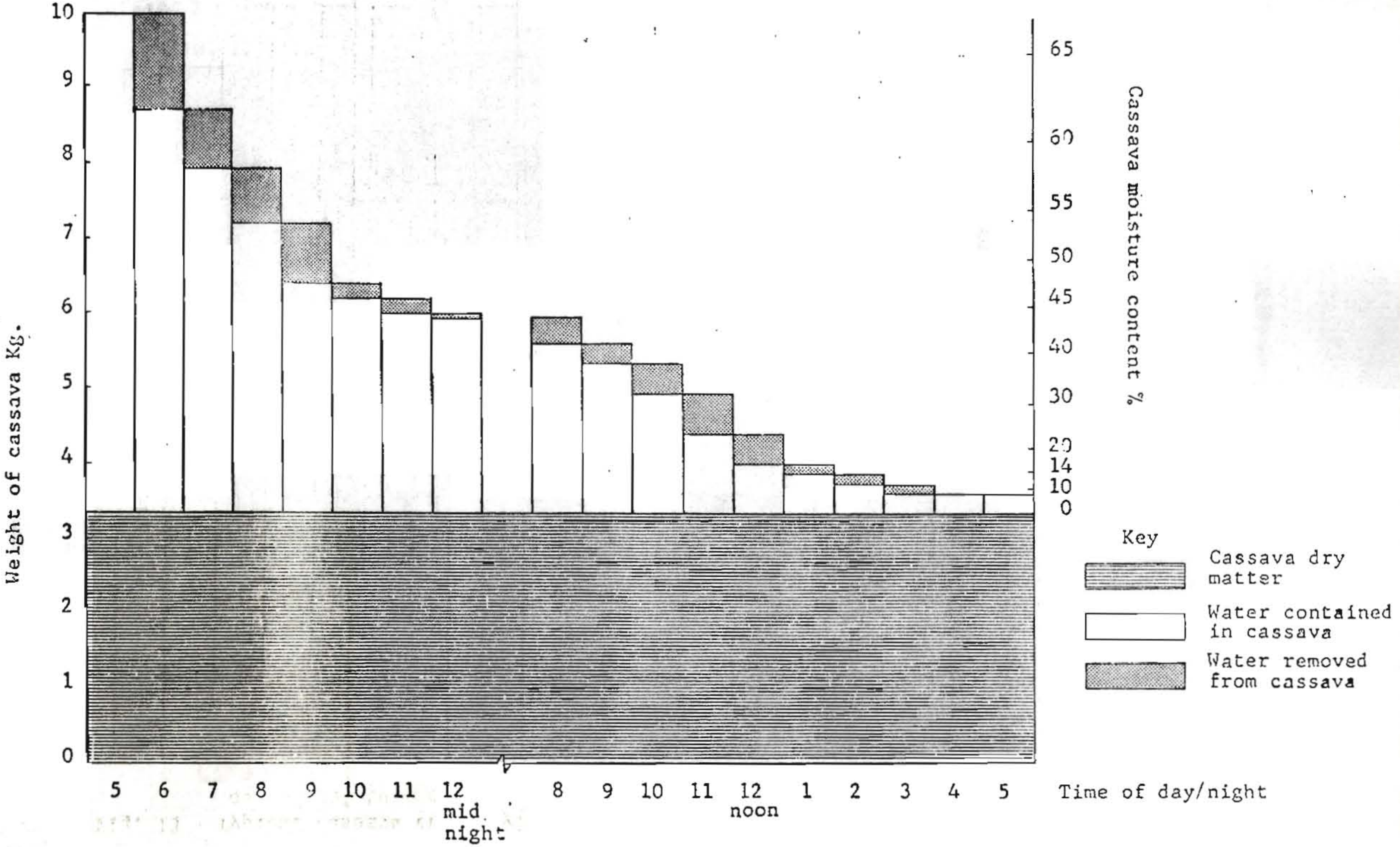
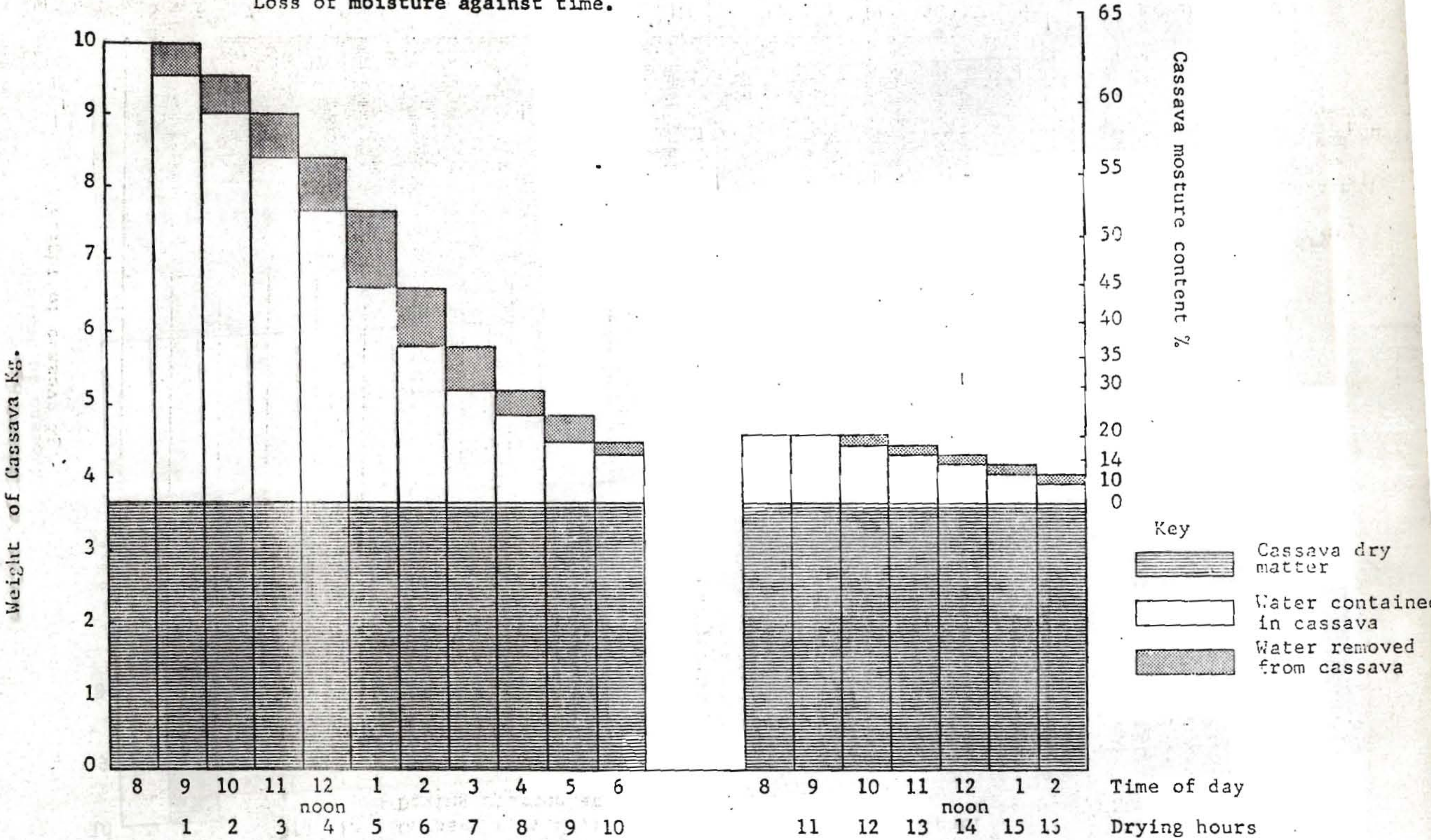


Fig. 13 - Typical cassava tray drying curve. Loss of moisture against time.



Chipping and drying costs

The cassava chipper can be constructed by small local workshops. In 1977 the cost of having one machine made in Colombia was US$220, and with a 3 hp petrol engine the total cost was US$400.

The costs of the materials required for laying concrete and making trays are shown in Table 6. The prices of cement, sand, gravel and wood include a transport cost to CIAT which is approximately 20 km from the point of origin of the materials. Therefore in more isolated places these prices will be higher. The cost of trays per square mater of drying surface is greater than that of concrete drying floors. However, taking into account the higher loading rate possible, a 35% saving in capital outlay could be made using a tray drying system. Both the cost of maintenance and the life of the trays depend on the care with which the trays are made and handled, whereas a concrete patio requires little maintenance and will last indefinitely.

