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CASSAVA CULTURAL PRACTICES WORKSHOP

Sponsored and organized by IDRC
and EMBRAPA/CNPMF/Secretariat
do Agricultura do Estado do
Bahia with collaboration of CIAT

Salvador, Bahia, Brasil
March 17 to 21, 1980

"Soil Related Intercropping Practices in Cassava Production"

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Turrialba, Costa Rica

"SOIL RELATED INTERCROPPING PRACTICES IN CASSAVA PRODUCTION"

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1980

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Introduction

Intercropping is a practice widely used in the world and is very often found among small cassava farmers of Latin America (4).

Cassava is frequently intercropped with maize, common bean (5, 19, 14), yams (2), potatoes, tomatoes and several other species, according to traditional practices based on agronomic criteria little understood (4).

Yields of cassava intercropped with either maize or common bean are sometimes similar to those of the monocrop (5). In other cases, cassava yields have been reduced about 50% when intercropped with maize and soybeans in relation to the monocrop (6).

Cassava associated with maize is a system commonly used in the low-humid tropics of Central America. Sometimes both crops are planted simultaneously at the beginning of the rainy season.

At CATIE (Tropical Agricultural Research and Training Center) in Turrialba, Costa Rica, several cropping systems which include cassava were studied in an experiment from 1974 to 1978.

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For the November planting of the first year, 1974-1975, no significant differences were obtained for those treatments which included maize. This crop, maize, competed successfully, lowering the yields of crops associated with it. Only cassava, cultivar Valencia, seemed to have made some competition for maize Tuxpeño-1, especially when they were planted simultaneously. In this case, maize intercropped yielded 2.21 metric tons per hectare which was significantly inferior to the maize yield of 3.20 metric tons per hectare in monoculture. Cassava yield decreased by 50%, from 23.63 metric tons per hectare in monoculture to 11.61 metric tons in association.

In the period from 1975 to 1976, yields of cassava and maize were evaluated in terms of dry matter. Maize yields were lower in the second planting (May) and showed better response to fertilizer applications in this planting, than in the first one. In the first planting, maize intercropped with cassava yielded 3524 Kg per hectare of dry matter which was similar to that yielded by the monocrop. Cassava yielded 1570 Kg per hectare which represented a decrease of 51% in relation to the monocrop (3). Between 1976 and 1977, the yield range for cassava was from 6.5 metric tons per hectare at 10 months harvest to 17.3 metric tons per hectare for the monocrop harvested at 11.5 months. Yields of cassava intercropped with maize were 9.3 metric tons per hectare which indicates a strong competition caused by maize (2).

From the reports available, it can be stated that the associations of cassava and other crops, mainly maize, is widely practiced in Central America, and that the degree of competition between cassava and maize depends on the morphology of both crops and plant density.

Intercropping of Cassava and other Tropical Food Crops in Relation to Soil Management Practices

Reduced soil and nutrient losses as well as maintenance of good physical properties have been suggested as reasons for increased yields in simultaneous intercropping.

Reduced soil losses

It has been proposed that in regions of high rainfall intensity the soil surface should be kept covered for as long as possible. Cassava grown on an Inceptisol of Turrialba showed highest increments of total biomass between 4 to 8 months after planting (8). Cassava in monoculture reached its peak of leaf area production before any of the five cropping systems under study, namely[a/]: rotations of cassava → sweet potato → sweet potato, cassava → maize → maize, and intercropping of cassava + common bean → maize, and cassava + common bean + maize → sweet potato. However, it shed leaves sooner than in the other systems.

The highest leaf area index measured for cassava was 1.44 for the monocrop at the age of six months, and 1.51 at eight months for cassava + common bean intercropping (8). These values are low (8) when compared to values obtained elsewhere: Colombia 2.0, Nigeria 5.6 and 7.5.

Experimental results reported of leaf area index curves and reserve roots (8) showed for cassava monoculture a progressive leaf area increase

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a/ The symbol → means rotation; + means association.

up to six months of age, when the leaf area began to diminish. However, the biomass of the roots increased rapidly starting the sixth month. Therefore, to prevent soil losses, cassava should be simultaneously intercropped with a fast-growing crop which can cover the ground rapidly while cassava grows slowly. The intercropped plant should then be harvested when cassava canopy and roots provide protection against erosion to the soil.

In a forest under a rainfall of 2000 mm per year, soil losses of 900 Kg per hectare per year have been reported from small plots with slopes of 2 to 15%. A similar plot of 7 to 8% slope under bare fallow lost 100 metric tons per hectare per year (10). On moderate slopes planted very closely, soil losses may not be so important. It has been reported (10) that erosion plots located under forest with a rainfall of about 2500 mm per year and 25% slope, cleared from forest and planted to upland rice with little disturbance of the soil, lost 4050 Kg per hectare in the first year and less than 900 Kg in the second.

Mounding or ridging of the soil for root crops such as yams, sweet-potato and cassava accelerates erosion in forest environments (10).

Experiments with two years of rice followed by sweet potato on ridges or by cassava planted on flat soil showed a further loss of 4 metric tons per hectare from the ridged plot but only small loss from the undisturbed plot. Soil losses measured vary in magnitude depending on: rainfall intensity, percent slope, soil type, and soil and crop management. Amounts of soil losses range from as little as 2.7 to 4.9 metric tons per hectare per year (10). Traditional systems used by small farmers in forest regions seem to protect the soil well from erosion even on steep slopes and under heavy rainfall.