Washing, chipping and spreading of the chips are the most time consuming operations in terms of manpower and careful positioning of the washing tank, chipper and drying area will help to reduce this time. The handling of the cassava after spreading is made considerably easier by the use of trays because neither turning nor respreading are necessary. In terms of the labour required for the whole process a saving of twenty per cent is made, (Table 7).

TABLE 7: Labour requirements for chipping and drying one ton of cassava with two operators

Activity	Labour, man - hours	
	Concrete drying	Tray drying
Weighing and washing cassava	3	3
Chipping cassava	2	2
Total	5	5
Extending over concrete/trays	2	2
Turning, 4 times per day	1.5	-
Collecting and covering at night	1	1
Turning	1.5	-
Collecting and bagging	2	2
Extending in the morning	1.5	1
Total	9.5	6
Total labour	14.5	11

TABLE 4: The loss of moisture between 5 pm and 8 am in five locations with different climatic conditions. Inclined tray drying with 10 kg of fresh cassava per metre^2.

Location	Average climatic conditions between 5 pm and 8 am: Temperature °C	Humidity %	Windspeed m/s	Cassava moisture content % at 5 pm	at 8 am	% loss of water 5 pm to 8 am %
1	19	87	0.30	59	58	7
2	20	87	0.45	60	57	11
3	22	79	0.87	63	47	48
4	27	71	0.35	61	50	34
5	27	84	0.15	64	61	10

TABLE 5: Hours required for drying cassava to 14 percent moisture content in five different locations. Drying between 8 am and 6 pm.

Location	Temperature °C	Humidity %	Windspeed m/s	Solar radiation cal/cm^2/s	Inclined trays loades at 10 kg/m^2	Black concrete loaded at 5 kg/m^2
1	24	70	1.9	0.73	12	11
2	26	67	0.8	0.58	19	17
3	26	66	1.2	0.61	13	15
4	30	64	0.9	0.65	12	10
5	31	68	1.0	0.71	13	13

TABLE 6: COMPARISON OF MATERIAL COSTS, US DOLLARS

a. Concrete drying patio, material requirements for 10 cubic metres of concrete equivalent to 100 square metres of drying surface.

Item	Unit	Unit Cost $	Units Required	Cost $
Cement	Sack	1.50	40	60.oo
Sand	m^3	3.00	5	15.oo
Gravel	m^3	4.10	10	41.oo
Black pigment	Kg	1.40	20	28.oo
Wood boards	2.80 x 0.24x0.025 m	1.10	30	33.oo
Total				177.oo
5% losses				9.oo
Total cost				186.oo
Cost per square metre of drying surface				1.86
Cost per kg of fresh cassava loaded at 5 kg/m^2				0.37

b.

Tray drying, material requirements for 60 trays (1.85 x 0.90 x 0.55 m) and supports equivalent to 100 square metres of drying surface.

Item	Unit	Unit Cost $	Units Required	Cost $
Wood	2.80 x 0.24 x 0.025 m	2.70	42	113.40
1" Chicken wire	0.90 x 36 m roll	18.90	3.2	60.50
Plastic mosquito netting	0.90 x 30 m roll	11.50	3.8	43.70
Nails	kg	0.82	10	8.20
Bamboo	m	0.14	255	35.70
Total				261.50
5% losses				13.10
Total cost				274.60
Cost per square metre of drying surface				2.75
Cost per kg of fresh cassava loaded at 10 kg/m^2				0.28

CONCLUSIONS

1. Cassava roots deteriorate rapidly after harvesting and for long terms storage they must be chipped and dried to below 14% moisture content. Drying can be carried out on the farm by spreading the chips either on concrete patios or inclined mesh trays.

2. The drying time depends on the climatic conditions and the loading of chips on the drying surface. The shorter the drying time the higher the visual quality of the product.

3. On concrete patios the loading of fresh cassava is limited to a maximum of 10 kg/m^2, above this quantity even spreading and turning is difficult. The optimum loading is between 5 and 7 kg/m^2.

4. In trays the air circulation around the chips is improved and no turning is necessary. Trays can be loaded with between 10 and 16 kg/m^2 depending on the windspeed.

5. With average daytime temperatures above 23°C and relative humidity below 70%, drying takes between 1 and 2 days when chips are dried at 5 kg/m^2 on concrete or at 10 kg/m^2 on inclined trays. Therefore, in the same time, approximately double the quantity of chips can be dried per square meter on trays as compared with concrete.

6. Tray drying gives the advantage that, in regions with appreciable windspeeds, the night hours can be used to remove moisture from freshly chipped cassava. The lower humidity during the following day are then available to complete the drying process.

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ROA, 6 1974. Natural drying of cassava. Ph.D. Thesis. Dep. of Ag. Eng. Michigan State University.

APPENDIX 1.

Construction and operation of the cassava chipper

The frame, rotor disc drive shaft and feed hopper are manufactured as shown in drawing D 1. The rotor disc is mounted on the drive shaft and fixed in the bearings (bought in standard items) on the frame. The hopper is fitted in position.

A rotor speed of 500 rpm is required and this may be achieved via belt drive to 3 BHP motor. The machine can also be driven via a powered wheel tractor provided that the correct output speed can be obtained.

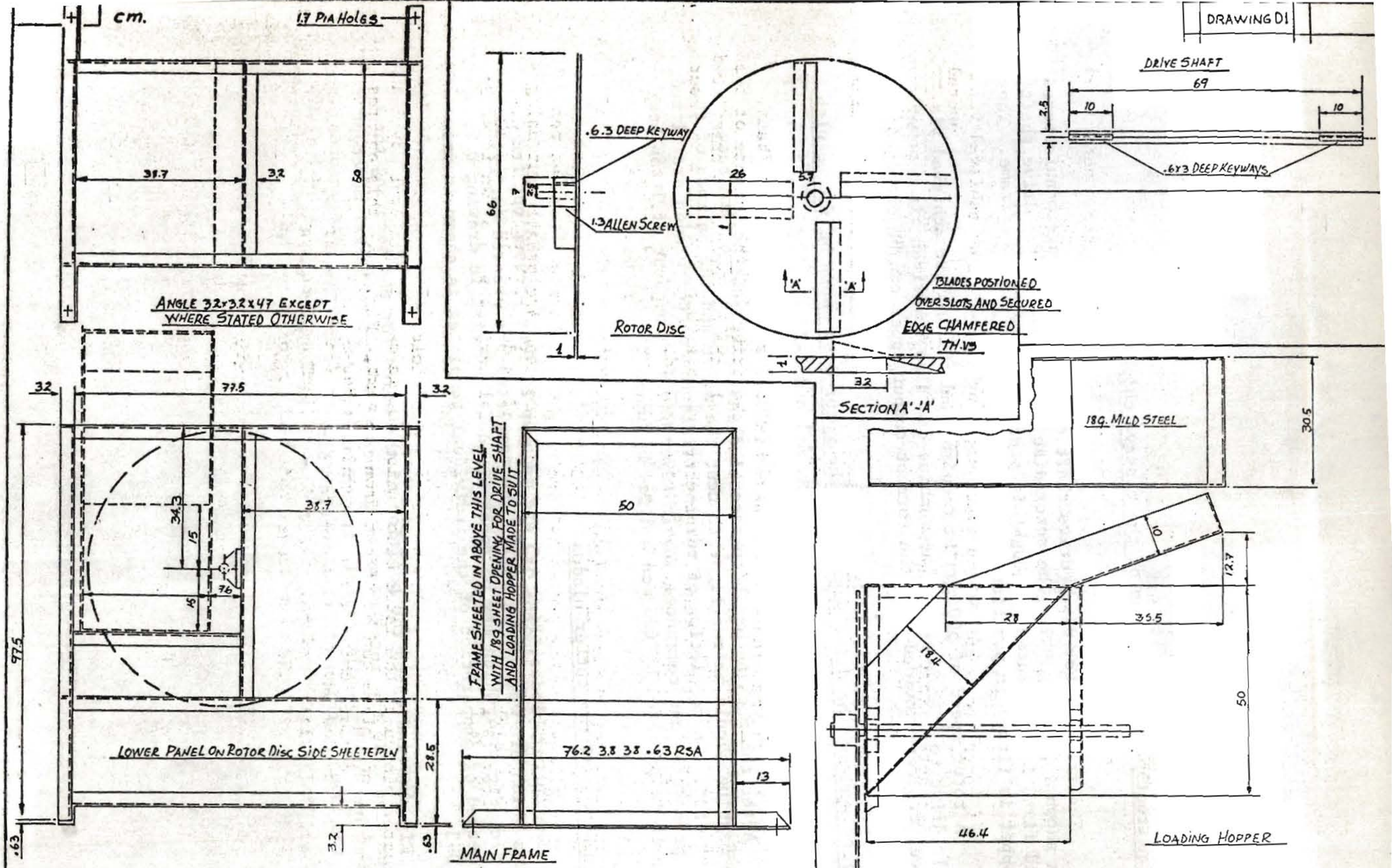
Before running, the drive system and the rotor disc must be fitted with guards to protect the operators, Fig. A-1 and A-2

After the machine has been assembled and secured to a firm base, the machine should be run light to test the drive and the balance of the rotor disc. On completion of running trials the cutter blades are fitted and processing can commence. The chipper has a throughout of 1 ton/hour when it is operated by two men and fed by hand.

Manufacture of the cutter blades

The cutter blades, Fig. A-3 are made up of four pressed out templates which are welded together. The templates are pressed out using the die. Fig. A-4, which may be constructed as detailed in drawing D 2; the method of preparation of the individual templates is shown in drawing D-3.

Fig. A-5 indicates the position of the holes for the securing the cutter blades to the rotor disc allowance is made for lateral movement so that one blade can be offset from the next, Fig. A-6; this ensures that the cassava chips are of a regular size.

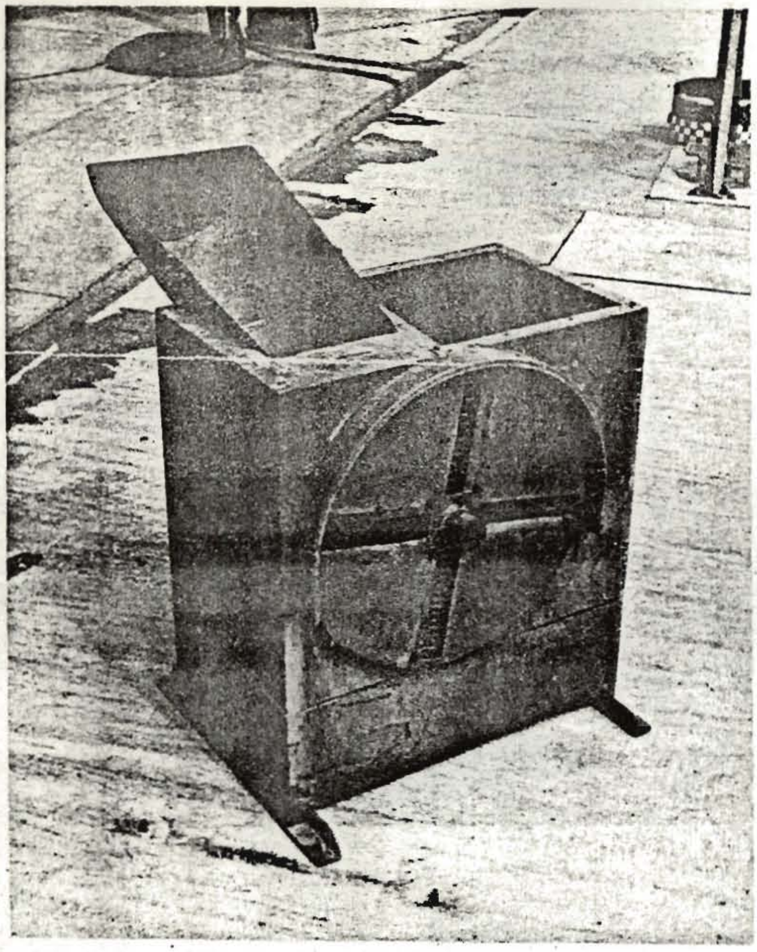


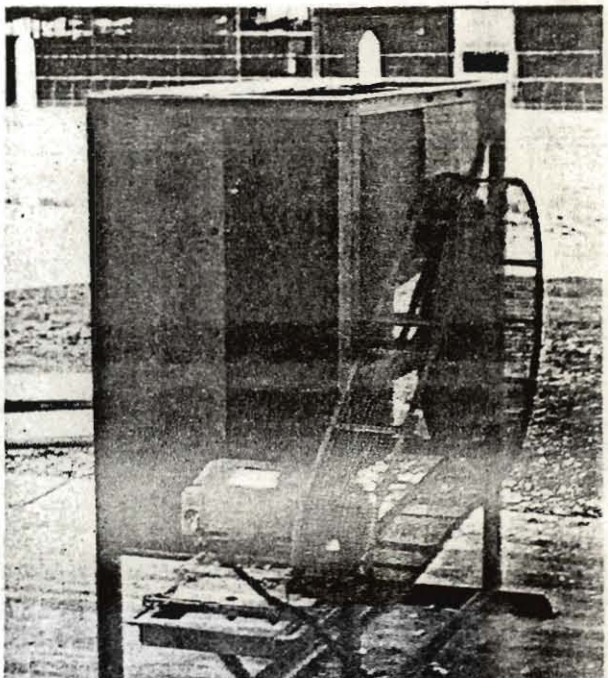
SCALE 2 : 25

Dimensions in cm.

MAIN DETAILS OF CASSAVA CHIPPER

TROPICAL PRODUCTS INSTITUTE
ENGINERINNG SERVICES CULHAM OXON





Figs. A1, A2. Front and back view of chipper.

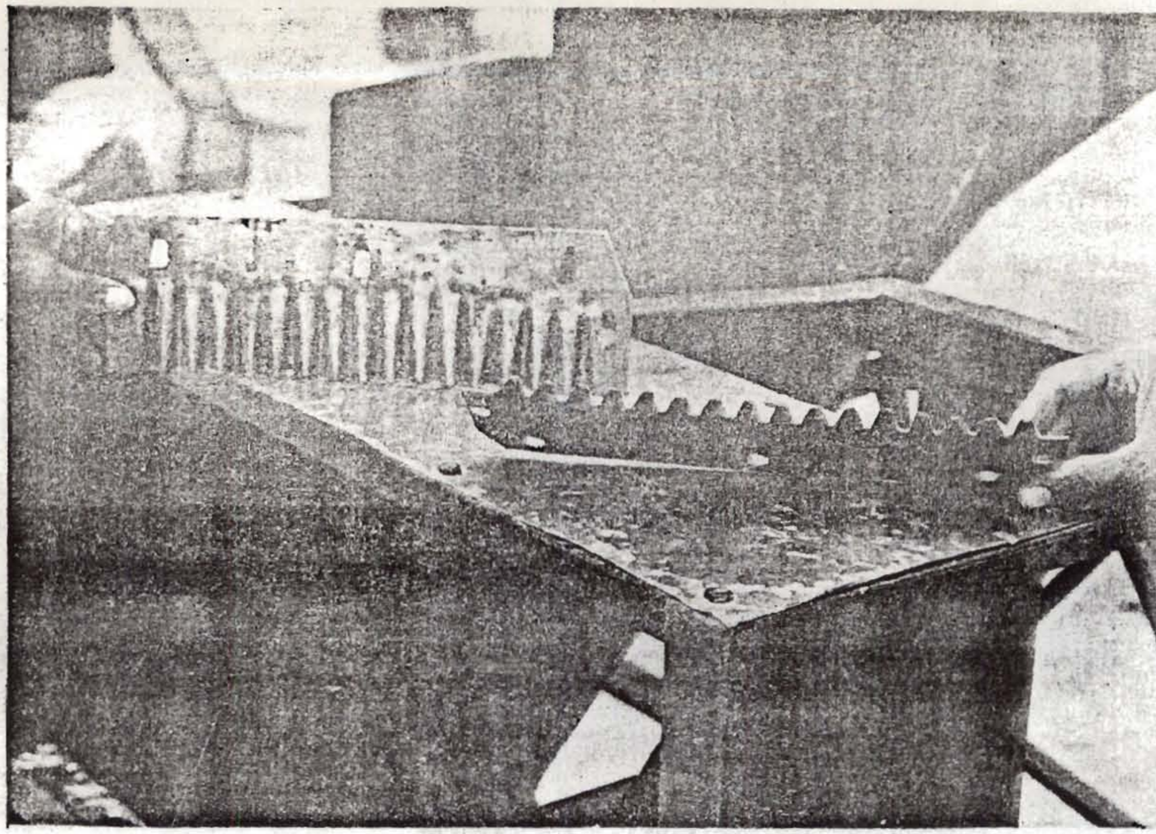


Fig. A3. Cutter blades.