Soil erosion problems have been studied in Nigeria (16) for different soil management practices and four cropping systems: maize → maize with mulch; maize → maize with till; maize → cowpea with no till; and cowpea → maize tilled.

The study was carried out on an Alfisol; average rainfall was 1100 to 1300 mm bimodally distributed. Soil losses in metric tons per hectare for a 10% slope were: bare fallow, 153; maize → maize with mulch, 0.1; maize → maize tilled, 4.4; maize → cowpea no tilled, 0.1; and cowpea → maize tilled, 3.3. The same trend was found for 1.5 and 15% slope (16). These results show that mulching and no tillage treatments are very effective in preventing soil losses on land with slopes ranging from 1 to 15 percent.

Crops and soil managements which assure an early ground cover controlled runoff and erosion better than those which take longer for full canopy to develop. (15).

Number of days required for 50% canopy to form was approximately 38, 48 and 63 for respective cultivars of soybeans, pigeon peas and cassava, grown at Ibadan, Nigeria (15).

Soil-conserving crops are those with quick growth; soil-depleting crops take longer to cover the ground. Practices such as mixed cropping affect ground cover also. It took cassava as monocrop 63 days to cover 50% of the ground, while the intercropping of maize and cassava took only 51 days (15).

Soil erosion and runoff losses were proportionately less from mixed-cropping as compared with monocrops, table 1 (15). Other cultural practices which affect erosion control are plant density, planting time and level of fertility. More important than the growth habit is the soil management practice. Soil-depleting crops grown with proper soil-conserving techniques could result in less runoff and soil losses than a soil-conserving crop grown without conservation practices (15). This was the case with maize grown with no-tillage techniques as compared to cowpea grown with no conservation practices. Runoff and soil losses were less for maize than for cowpea; especially on slopes greater than 5%, as shown in table 2 (15). Maize is considered a soil-depleting crop while cowpea is a soil-conserving crop.

Soil losses for rotations in tropical regions of Africa and Madagascar are shown in table 3 (7). It is interesting to note that rotations which included cassava showed higher soil losses and higher mean annual runoff. This effect was probably due to the delay in developing effective ground cover of cassava as compared to maize. Soil losses in the system peanuts → green manure cowpea → cassava → forages (soybeans + maize) were higher, 15.80 metric tons/ha/yr, in non-fertilized plots than in plots receiving manure plus potash which lost 11.73 metric tons/ha/yr. Plots which received potash alone had a slightly lower soil loss (15.67 metric tons/ha/yr).

Soil losses for each of the crops in the rotation mentioned above showed that cassava in the first year lost 19.60 metric tons/ha/yr; in the second year soil loss was 17.46 metric tons/ha/year. These losses were less appreciable on plots fertilized with manure and potash, namely: cassava first year, 15.28 metric tons/ha/yr; and cassava second year, 2.90 metric tons/ha/yr (7).

At Turrialba on December 6, 1949, a high intensity rainfall (410 mm approximately 250 mm fell in less than 10 hours) occurred on plots utilized to study soil and water runoff from grass, bare soil and rotation of molasses grass, tropical kudzu, potatoes, peanuts, grain sorghum and cassava. Soil losses from plots planted with cassava were 101 and 111 metric tons/ha for the 16 and 45% slope plots, respectively. Plots covered with grass showed zero losses. The high losses reported for cassava plots were due to the early growth stage of cassava and to the fact that they had been freshly cultivated just previous to the storm (11). Plots covered with corn had not been touched since September, and good vegetative cover made up of crop, weeds, and/or cover crop was on the ground. No soil losses were observed from these plots. These results give support to the suggestion mentioned earlier that intercropping and mixed cropping reduce soil losses and in this way help to maintain the soil in good condition; in addition they sometimes increase yields.

Soil losses under cassava in monoculture have been calculated (1) by applying the Universal Soil Loss Equation in two soil series, Colorado and Instituto at CATIE. Soil losses obtained are shown in table 4. The data indicate rather low soil losses, which is mainly due to the low intensity of most rains in Turrialba.

Physycal properties

The effect of various cropping systems on the mechanical resistance of soils was studied in the Central Experiment at CATIE and in a complementary study (18). Criteria for interpreting resistance to penetration are as follows: 0-6 bars, excellent; 7-12 bars, acceptable; 13-25 bars, non-acceptable; 25 and above restricts root growth. Variations measured for all 48 treatments, 24 cropping systems at two levels of technology, were not significant. Values obtained ranged from 13.64 to 8.74 bars. At the time of measurements, correspondence between resistance and number of crops grown on the soil was not detected. Lowest resistance values were found on the soil surface, 6.46 bars, and this increased significantly to 13.20 bars at the depth of 30 cm.

At the time common beans were harvested resistance to penetration values adjusted at the 40% of soil moisture was on the average higher on treatments not intercropped with cassava than on treatments intercropped with cassava. Treatments which included maize without cassava gave lower resistance readings, 16.4 bars, than those intercropped with cassava, 17.78 bars.

Substracting the resistance just before harvesting from the resistance before the experiment was started, the nine treatments which included cassava ranked as shown in table 5 (18). The results indicate that increase of soil resistance to penetration is more related to human traffic than any other activity.

The dynamic pattern of soil resistance during the 10 months of the cropping season is summarized as follows: on the soil surface, soil resistance adjusted at 40% soil moisture increased from 4.2 to 8.8 bars after ten months of cropping; at 10 cm depth, the changes of adjusted resistance were very small; at depth of 20 to 30 cm, variations of the resistance depended greatly on soil moisture changes, while on the soil surface the changes were attributed to human traffic (18).

Sweet potato intercropped with cassava and maize significantly increased the adjusted resistance from the surface to 20 cm depth when compared to bare and covered soils. In maize plots the times when the same spot was walked or stepped on was 80 and 94%, respectively. For plots with cassava and sweet potato the value was 148%. It is estimated that a second step occurs when the value is 100%. On plots planted with maize, a larger part was walked or stepped on twice, while on plots with sweet potato intercropped with cassava the entire area was stepped on twice and in some places three times (18).

Soils with cassava and sweet potato simultaneously intercropped and maize monocrop had air space of 8.1 and 10.8%, respectively. This difference was not significant. The smaller average aeration of the association is probably due to compaction caused by human traffic.

The effect of ridging or hilling up on the performance of cassava intercropped with maize, string beans plus maize, and string beans was assessed at CATIE (9). Results from this experiment indicated that at the beginning of the experiment bulk density was 0.75 g/cm^3 on the ridge, and 0.89 g/cm^3 on flat soil. At harvest average bulk density was 0.86 gr/cm^3 and the differences between soil management systems had disappeared.

Soil resistance to penetration was 2.15 bars for the flat soil and 1.12 bars for the ridged soil; both values are within the range of 0-6 bars (18), considered as excellent. At harvest the values were 5.27 bars for flat and 2.92 for ridged soil; this difference was significant (P = 0.01). However, they are within the range of values considered excellent for root penetration and development. Soil resistance values depend on soil compaction and soil moisture content. At harvesting the soil from which cassava was harvested was moist and manual harvest was not difficult.

Cassava planted on flat soil yielded more total roots, 24.8 metric tons/ha for monoculture and 14.4 metric tons/ha/year for the association, and commercial roots, 17 metric tons/ha in monocrop and 9 metric tons/ha in the association, than on ridged soil where average yields of total roots for cassava monoculture and maize-cassava intercropped were 21.6 and 12.4 metric tons/ha, respectively. Commercial root yields on ridged soil were 12.3 and 6.2 metric tons/ha for cassava monocrop and maize-cassava intercropping, respectively. For both cassava monocrop and cassava-maize intercropping planted on flat soil, more roots of commercial quality were obtained in relation to yields on ridged soil. No differences were found among management systems on flat and ridged land in regard to number of total and non-commercial roots.

More broken roots were obtained from flat than from ridged soil. Average number for the flat system was 9.4 roots per plot and 5.9 for the ridged soil. The area harvested for each plot was 30 m^2. In summary, planting without hilling increased cassava and bean yields, but maize yields were similar for both practices (9).

<u>Reduced nutrient losses</u>

As indicated earlier, the reduction in nutrient losses has been proposed as one of the reasons for increased yields of intercropping. However, reduced soil losses may not affect yields of crops in the same growing season but will conserve soil fertility in the long run (13). There are few studies of intercropping where the effect of this practice on soil nutrients has been measured (13).

The cropping system did not have a significant effect on the exchangeable Ca, Mg and K content of the soil sixteen weeks after planting maize and pigeon peas in monoculture and simultaneous intercropping. This study was carried out in a soil with an exchange capacity of 12 me per 100 g and in an environment with a monthly rainfall less than 10 mm; under these circumstances leaching of nutrients would probably be small (13). Nutrient losses on sandy soils of the Tracuateua Experiment Station (UePAE), Pará, Brasil, mapped as dystrophic red and yellow quartz sands, and under a precipitation of 8 months with more than 100 mm and four months with less, showed that about 5 times as much magnesium, 85 Kg/ha, was lost from the soil rooting zone as was recovered in the plants, 18 Kg/ha, in the cassava monoculture, cassava plus maize, and cassava + maize + rice treatments. About four times as much is lost, 58 Kg/ha, in the rice → cowpea sequence, and less than three times, 33 Kg/ha, as much in the rice + cassava combination (13).

This indicated that soil losses of magnesium in the 0-40 cm depth were considerably less for simultaneous intercropping of rice and cassava than for the other cropping systems tested. A similar but less marked pattern was observed for potassium. Potassium soil losses were: 113, 100, 112, 103 and 143 Kg/ha for cassava monocrop; rice → cowpeas; cassava + maize, cassava + rice, and cassava + maize mixed cropped with rice, respectively.

In experiments with polycultures at CATIE, Turrialba, it was found that cassava increased its nutrient uptake in relation to the monocrop.

Cassava intercropped with maize resulted in larger nutrient uptake with a total of 417, 51 and 357 Kg/ha of N, P and K, respectively. These amounts were higher than the amounts added in the form of chemical fertilizer (12). According to this study, it appears that cassava as a monocrop absorbs larger amounts of K and N that any other nutrient.

At CATIE (17), several cropping systems which included maize, beans, sweet potato and cassava were studied. The spatial and chronological arrangements tested consisted of association, sequences and relay of crops. In some cases, the cropping systems were managed at two levels of fertilizer application. The information presented and discussed in the next section comes from data collected from the main experiment on cropping systems, carried out at CATIE from 1974 to 1978.

Nutrient changes in the soil

The nutrient content in the soil for systems which included cassava is shown in tables 6 and 7. Nutrients selected for discussion are: phosphorus, potassium, calcium and magnesium. The obtained data was graphed and the interpretation of results was related to the different cropping systems. Representative trends are shown in Figures 1 through 4.