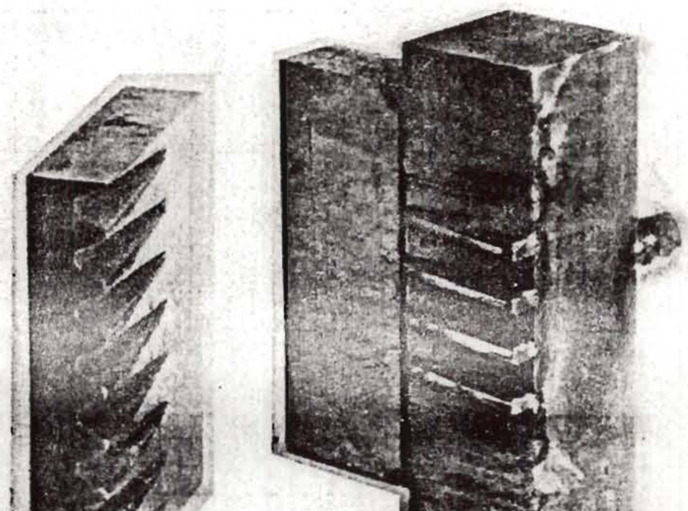
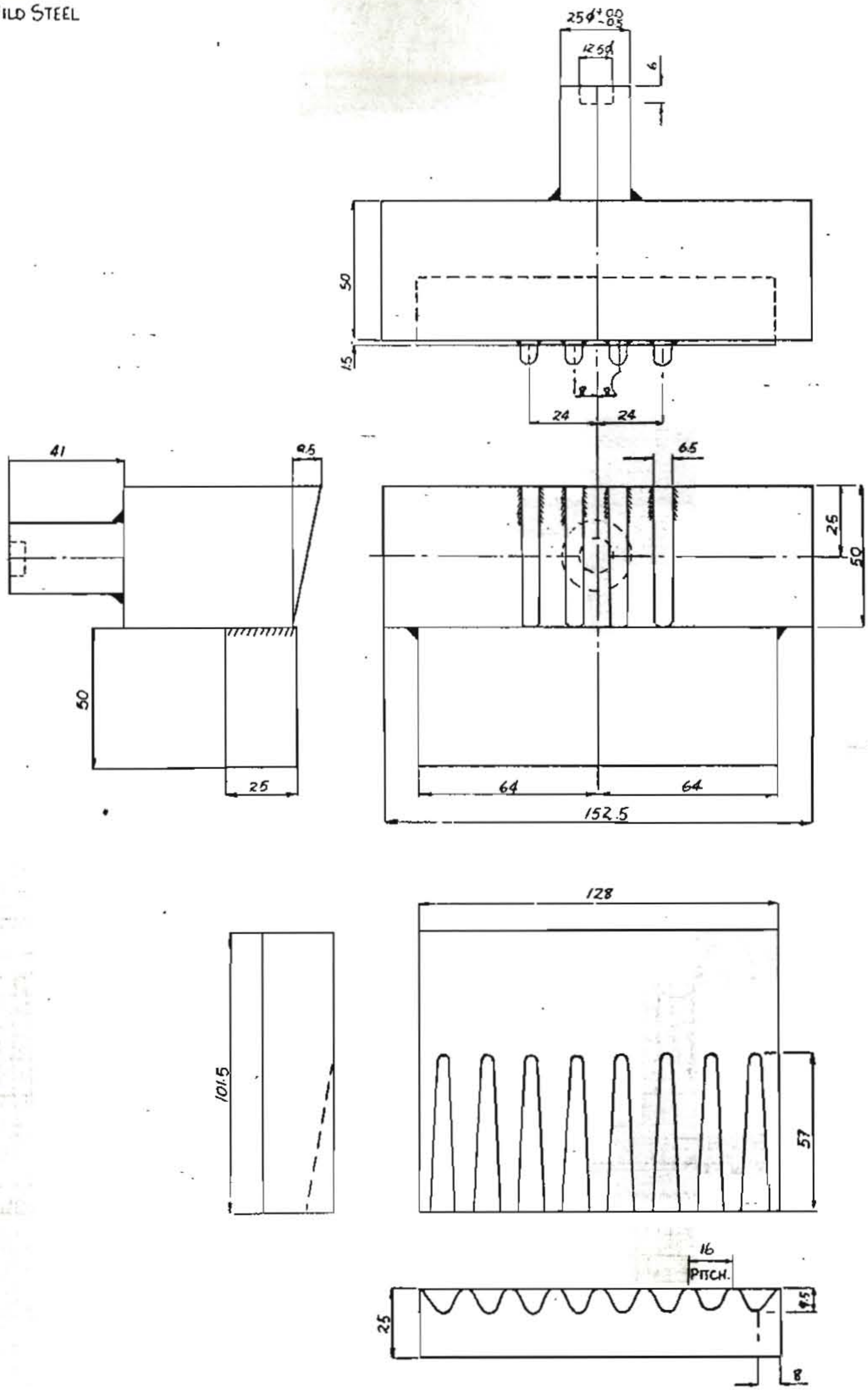


Fig. A4. Die used to press out the templates.

DIMENSIONS IN MILLIMETRES

BR MILD STEEL

DRAWING D 2

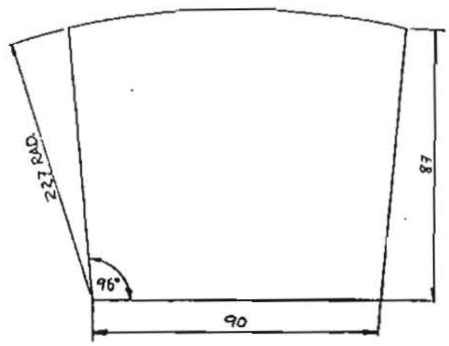


BLADES AND DIES

DRAWING D 3

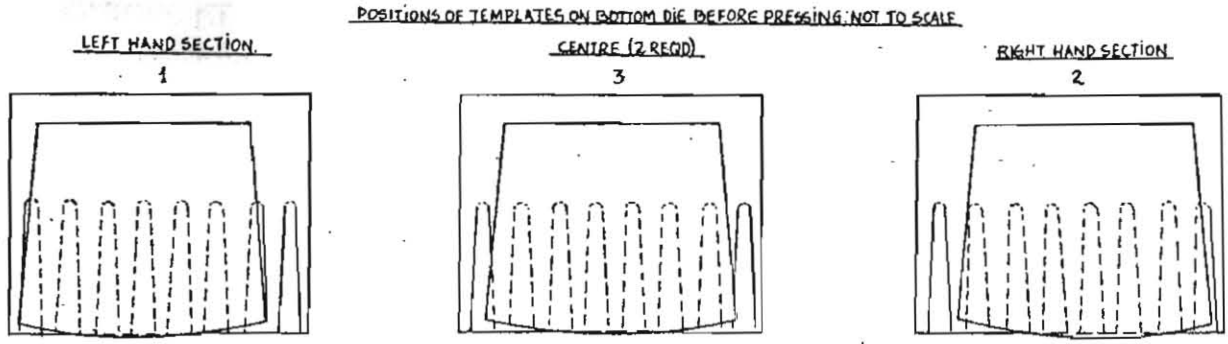
DIMENSIONS IN MILLIMETRES

BR MILD STEEL

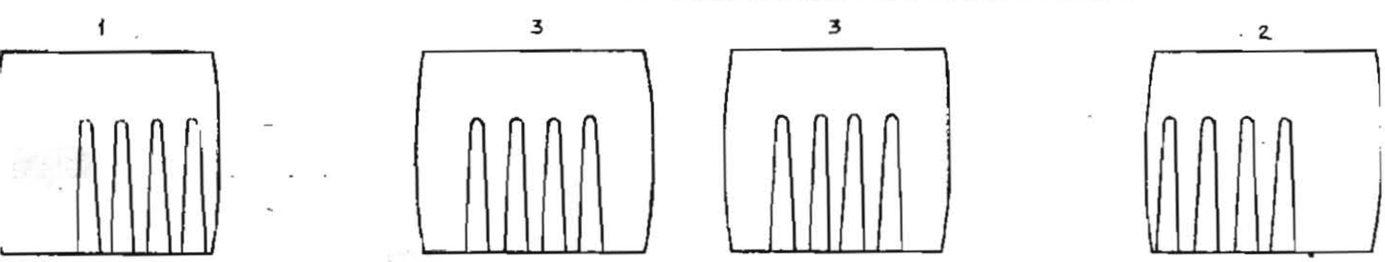


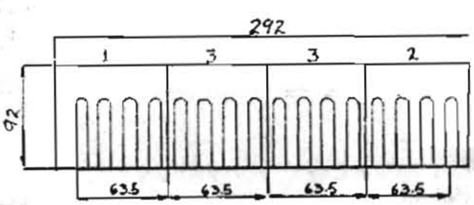
FULL SIZE TEMPLATE 18 S.W.G.
FOUR REQD. FOR EACH COMPLETE BLADE

POSITIONS OF TEMPLATES ON BOTTOM DIE BEFORE PRESSING: NOT TO SCALE



4 BLADES PRESSED OUT SHOWING UNTRIMMED EDGES NOT TO SCALE





COMPLETE BLADE NOT TO SCALE
EDGES TRIMMED SQUARE BEFORE WELDING

BLADES AND DIES

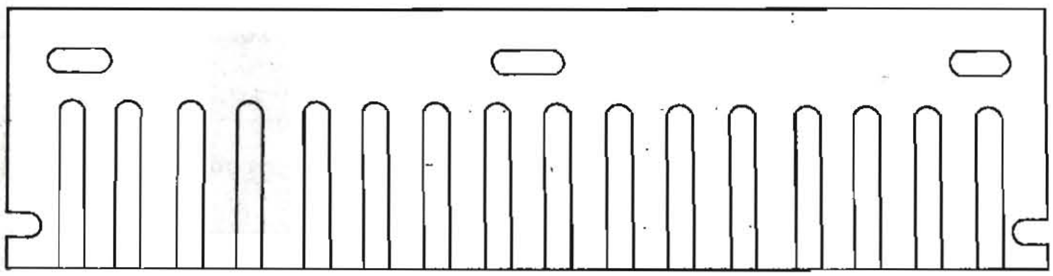


Fig. A5 - The position of holes for securing the cutter blades to the rotor disc to allow lateral movement.

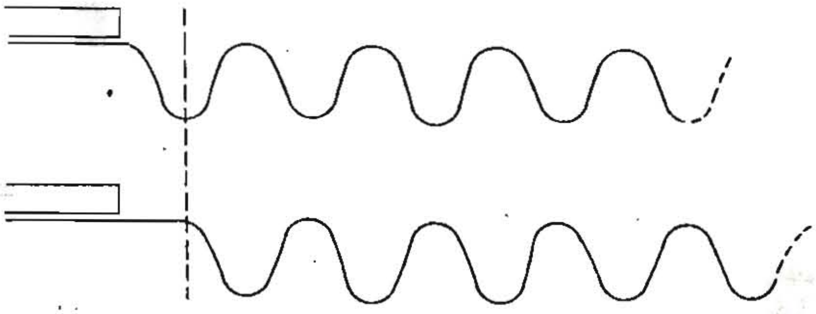


Fig. A6 - The offsetting of one blade from the next to give regular sized chips.

SUGGESTED GUIDELINES FOR CONDUCTING REGIONAL TRIALS

Julio César Toro M.

Regional Trial

Regional trial is an experiment where a large number of varieties (no more than 20) are agronomically evaluated under a uniform technology to see its geographical adaptability and yield potential over a wide range of ecological conditions as compared to the best local prevalent variety.

Objectives

1. To validate current cassava technology produced by the cassava program team.

2. To transfer this techonology to national agencies once it proves adequate results.

3. To extrapolate results to other parts of the world.

Criterion

Since we can not have a germplasm bank everywhere we need to evaluate our promising materials across contrasting regions once this material has already undergone preliminary yield trials conducted by the Breeding pro - gram. We have to measure the performance of these varieties before we think in releasing them to the national agencies.

Guidelines

1. Identify collaborating Institutions. National agencies must have the need and interest in cassava before we think in planting a trial, otherwise, it could be a waste of time and effort.

2. Selection of sites. In a given country, we should consider, the actual cassava growing areas so that trials are more representative and most relevant. These sites should be selected in visible fields so that farmers of the region have an easy access to them.

3. Identify the responsible person. Usually, we prefer to work with a person in which we can trust, and relay in order to get appropriate management of the trial. We prefer to give a training to this person, before a Regional trial is undertaken.

   Usually, we can not trust in data that an inexperienced person in cassava will hand to us. We have to be sure that data is fine and well taken so we can be confident of what it represents and means.

4. Time of planting . This is decided after consulting with cassava farmers of what is the most common time they use in a given region. Since the trials are not irrigated, we usually plant at the beginning of the rainy season.

5. Time of harvesting. We follow the most common practice used by the farmers of the region under study. In the case of Colombia, this usually occurs between 10 and 12 months in regions below 1.000 meters of elevation; above this altitude we delay one month for every 100 meters of elevation. As a rule of thumb.

6. Design. The trials should be planted in randomized blocks with a minimum of four replications.

7. Size of the plot. Plots located at the end of each block will have 9 x 8 72 plants and those located in the middle will have 8 x 8 = 64 plants. In both cases, the area occupied by the middle 24 plants will be harvested from each plot. In plants are missing at harvest, they should not be replaced by border plants. The number missing should be noted. Yield will be given by area not by number of plants in the plot.

8. Border rows. As can be seen in the enclosed diagram, it is recommended to leave 2 border rows in each plot for each variety in order to eliminate border effects because of competition for light and water mainly due to the different growth habits of the varieties.

9. Aisles. For demonstration purposes and to take notes each time is needed, the block should be spaced by aisles 3-4 meters wide according to limitation of the field.

TECHNOLOGY USED

1. Seed selection. Seed is selected from mature, clean and healthy cassava plants generally obtained by the rapid propagation system. From selected plants we cut stakes of 20 centimeters of lenth and after they are cut, we select the ones with adequate number of buds, without any cankers, mechanical damage, improper cut, spots or galleries in the central pyth.

2. Seed treatment. Since no selection can be applied as to find resistance to soil pathogens and insects we use a simple and inexpensive mixture of fungicides and one insecticide to protect the cuttings in the soil and to ensure a good stablishment of the crop.

3. Population. We plant 10.000 cuttings per hectare usually on the 1 x 1 pattern unless the growing habits of farmers mostly determined by the type of machinery they use do not allow rows at one meter. In all cases population is fixed.

4. Cuttings required. For those varieties planted at the ends of each block and additional eight cuttings will be required for each replication. An additional 10-15% of cuttings of each variety should be prepared so as to be able to replant each block to a full stand in those cases where germination is not complete.

   To take care of all unforseen situations, a minimum of 320 cuttings of each variety should be available for each regional trial.

5. Soil preparation. We follow the best common practice in the region. In regions where rainfall is more than 1200 mm per year and soils are heavy we make ridges. This is to avoid root rot diseases to occur. The height and width of ridges changes with the machinery available.

6. Planting position. Cuttings are planted vertically with buds facing up and trying to get at least four buds below the soil. Vertically planted position seems to be the safest way to plant cassava. In a region of adequate amount of rain and good distribution it could be the same to plant horizontally or vertically. In this case all buds with good moisture and high temperature will germinate without problems. In regions with erratic rain if cuttings are planted horizontally they may not germinate because of the following reasons:

   a. cuttings are more vulnerable through their buds which constitute the less lignified tissue easier to penetrate by any pathogen and or insect.

   b. Since soil temperature is always higher than air temperature, buds may cook and roten. When a cutting is planted vertically in a region of erratic rain one extreme of the cutting is deeper and closer to available moisture and the other extreme having some buds on the outside may permit sprouting because they do not suffer of excess heat since the cutting on the outside serves to diffuse heat.

7. Herbicide and Insecticide application. To avoid weed and insect problems the application of a mixture of herbicides and one insecticide is an standard practice. The insecticide we are using is Toxaphene DDT-40-20 without incorporation. Other insecticide, specially Aldrin, can be used if this is not available. Both at the rate of 1 gallon per hectare.

8. Insect control. Will be given only to severe attacks of Hornworm. Biological control will be prefered but when is not practical as the last resource a contact narrow spectrum insecticide as Dipterex could be used. Other insects should not be controlled to check the varietal differences.