Extractable P for cassava monoculture had a marked decline in 1975, but it increased in 1976 to a content higher than the initial level, Fig. 1 and tables 6 and 7. Soil analyses are not available for 1977. At harvest in 1978, P had increased 1 ppm in relation to the 1974 level. The same pattern obtained for cassava monocrop was observed for polycultures such as: cassava + green maize, cassava + maize, cassava + maize + green maize, cassava + sweet potato, and cassava + maize + beans → sweet potato. The cropping system bean intercropped with maize gave lower values than cassava monoculture (tables 6 and 7).

Exchangeable potassium in the 0-30 cm soil layer of the cassava monoculture decreased during the experimental period from 0.29 to 0.22 me per 100 g. The treatment cassava monoculture fertilized with a higher dose of fertilizer (table 8) resulted in a larger decrease of the soil exchangeable potassium (0.29 to 0.14 me per 100 g), table 7.

The decrease of soil exchangeable potassium was the trend followed by every system, tables 6 and 7 and Figure 2.

Soil exchangeable magnesium diminished with time for all systems; a sharper decline was measured for the more intensive systems (tables 6 and 7). This trend is depicted in Figure 3.

Alterations of exchangeable calcium in the soil presented an unusual pattern, Figure 4. In 1976, a marked drop of the calcium level was observed for most treatments, but in 1978, calcium levels increased to about the level of 1974.

The possible mechanisms which may explain this phenomenon are: excess leaching which occurred in 1974 and 1975 and calcium removal by both cassava and accompanying crop. For the year 1978, the calcium level measured was higher than expected, probably because the soil-extracting solution employed (ammonium acetate pH 7.0) was different to the one used previously. Preliminary comparisons, carried out with different soils at the soil testing laboratory in CATIE, indicate that calcium measured in ammonium acetate extract was approximately two times as much as the amount found in the 1 N KCL soil extract. This would bring the 1978 calcium levels to about 2.5 me per 100 g which would then be consistent with the trend observed in 1975 and 1976 (Fig. 4). A liming experiment conducted on one of the replications of the main intercropping experiment at CATIE during the season 1977-1978 indicated that liming of the soil with calcium carbonate incorporated into the soil surface in sufficient amounts to neutralize 100 percent of the soil exchangeable aluminum increased yields on the first corn harvesting. The highest yield was obtained when 200 percent of the exchangeable aluminum was neutralized. The chemical changes detected as the result of liming in the rotation maize → beans → maize or sweet potato included slight increases of pH, Ca, Mg, K and P; a decrease of exchangeable aluminum and percent aluminum saturation were also observed. Liming effects diminished for the bean and maize + sweet potato sequences of the rotation. At the end of the experiment, amounts of Ca, Mg, K, Fe, Mn, Zn, Cu, and total N in the soil were similar to the initial values; only the content of P increased about 100% after the third crop in all systems (20).

Nutrient balance sheet

For the proper evaluation of nutrient losses from cassava intercropped systems, it is necessary to elaborate blance sheets; in these, nutrients removed by the crops and weeds are subtracted from the nutrient change in the soil.

The amounts of nutrients in the parts of the plant removed from the field are summarized in tables 8 and 9. The content in the total biomass is included since stover was not returned to the plots with the exception of treatment T 6-1 (green maize in rotation with cassava) where, in 1976, maize stover was left on the ground between the rows of cassava.

The amounts of fertilizer added annually to each treatment are shown in table 10.

The results are presented in tables 11, 12, 13 and 14 as four balance sheets, one for each phosphorus, potassium, calcium and magnesium. Since crop analysis or total biomass was not available for every year for all plants intercropped with cassava, cropping systems with more information about the accompanying crop were selected for calculations. Values of crop removal for years with missing data were assumed to be equal to the amounts obtained for the previous year.

Examination of table 11 indicates that phosphorus losses were highest for cassava monocrop than for any other system. The other systems in descending order in regard to phosphorus losses are: simultaneous intercropping of cassava plus beans (T 52 B+C); beans + cassava followed by green maize (T 16-2 B+C→Me), fertilized with higher fertilizer rate than T 16-1 (B+C→Me); maize + cassava (T 6-2 M+C); beans plus cassava followed by maize (T 16-1 B+C→Me); beans + maize + cassava followed by sweet potatoes (24-2 B+M+C+→SP), fertilized with a high dosis of fertilizer (table 10); and in last place, the system beans + maize + cassava followed by sweet potatoes (24-1 B+M+C+→SP). It is evident that soil phosphorus losses were less in systems which included maize and much less in three-crop polycultures. Another interesting fact is that phosphorus removal by aerial parts of cassava was higher in four-crop polycultures than in two or three-crop intercropping. Phosphorus loss was influenced more by the number of crops in the system than by the rate of phosphorus application.

The potassium balance sheet, table 12, shows that potassium losses from the system did not occur from systems which contained maize harvested for grain, regardless the amount of applied potassium. Also, no loss was detected for the cropping system which included maize to be harvested as green corn and received a relative low application of potassium in the form of chemical fertilizer. Data of table 12 indicate that cassava in monoculture removes higher amounts of potassium from the soil than when associated with one, two or three crops. However, at high rate of fertilization and in association with three other crops, one of which is maize to be harvested for grain, potassium removal is higher than for the cassava monocrop.

In general terms, the calculations presented in table 11 show that in cassava monoculture five times more phosphorus is lost than absorbed by the crop. However, the amount lost in two-crop polycultures ranged from 2 to 3 times as much as the amount absorbed by the plants, and four-crop polycultures lost less than half the amount of phosphorus removed by the crops.

In the case of potassium, cropping systems which showed some loss absorbed five times as much nutrient as was lost for the system cassava monocrop, three times the amount lost by the two-crop intercropped, and ten times the losses in a three-crop intercropped system.

Data in table 13 indicate calcium losses in three systems, namely: maize associated with cassava (M+C), beans associated with cassava followed by green maize (B+C→Me) and beans associated with maize and cassava followed by sweet potato (B+M+C+→SP). These losses in kilograms per h hectare were: 210, 212 and 60, respectively. The mechanism which may explain calcium losses for maize plus cassava (M+C) is that calcium loss from the soil was higher in this system than in cassava monoculture due to reduced ground cover after the bending of corn stalks. This system (C-2 M+C) received a rate of fertilizer application (table 12) which resulted in a vigorous corn growth and a slow growth of cassava in competition with maize.

The effect is clearly evident in table 8 where total cassava biomass for 6-2 M+C is about 70% of the one produced by cassava in monoculture. At the first of the growing period when cassava was left alone in the field, the increase of soil losses was probably due mainly to erosion and leaching as the result of inadequate ground cover. Corn stover was not returned to the soil which was left covered only by the thin cassava canopy, and therefore exposed to weed invasion and the action of rainfall.

The case of system 16-2 B+C→Mc also shows a high calcium loss from the soil, the probable reasons for this being early harvesting of cassava, 8 to 9 months, and inadequate ground cover during establishment of maize for green corn. Calcium loss for the system 24-2 B+M+C↔SP was low, 60 Kg per hectare in comparison to the systems mentioned above. This loss was probably caused by the same mechanism formerly described for system 6-2 M+C, which is inadequate ground cover by cassava and sweet potato following maize and bean harvest due to the high fertilization rate which enhanced vegetative growth of maize and diminished cassava growth rate. After maize stalks were bent, calcium from the soil was lost to weeds, soil erosion and leaching. Data of table 13 show that similar amounts of calcium were removed from the soil when cassava was planted in monoculture and when it was associated with one, two or three crops, regardless of the fertilization rate employed. It appears tha calcium loss from the system is greatly influenced by the ground cover provided by cropping patterns.

Magnesium absorbed by cassava monoculture was about half the amount taken up by two, three and four-crop systems, table 14. Magnesium losses were detected for cassava monoculture, cassava associated with beans and for two four-crop polycultural systems. These losses were associated with larger magnesium losses from the soil: 72, 72, 264 and 192 kilograms per hectare of magnesium, respectively. As in the case of calcium, it appears that magnesium is lost from the soil in systems which did not cover the soil properly. In the case of the four-crop polycultures, the chronological sequence of harvesting and the establishment of the last crop (sweet potato) had a marked effect on magnesium lost from the soil, table 14. In general, data show larger absorption than loss of magnesium from the soil for two and three-crop polycultures and larger soil magnesium losses than absorption for cassava monocrop and four-crop polycultured systems which included cassava.

All things considered, the advantages of intercropping cassava with other crops are many: the system reduces runoff and soil losses, helps to conserve good soil physical properties and aids to maintain soil fertility for a longer period. When possible, stover of the accompanying plant should be left or semi-incorporated on the soil surface to maintain the recycling of nutrients in the system.

Possible Areas for Future Research with Intercropping of Cassava

Studies on the performance of cassava intercropped systems and its relation to various environments deserve attention because of the possibilities presented by these systems for recycling of nutrients on low base status soils.

More information is needed about soil losses under varios situations of rainfall intensity, slope and soil coverage by plant canopy of cassava intercropped systems.

The role of weeds in the protection of soil against soil and nutrient losses should be studied in order to assess their contribution to the preservation of soil in good conditions.

The effect of cassava intercropped systems on the physical properties of the soil should be studied in regard to soil compaction caused by excessive human traffic on soils, which is closely related to the assistance required by the plant intercropped with cassava. Human traffic causes changes of the physical properties of the soil depending on ground cover and soil moisture content.

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Table 1. Soil loss and runoff with cassava monoculture and intercropping of cassava with maize (Alfisol, Ibadan, Nigeria) (15).

Slope %	Soil loss (metric tons/ha/yr)		Runoff (%)	
	Monoculture	Intercropping	Monoculture	Intercropping
1	2.7	2.5	18	14
5	87.4	49.9	43	33
10	125.1	85.5	20	18
15	221.1	137.3	30	19

Table 2. Effect of nature of crop and soil management practices on runoff and soil loss (Alfisol, Ibadan, Nigeria) (15).

Slope %	Runoff (% of rainfall[a/]) Maize (No-till)	Cowpea (Conventional till)	Soil loss (metric tons/ha) Maize (No-till)	Cowpea (Conventional till)
1	1.2	15.8	0.91	0.24
5	1.8	31.1	0.03	0.65
10	3.1	40.0	0.00	1.71
15	3.5	17.2	0.10	1.22

a/ Rainfall during cropping period = 781 mm.

Table 3. Effect of crop rotations on runoff and soil losses (Red ferralitic soils derived from amfibolites, Africa) (7).