9. Fertilization. Fertilization should be carried out according to the prevailing local practices with cassava. Since in many areas the crop is not fertilized it is also desirable, where resources permit, to use a fertilizer level based on sound agronomic recommendations in addition to the prevailing local practice. In the case of Colombia, we are only applying medium levels of fertilizer to Carimagua and Santander de Quilichao Oxisoils.

10. Visits required. A minimum of 7 visits will be required as follows:

1. To select the site and order soil preparation
2. To plant
3. After 20-25 days to replant
4. After 2 months to observe weeds and weed control if necessary.
5. After 4 months to observe diseases, insects and weeds.
6. After 7 months to observe diseases, insects and weeds.
7. To harvest the crop.

In all visits careful notes of problems and developlent are taken.

11. Collection of data

a. Soil analysis. Should be as complete as possible making a characterization of it including minor elements as Zinc, Iron, Boron, Manganese, and Cooper. A history of the field where trial is planted should be recorded too. This should include at least the following items: location, municipality, state, altitude, latitude, mean anual temperature, mean annual rainfall, soil texture, soil classification, former crop, fertilizer and pesticides used.

On each site a raing gauge must be installed so that rainfall amount and distribution can be measured.

b. Germination. Between 20 and 30 days after planting germination must be checked. Plots with less than 80% germination should be discarded. Where replanting is needed it should be performed within 3-5 weeks of the original planting date. On cuttings nor germinated or germinated with poor vigor or symptoms of problems they should be dig out and find out the cause of the problem. Items to be checked as responsible for bad germination are:

1. Rot cutting
2. Cutting too dry
3. Cutting too thin
4. Cutting too thick
5. Cutting without roots
6. Cutting planted, upside down (inverted cutting)
7. Bad cut
8. Bad buds
9. Root insects
10. Cutting insects
11. Insects in shoots
12. Leaf insects
13. Deformed bud
14. Rot shoot
15. Difficulty in emergency (lack of vigor)
16. Cutting in a puddle
17. Others.

The total number of plants properly germinated should be recorded.

c. Prevalents Weeds. The magnitude of the infestation should be recorded indicating the type of weeds. Common and scientific names.

d. Important diseases. 23 items can be recorded according to incidence of prevalent diseases.

	Common name	Scientific name
1.	Cassava bacterial blight	Xanthomonas manihotis
2.	Bacterial stem rot	Erwinia sp.
3.	African Mosaic	Unknown causal agent
4.	Common Mosaic	Caused by a virus
5.	Leaf Vein Mosaic	Caused by a virus
6.	Witches' Broom	Micoplasma
7.	Brown leaf spot	Cercospora henningsii
8.	Blight leaf spot	Cercospora vicosae
9.	White leaf spot	Cercospora caribaea
10.	Concentric-ring leaf spot	Phoma (Phyllosticta) sp.
11.	Superelongation	Sphaceloma manihoticola
12.	Cassava ash	Oidium manihotis
13.	Anthracnose	Colletotrichum or Glomerella manihotis

14. Rusts	Uromyces spp.
15. Stem rot	Various pathogens
16. Frog skin	Unknown causal agent
17. Root rot	(various pathogens) Phytophthora Drechsleri
18. Root rot	Phytium spp.
19. Root rot	Rosellinia necatrix
20. Root rot	Armillaria Mellea
21. Root rot	Fomes lignosus etc.
22. Post harvest root rot	Physiological and or pathogenic causes.
23.	
24. Others	

e. Important pests

Common name	Scientific name
1. Mites	Mononychellus tanajoa
2. Mites	Tetranychus urticae
3. Mites	Oligonychus peruvianus
4. Thrips	Frankliniella williamsi
5. Thrips	Corynothrips stenopterus
6. Thrips	Caliothrips masculinus
7. Cassava hornworm	Erinnyis ello
8. Shoot fly	Silba pendula
9. Shoot fly	Carpolonchaea chalybea
10. Fruit fly	Anastrepha pickeli
11. Fruit fly	Anastrepha manihoti
12. White fly	Aleurotrachelus sp.
13. White fly	Aleurothrixus sp.
14. White fly	Bemisia tabaci
15. White fly	Bemisia tuberculata
16. White fly	Trialeurodes variabilis
17. White grubs	Larvae of coleoptera belonging to the Scarabaeidae or Cerambycidae families.
18. Surface cutworms	Larvae of Agrotis ipsilon
19. Climbing cutworms	Larvae of Prodenia eridania
20. Subterranean cutworms	Various
21. Stemborer	Coelosternus sp. (coleoptera larva).
22. Stemborer	Lagochirus
23. Stemborer	Phyctaenodes sp. (Lepidoptera)
24. Scale insects	Aonidomytilus albus
25. Scale insects	Saissetia miranda
26. Lace bugs	Vatiga manihotae
27. Lace bugs	Vatiga spp.
28. Termites	Coptocermes spp.

29. Leaf cutting ants — *Atta* sp.
30. Leaf cutting ants — *Acromyrmex* sp.
31. Gall midges — Cecidomyiidae
32. Others.

f. Problems of nutritional deficiencies and toxicities

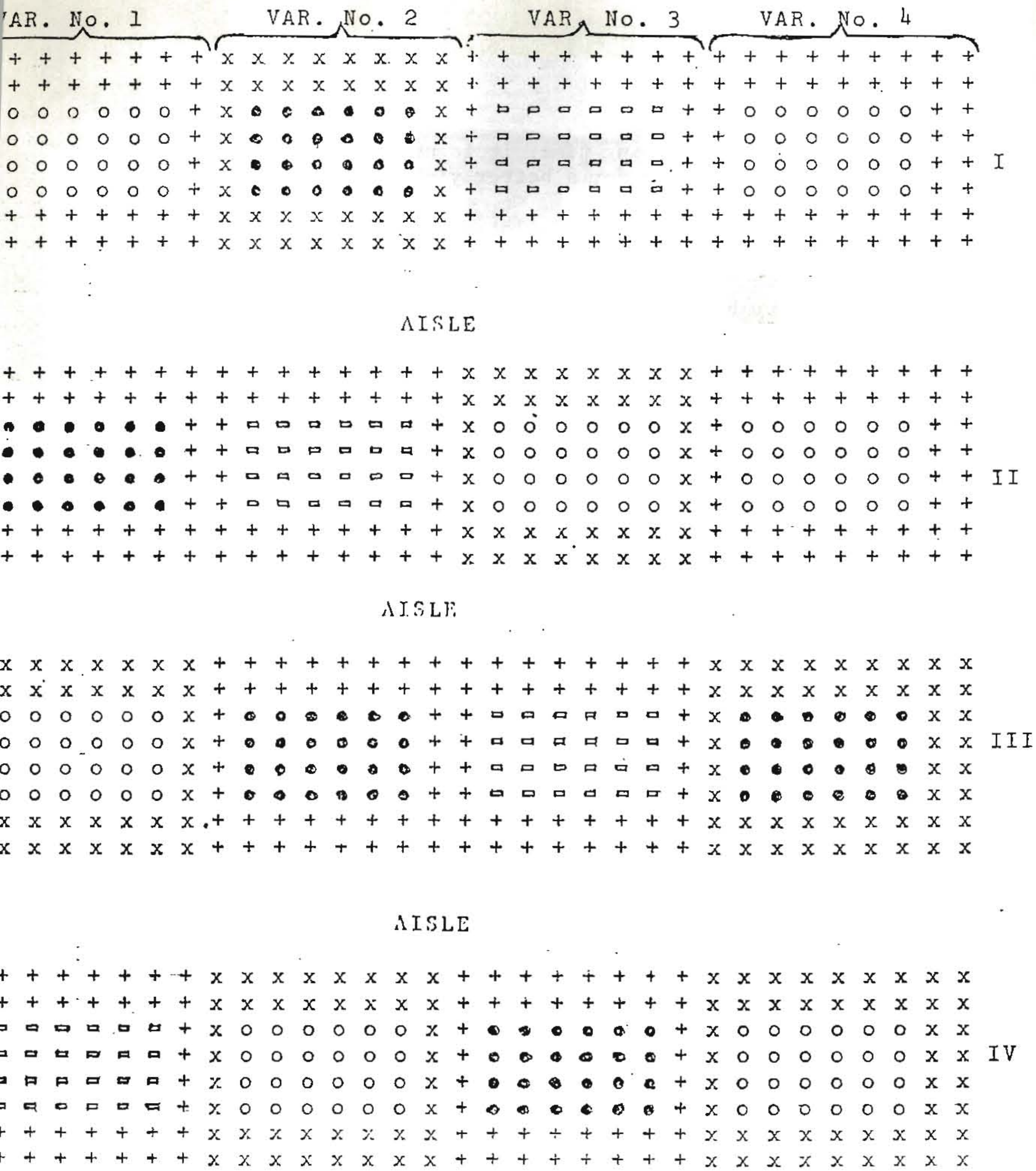
1. Nitrogen (N)
2. Phosphorus (P)
3. Potassium (K)
4. Magnesium (Mg)
5. Sulfur (S)
6. Zinc (Zn)
7. Cooper (Cu)
8. Iron (Fe)
9. Manganese (Mn)
10. Boron (B)
11. Boron Toxicity
12. Salinity and or Alkalinity
13. Others

g. Damages caused by herbicides

1. Diuron or Karmex (as preemergent)
2. Diuron or Karmex (as postemergent)
3. 2, 4-D or 2, 4, 5 T
4. Paraquat or Gramoxone
5. Butylate
6. Atrazines
7. Others.