Systems	Period year 1953-1958	Soil losses metric tons/ha/yr	Runoff %	Average year runoff mm
Five year rotation	53-58	15.6	9.6	113
peanuts → green manure -	54-58	15.5	9.4	118
→ cassava → forage				
Four year rotation	53-58	12.1	8.3	90
peanuts → green manure →	54-58	11.0	8.1	101
maize → forage				
peanuts → temporary	53-58	7.7	6.9	75
grassland (4 y 5)	54-58	6.0	5.9	74

Rainfall during cropping period: 1953-1958 5464 mm
1954-1958 6239 mm

Table 4. Calculated soil losses for cassava monocrop grown in two soil series of Turrialba (Ultisol-Inceptisol CATIE 1975) (1)

Slope %	Length m	Soil series	Soil loss (metric/ton/ha/yr)
5	15	Colorado	1.61
5	30	Colorado	3.21
10	30	Colorado	5.97
5	15	Instituto	2.42
5	30	Instituto	4.83
10	30	Instituto	8.98

Table 5. Difference of resistance to penetration between initial and pre-harvest reading for nine cropping systems of which cassava is a component.

Order	Cropping system[a/]	Difference between readings
		Bars
1	C	2.72
2	M + C + SP_1	3.98
3	C / SP_2	4.47
4	M + C → C/SP_2	4.50
5	B + C	4.61
6	B + M + C → C/SP_2	4.68
7	M + C	4.70
8	SP_1 + C	4.74
9	SP_1 + C → C/SP_2	6.37

a/ C = cassava; M = maize; SP = sweet potato; B = common bean.
SP_1 = SP first planting; SP_2 = SP second planting.
\+ = association, / = relay cropping; → = rotation.

Table 6. Phosphorus, potassium, calcium and magnesium content in the first 30 cm of an Inceptisol planted to cassava intercropped systems. CATIE, Turrialba, Costa Rica.

System[a/]		P				K				Ca				Mg			
		Year															
		74	75	76	78	74	75	76	78	74	75	76	78	74	75	76	78
		µg/ml				me/100g											
T 1-1	C	5	3	7	6	0.29	0.18	0.17	0.22	5.3	5.6	2.6	5.2	1.7	1.7	1.3	1.4
T 5-1	B→C	4	3	7	5	0.29	0.16	0.15	0.15	6.2	5.6	3.4	5.5	2.0	1.6	1.3	1.4
T 6-1	Me→C	6	2	9	5	0.24	0.14	0.19	0.22	5.8	5.0	2.5	4.6	2.0	1.4	1.1	1.3
T 7-1	SP+C	5	2	8	4	0.31	0.14	0.20	0.24	5.3	4.6	2.5	4.4	1.7	1.4	1.5	1.3
T13-1	SP+C→SP	5	4	8	4	0.35	0.17	0.15	0.20	6.1	5.5	2.4	4.4	1.8	1.6	1.2	1.3
T14-1	M+C→Me	5	4	9	4	0.33	0.17	0.18	0.14	6.0	5.1	2.8	4.7	1.9	1.6	1.3	1.1
T16-1	B+C→Me	5	4	8	8	0.23	0.14	0.17	0.15	5.4	6.0	3.1	4.8	1.6	1.6	1.6	1.4
T17-1	M+C+→SP	6	3	9	6	0.30	0.13	0.14	0.16	6.8	4.8	2.8	5.3	1.9	1.5	1.3	1.3
T24-1	B+M+C+→SP	5	3	9	4	0.33	0.13	0.17	0.16	5.4	5.4	3.2	5.5	1.5	1.9	1.4	0.8
T 2-1	B→M	5	3	7	4	0.35	0.42	0.19	0.25	4.8	5.1	2.9	4.3	1.7	1.5	1.6	1.4
T 4-1	M→SP	5	3	8	4	0.24	0.15	0.15	0.27	4.9	4.8	2.6	5.0	1.4	1.4	1.4	1.3

a/
C = cassava
B = beans
Me = green maize
M = maize
SP = sweet potato

→ = double cropping
\+ = association of crops
+→ = double cropping of crop association

Table 7. Phosphorus, potassium, calcium and magnesium content in the first 30 cm of an Inceptisol planted to cassava intercropped systems. CATIE, Turrialba, Costa Rica.

System[a/]		P				K				Ca				Mg			
								Year									
		74	75	76	78	74	75	76	78	74	75	76	78	74	75	76	78
		µg/ml				me/100 g											
T 1-2	C	5	3	7	6	0.29	0.18	0.19	0.14	5.3	5.2	2.9	5.1	1.7	1.6	1.4	1.3
T 5-2	B+C	4	2	10	4	0.29	0.15	0.23	0.12	6.2	5.4	3.3	5.0	2.0	1.6	1.5	1.3
T 6-2	M+C	6	2	8	3	0.24	0.14	0.18	0.14	5.8	5.4	5.4	4.4	2.0	1.3	1.2	1.2
T 7-2	C→SP	5	4	9	6	0.31	0.20	0.23	0.14	5.3	4.9	2.7	4.3	1.7	1.5	1.6	1.3
T13-2	SP+C↔SP	5	5	8	4	0.35	0.15	0.17	0.12	6.1	5.0	2.8	4.3	1.8	1.6	1.3	1.2
T14-2	M+C→Me	5	4	8	4	0.33	0.13	0.19	0.10	6.0	4.9	2.8	4.4	1.9	1.2	1.3	1.0
T16-2	B+C→Me	5	3	6	3	0.23	0.18	0.17	0.13	5.4	3.8	2.8	5.0	1.6	1.3	1.4	1.4
T17-2	M+C↔SP	6	2	7	4	0.30	0.18	0.14	0.12	6.8	4.6	3.1	5.4	1.9	1.4	1.3	1.3
T24-2	B+M+C↔SP	5	2	10	6	0.33	0.13	0.19	0.11	5.4	5.6	2.9	4.9	1.5	1.6	1.4	0.8
T 2-2	B+M	5	4	7	5	0.35	0.20	0.25	0.13	4.8	5.8	2.5	4.5	1.7	1.6	1.6	1.4
T 4-2	M+SP	5	2	8	4	0.24	0.16	0.14	0.15	4.9	5.1	2.9	4.7	1.4	1.3	1.3	1.3

a/
C = cassava
B = beans
M = maize
Me = green maize
SP = sweet potato

→ = double cropping
+ = association of crops
↔ = double cropping of crop association

Table 8. Average cassava biomass of roots, stem plus leaves and nutrient accumulated in the stem and leaves of nine cassava intercropped systems tested at CATIE, Turrialba, 1975-1978.

System[a]			Roots	Stem plus leaves	N			P			K			Ca			Mg		
			Kg/ha		75	76	78	75	76	78	75	76	78	75	76	78	75	76	78
					Kg/ha														
1	1	C	5942	4537	50.46	110.59	98.89	4.69	5.63	5.14	13.78	45.81	36.41	22.39	66.60	44.20	10.00	22.75	17.26
	2	C	6223	4314	49.43	77.84	91.60	4.64	5.29	4.85	16.59	41.27	34.69	22.20	55.22	42.51	9.52	16.00	18.53
5	1	B→C	4193	3764	73.17	88.83	50.43	7.13	4.62	3.68	26.54	36.77	20.37	34.30	36.35	29.77	11.43	16.51	11.79
	2	B+C	5277	3287	61.06	75.04	69.23	4.79	4.33	3.77	12.85	26.80	16.76	22.01	41.60	28.54	10.85	15.88	12.84
6	1	M→C	3810	4537	51.32	91.94	133.08	7.19	6.30	8.36	23.49	62.37	83.59	25.67	40.27	59.76	8.76	14.02	18.22
	2	M+C	3502	4039	53.12	112.36	90.42	5.85	3.88	4.64	17.34	21.81	23.29	25.08	37.31	36.96	9.98	15.68	15.48
7	1	C+SP	4095	3785	44.60	80.39	93.39	4.64	4.34	5.90	11.77	38.76	45.69	17.00	44.76	43.38	7.81	15.00	17.26
	2	C+→SP	6339	3880	59.91	69.15	121.65	6.01	4.47	5.76	17.99	30.91	65.19	26.29	44.25	54.08	12.18	16.23	20.07
13	1	SP+C→SP	4602	2913	73.78	53.84	86.75	6.22	2.89	5.11	19.76	15.69	31.82	23.60	21.55	37.57	9.98	7.41	15.65
13	2	SP+C→SP	6838	3591	63.74	69.09	101.55	7.42	4.00	5.97	28.71	27.68	40.72	30.06	36.04	53.85	13.57	13.02	18.65
14	1	M+C→Me	5779	3647	80.74	92.85	52.49	8.66	4.99	4.21	22.43	25.49	17.44	37.59	48.04	27.45	16.71	18.24	11.89
	2	M+C→Me	3670	4043	86.01	77.68	74.27	8.65	4.38	3.99	29.01	25.27	18.85	36.57	43.03	30.55	12.35	15.19	14.13
16	1	B+C→Me	4560	2963	59.31	65.70	46.32	6.58	3.72	2.49	14.83	24.45	15.75	28.73	42.11	23.20	11.04	12.96	9.31
	2	B+C→Me	5102	2699	63.27	65.08	63.97	6.27	3.25	3.01	14.27	19.75	16.35	25.20	30.69	25.28	10.32	12.85	11.58
17	1	M+C+→SP	3193	4164	80.35	79.06	83.31	9.66	4.57	6.03	23.68	20.83	26.71	34.67	37.64	41.77	13.08	15.09	16.43
	2	M+C+→SP	4827	4227	69.85	74.07	106.32	9.[illegible]	3.66	6.06	25.06	17.93	31.55	38.62	31.69	43.54	12.50	14.05	18.30
24	1	B+M+C+→SP	3030	3643	68.64	79.19	83.74	7.34	4.47	5.76	18.34	32.03	27.28	28.31	44.25	34.92	10.29	15.05	12.93
	2	B+M+C+→SP	2653	4476	98.72	94.99	116.70	10.77	4.47	6.32	35.01	25.95	38.79	44.44	40.15	44.05	14.51	14.75	18.52
Σ			83581	66709	1207.48	1457.69	1564.11	126.38	79.26	91.27	371.45	539.57	539.45	523.33	741.95	701.38	205.32	270.68	279.44
$\bar{x}$			4643	3817	67	81	87	7.0	4.4	5.1	20.64	29.97	32.97	29.07	41.22	38.96	11.41	15.04	15.52

a/ C = cassava; B = beans; Me = green maize; M = maize; SP = sweet potato; → = double cropping; + = association of crops; +→ = double cropping or crop association

Table 9. Average biomass and accumulated nutrient for the accompanying crop of cassava intercropped systems tested on an Inceptisol at CATIE, Turrialba, Costa Rica 1975-1978.