h. Damages caused by insecticides

1. Others.



· ● CASSAVA PLANTS TO BE HARVESTED (USEFUL PLOT)

CASSAVA PLANTS USED AS BORDER ROWS

12. Harves data. At harvesting time, it is necessary to record a lot of very important items for a better yield evaluation.

1. Total number of plants por plot

2. Total number of plants harvested in the useful are per plot because border rows are not included.

3. Number of lost plants per plot

4. Total number of roots per plot

5. Total fresh weight per plot in kgms.

6. Number of roots per plant

7. Average of root rot

8. Number of root rot

9. Root length (cm)

10. Root diameter (cm)

11. Fresh root weight in air

12. Fresh root weight in water

13. Specific density of roots

14. Percent Dry matter

15. Percent starch

16. Cooking quality

17. Yield (kg/ha)

18. Months from planting to harvest.

DAMAGE EVALUATION BY PESTS AND DISEASES IN CASSAVA

Every evaluation should be calibrated from 1 to 5 with increments of 20 to 25% for each level of damage. The absence of aparent damage will have a value of zero.

The magnitude of the damage caused by some pests and diseases is detailed so as to make evaluation easier. It is recommended to make written description in each case. This is very important because in some cases like when evaluating the Hornworm we may not see any damage at all but we can observe a lot of hornworn egs parasitized or a lot of Polystes wasps. By this mean we can plan better the kind of control more adequate since we do not want to break the biological equilibrium in as much as possible.

GUIDELINES FOR EVALUATION OF DISEASES IN CASSAVA

1. Bacterial blight

Value

1. Without visible symptoms
2. Water-soaked angular spots
3. Up to 50% defoliation
4. More than 50% defoliation, dieback and radical necrosis up to 10%.
5. Generalized dieback - more than 80% defoliation - radical root rot more than 10%.

2. Cercosporas

1. Healthy plants
2. Up to 25% defoliation
3. 26 to 50% defoliation
4. 51 to 75% defoliation
5. More than 80% defoliation

3. Superelongation

1. No damage
2. Cankers in main veins and leaves
3. Cankers in petioles and branches
4. Elongation of internodes, petioles and growing point
5. General necrosis and death of plants.

GUIDELINES FOR EVALUATION OF PESTS IN CASSAVA

1. Mononychellus Tanajoa-Mite

   1. Mites in growing points, few spots.
   2. Many mites, little spots in the growing point and terminal leaves.
   3. Growing point afected and surrounding leaves with many spots.
   4. Deformed growing point, surrounding leaves full of mites.
   5. Death growing point, general defoliation.

2. Tetranychus Urticae-Mite

   1. Few mites. Yellow spots noticeable in some leaves.
   2. Yellow spots moderately present in basal and middle part of the plant
   3. Lower leaves deformed, necrotic zones and leaves drop.
   4. Severe defoliation in middle part of the plant growing point and surrounding leaves plenty of mites and yellowish.
   5. Defoliation plant. Growing point death.

3. Thrips

   1. Little yellow dots in leaves
   2. Growing point and surrounding leaves with partial deformation and yellow dots.
   3. Intense deformation of leaves and large reduction of leaf area.
   4. Growing point completely deformed or death, no surrounding leaves present.
   5. Symptoms of witches'broom; death of growing point and surrounding lateral buds.

4. Schoot fly

   1. No damage
   2. Up to 25% if shoots affected
   3. From 26% to 50% of shoots attacked
   4. From 51 to 75% of shoots attacked
   5. From 76% to 100% of shoots attacked

5. White fly

   1. Less than 20% of leaves infested
   2. 20-40% of leaves infested
   3. 40-60% of leaves infested
   4. 60-80% of leaves infested
   5. 80-100% of leaves infested

DRY MATTER AND STARCH CONTENT DETERMINATION IN CASSAVA BY SPECIFIC GRAVITY SYSTEM

Since a significant portion of cassava production is expected to go for animal feeding and starch extraction, yield should be expressed in terms of root dry matter or starch yield, as well as root fresh yield.

Both, dry matter and starch content determinations in cassava are also very important to stablish a production potential of a given variety for industrial purposes. The varietal differences related to these factors are high as indicated by CIAT (1) consequently, the determination of these factors in different varieties acrros locations is highly recommended for regional trials.

These determinations are usually performed through laboratory methods that require a lot of time and labor.

Due to the high correlation between root specific gravity and root dry matter content, and between root specific gravity and root starch content it is possible to make fast and efficient determinations based in the specific density of roots taken through the use of a hydrostatic scale.

Wania Goncalves de Fukuda who worked under Dr. Kawano's guidance prepared a table to which we made some additions to cover a wider range. These tables are appropriate for cassava varieties harvested between 10-12 months.

To formula used for these determinations is as follows:

$$\text{Specific gravity} = \frac{\text{Fresh root weight in air (FRWA)}}{\text{(FRWA)} - \text{(Fresh root weight in water) (FRWW)}}$$

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CONVERTION TABLE TO DETERMINE DRY MATTER AND STARCH PERCENT IN CASSAVA

SPECIFIC GRAVITY	% D.M.	% STARCH
1.0200	19.53	17.73
05	19.61	18.80
10	19.69	17.88
15	19.76	17.96
20	19.84	18.03
25	19.92	11.11
30	20.00	18.19
35	20.08	18.26
40	20.15	18.34
45	20.23	18.41
50	20.31	18.49
55	20.39	18.57
60	20.47	18.64
65	20.54	18.72
70	20.62	18.80
75	20.70	18.87
80	20.78	18.95
85	20.86	19.03
90	20.93	19.10
95	21.01	19.18
1.0300	21.09	19.25
05	21.17	19.33
10	21.25	19.41
15	21.33	19.48
20	21.40	19.56
25	21.48	19.64
30	21.56	19.71
35	21.64	19.79
40	21.72	19.86
45	21.79	19.94
50	21.87	20.02
55	21.95	20.09
60	22.03	20.17
65	22.11	20.25
70	22.18	20.32
75	22.26	20.40
80	22.34	20.47
85	22.42	20.55
90	22.50	20.63
95	22.57	20.70
1.0400	22.65	20.78

SPECIFIC GRAVITY	% D.M.	% STARCH
1.0405	22.73	20.86
10	22.81	20.93
15	22.89	21.01
20	22.97	21.09
25	23.04	21.16
30	23.12	21.24
35	23.20	21.31
40	23.28	21.39
45	23.36	21.47
50	23.43	21.54
55	23.51	21.62
60	23.59	21.70
65	23.67	21.77
70	23.75	21.85
75	23.82	21.92
80	23.90	22.00
85	23.98	22.08
90	24.06	22.15
95	24.14	22.23
1.0500	24.22	22.31
05	24.29	22.38
10	24.37	22.46
15	24.45	22.54
20	24.53	22.61
25	24.61	22.69
30	24.68	22.76
35	24.76	22.84
40	24.84	22.92
45	24.92	22.99
50	25.00	23.07
55	25.07	23.15
60	25.15	23.22
65	25.23	23.30
70	25.31	23.37
75	25.39	23.45
80	25.46	23.53
85	25.54	23.60
90	25.62	23.68
95	25.70	23.76
1.0600	25.78	23.83

SPECIFIC GRAVITY	% D.M.	% STARCH
1.0605	25.86	23.91
10	25.93	23.99
15	26.01	24.06
20	26.09	24.14
25	26.17	24.21
30	26.25	24.29
35	26.32	24.37
40	26.40	24.44
45	26.48	24.52
50	26.56	24.60
55	26.64	24.67
60	26.71	24.75
65	26.79	24.82
70	26.87	24.90
75	26.95	24.98
80	27.03	25.05
85	27.10	25.13
90	27.18	25.21
95	27.26	25.28
1.0700	27.34	25.36
05	27.42	25.44
10	27.50	25.51
15	27.57	25.59
20	27.65	25.66
25	27.73	25.74
30	27.81	25.82
35	27.89	25.89
40	27.96	25.97
45	28.04	26.05
50	28.12	26.13
55	28.20	26.20
60	28.28	26.28
65	28.35	26.36
70	28.43	26.43
75	28.51	26.51
80	28.59	26.59
85	28.67	26.66
90	28.74	26.74
95	28.82	26.81
1.0800	28.90	26.89
05	28.98	26.96
10	29.06	27.04
15	29.14	27.11
20	29.22	27.19
25	29.30	27.27
30	29.37	27.34
35	29.45	27.42
40	29.53	27.50
45	29.61	27.57
50	29.69	27.65

SPECIFIC GRAVITY	% D.M.	% STARCH
1.0855	29.77	27.72
60	19.84	27.80
65	29.92	27.88
70	30.00	27.95
75	30.08	28.03
80	30.16	28.11
85	30.23	28.18
90	30.31	28.26
95	30.39	28.34
1.0900	30.47	28.41
05	30.55	28.49
10	30.62	28.56
15	30.86	28.64
20	30.78	28.72
25	30.86	28.79
30	30.94	28.87
35	31.01	28.95
40	31.09	29.02
45	31.17	29.10
50	31.25	29.17
55	31.33	29.25
60	31.41	29.33
65	31.48	29.40
70	31.56	29.48
75	31.64	29.56
80	31.72	29.63
85	31.80	29.71
90	31.87	29.79
95	31.95	29.86
1.1000	32.03	29.94
05	32.11	30.01
10	32.19	30.09
15	32.26	30.17
20	32.34	30.24
25	32.42	30.32
30	32.50	30.40
35	32.58	30.47
40	32.65	30.55
45	32.73	30.62
50	32.81	30.70
55	32.89	30.78
60	32.97	30.85
65	33.05	30.93
70	33.12	31.01
75	33.20	31.08
80	33.28	31.16
85	33.36	31.24
90	33.44	31.31
95	33.51	31.39
1.1200	33.59	31.46

SPECIFIC GRAVITY	% D.M.	% STARCH
1.1205	35.23	33.07
10	35.31	33.14
15	35.39	33.22
20	35.46	33.30
25	35.54	33.37
30	35.62	33.45
35	35.70	33.52
40	35.77	33.60
45	35.85	33.68
50	35.93	33.75
55	36.01	33.83
60	36.09	33.91
65	36.16	33.98
70	36.24	34.06
75	36.32	34.14
80	36.40	34.21
85	36.48	34.29
90	36.55	34.36
95	36.63	34.44
1.1300	36.71	34.52
05	36.79	34.59
10	36.87	34.67
15	36.95	34.75
20	37.02	34.82
25	37.10	34.90
30	37.18	34.97
35	37.26	35.05
40	37.34	35.13
45	37.41	35.20
50	37.49	35.28
55	37.57	35.36
60	37.65	35.43
65	37.73	35.51
70	37.80	35.59
75	37.88	35.66
80	37.96	35.74
85	38.04	35.81
90	38.12	35.89
95	38.19	35.97
1.1400	38.27	36.04
05	38.35	3612
.10	38.43	36.20
15	38.51	36.27
20	38.59	36.35
25	38.66	36.42
30	38.74	36.50
35	38.82	36.58
40	38.90	36.65
45	38.98	36.73
50	39.05	36.81

SPECIFIC GRAVITY	% D.M.	% STARCH
1.1455	39.13	36.88
60	39.21	36.96
65	39.29	37.04
70	39.37	37.11
75	39.44	37.19
80	39.52	37.26
85	39.60	37.34
90	39.68	37.42
95	39.76	37.49
1.1500	39.84	37.57
05	39.91	37.65
10	39.99	37.72
15	40.07	37.80
20	40.15	37.87
25	40.23	37.95
30	40.30	38.03
35	40.38	38.10
40	40.46	38.18
45	40.54	38.26
50	40.62	38.33
55	40.69	38.41
60	40.77	38.49
65	40.85	38.56
70	40.93	38.64
75	41.01	38.71
80	41.08	38.79
85	41.16	38.87
90	41.24	38.94
95	41.32	39.02
1.1600	41.40	39.10
05	41.48	39.18
10	41.55	39.25
15	41.63	39.33
20	41.71	39.41
25	41.79	39.48
30	41.87	39.56
35	41.94	39.64
40	42.02	39.71
45	42.10	39.79
50	42.18	39.86
55	42.26	39.94
60	42.33	40.02
65	42.41	40.09
70	42.49	40.17
75	42.57	40.25
80	42.65	40.32
85	42.72	40.40
90	42.80	40.47
95	42.88	40.55
1.1700	42.96	40.63

SPECIFIC GRAVITY	% D.M.	% STARCH
1.1705	43.04	40.70
10	43.12	40.78
15	43.19	40.86
20	43.27	40.93
25	43.35	41.01
30	43.43	41.08
35	43.51	41.16
40	43.59	41.24
45	43.66	41.31
50	43.74	41.39
55	43.82	41.47
60	43.90	41.54
65	43.98	41.62
70	44.06	41.70
75	44.13	41.77
80	44.21	41.84
85	44.29	41.92
90	44.37	42.00
95	44.45	42.07
1.1800	44.52	42.15
05	44.60	42.22
10	44.68	42.30
15	44.76	42.38
20	44.83	42.45
25	44.91	42.53
30	44.99	42.61
35	45.07	42.68
40	45.15	42.76
45	45.22	42.84
50	45.30	42.91
55	45.38	42.99
60	45.46	43.06
65	45.54	43.14
70	45.61	43.22
75	45.69	43.29
80	45.77	43.37
85	45.85	43.45
90	45.93	43.52
95	46.00	43.60
1.1900	46.08	43.67

METHODOLOGY OF THE TRIALS

The cassava Breeding Program is releasing each year a reasonable amount of elite material that is multiplied to be tested under regional trials by the agronomy unit.

It has been said before that the level of technology under which varieties are tested should be uniform. If some different technology is relevant to teste another trial must be planted with that technology so that a comparison can be done.

Each year the materials showing the best behavior in a given zone can be distributed to farmers after testing and evaluation. This distribution is done by the national agency through field days, after the regional trial is harvested. It is important to note that we do not promote the field day. The National Agency cooperating with us is the one that makes the invitations and we participate to give relevant information about results new finding as new measures of control of pests and diseases and cultural practices.

No variety is recommended. Farmers will take home any variety they want according to the results they have observed and to their preferences too. The economy unit makes a record of farmers to follow up on their results with the new varieties since they may test them under their own technology.

Farmers do not have better materials because the have not had enough varieties to select from, in the past. Since CIAT manages the largest collection of cassava germplasm the posibilities of finding superior varieties for each zone are very promising.

We need a good collaboration of National Agencies because they will be the ones responsible for the multiplication, promotion, technical assistance, credit and marketing. These collaboration must be on a continous basis so it will provide the benefit of promising elite materials replacing the local varieties, thereby obtaining inmediate or near-term yield and production increases.

STRATEGY TO SELECT PROMISING VARIETIES

It is relevant to briefly describe the two strategies commonly used. The first strategy, somehow conservative, would permit the testing of the same materials over three years without eliminating any material until the end of the third year. Decision over their naming as a variety would be based on excellence of performance throughout ecological zones during the three years.

The second strategy would only select for further testing those materials which have been definitely superior in that year's trial, discarding any material that does not show excellent perfomance the first time. Materials passing this rigid test would be tested during a total of three years after which they may become candidates to be named as varieties.

The main problem with the first strategy is that it accumulates large numbers of materials in a very short time. However, one would expect that with the second strategy the number of materials to be tested each year would remain more or less the same. This latter strategy would probably also lead to fewer named varieties being released.