System[a/]	Biomass total	N 75	N 76	N 78	P 75	P 76	P 78	K 75	K 76	K 78	Ca 75	Ca 76	Ca 78	Mg 75	Mg 76	Mg 78	Biomass used for the calculations
	Kg/ha	Kg/ha															Kg/ha
5-1 B	2371	43.4	-	-	3.7	3.8	-	34.6	41.6	-	35.2	141.7	-	9.3	25.0	-	2571
5-2 B	2477	47.7	-	-	4.2	4.2	-	37.8	52.4	-	23.6	138.6	-	9.7	24.7	-	2827
6-1 Me	8392	57.2	-	116.7	12.8	-	12.9	109.3	-	117.7	23.5	-	49.2	16.7	-	23.9	7466
6-2 M	5890	91.4	-	63.9	12.6	-	7.0	99.8	-	37.3	26.6	-	31.2	20.5	-	17.0	5864
7-1 SP	3914	166.0	-	55.4	15.2	-	4.4	85.7	-	30.2	74.9	-	26.9	29.9	-	12.4	4076
7-2 SP	2771	-	41.5	-	-	6.8	-	-	31.9	-	-	27.9	-	-	11.7	-	1903
13-1 SP	3421	121.7	66.9	32.4	12.5	10.9	3.0	56.8	50.2	15.5	74.8	38.6	23.5	26.7	17.1	9.9	3421
13-2 SP	2986	123.2	68.9	33.3	12.0	9.7	2.8	58.7	42.1	16.0	53.8	46.6	25.1	22.8	20.3	9.6	2986
14-1 M-Me	6500	-	-	-	15.6	-	8.3	147.6	-	45.27	38.5	-	45.7	27.0	-	21.1	8500
14-2 M-Me	11495	-	-	-	20.8	-	9.2	205.2	-	69.90	35.0	-	52.1	35.1	-	22.6	11495
16-1 B	1779	22.3	-	46.7	2.5	3.0	-	21.1	34.3	24.7	20.4	98.1	46.2	4.5	17.1	12.2	1779
16-2 B	2009	32.2	-	56.5	2.4	2.9	-	25.1	31.0	35.8	22.3	104.1	53.2	6.0	20.0	13.7	2009
16-1 Me	6111	-	-	-	11.5	10.4	4.1	73.9	67.5	55.2	25.8	23.0	30.2	17.3	13.3	15.5	6111
16-2 Me	6901	-	-	-	13.8	11.1	3.7	83.0	70.9	59.6	33.4	26.9	27.6	22.6	18.5	13.4	6901
17-1 M	8043	-	169.7	-	17.1	16.9	-	129.9	103.7	-	54.9	81.8	-	34.3	60.5	-	9170
17-2 M	7883		142.5	-	17.3	17.4	-	109.4	77.7	-	54.9	78.2	-	29.1	46.1	-	8443
17-1 SP	2591	-	38.3	-	-	8.7	5.9	-	29.4	24.7	-	25.1	24.3	-	11.1	7.5	1859
17-2 SP	2647	-	40.5	-	-	8.0	5.0	-	27.5	24.9	-	28.9	28.1	-	11.9	6.8	1832
24-1 M	5356	-	-	-	11.6	-	4.7	71.8	-	23.2	45.6	-	30.2	28.1	-	15.7	5182
24-2 M	6809	-	-	-	15.8	-	8.2	111.3	-	30.7	49.0	-	38.6	29.9	-	22.6	6304
24-1 B	1799	26.2	2.9	123.4	2.1	3.3	-	21.6	36.2	29.4	21.2	101.8	49.0	4.8	14.9	12.4	1799
24-2 B	1835	29.9	2.7	153.0	2.5	2.8	-	24.6	34.9	45.9	21.4	85.0	49.4	5.6	15.3	12.6	1835
24-1 SP	2617	114.7	29.0	-	10.0	6.0	7.7	141.6	29.6	24.6	31.5	22.1	27.7	27.5	7.4	8.9	2617
24-2 SP	2220	107.9	33.2	-	7.6	5.5	4.8	113.9	27.8	20.7	28.8	23.3	29.9	25.7	8.0	9.1	2210

a/ B = beans; Me = green maize; SP = sweet potato; M = maize; SP = sweet potato

Table 10. Fertilizer doses added annually to the soil of nine intercropped cassava systems tested at CATIE, Turrialba, Costa Rica 1974-1978.

System	Sub-treat.	System a/	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
			Kg/ha								
			74-75			75-76			76-77, 77-78		
1	1	C	65	100	30	65	75	30	65	75	75
	2	C	125	130	48	125	97	50	125	97	150
5	1	B→C	125	130	48	150	97	75	150	97	150
	2	B+C	145	140	54	150	97	75	150	97	150
6	1	Me→C	145	140	54	150	97	75	150	97	150
	2	M+C	145	140	54	150	97	75	150	97	150
7	1	SP+C	145	140	54	150	97	75	150	97	150
	2	C+→SP	150	140	54	150	97	75	150	97	150
13	1	SP+C+→SP	125	75	50	125	75	50	125	75	75
	2	SP+C+→SP	245	105	75	245	105	75	245	105	150
14	1	M+C→Me	125	75	50	125	75	50	125	75	50
	2	M+C→Me	245	105	75	245	105	75	245	105	75
16	1	B+C→Me	125	75	50	125	75	50	125	75	75
	2	B+C→Me	245	105	75	245	105	75	245	105	150
17	1	M+C+→SP	125	75	50	125	75	50	125	75	75
	2	M+C+→SP	245	105	75	245	105	75	245	105	150
24	1	B+M+C+→SP	125	75	50	125	75	50	125	75	75
	2	B+M+C+→SP	275	105	100	275	105	100	275	105	150

a/ C = cassava B = beans Me = green maize M = maize SP = sweet potato
→ = double cropping + = association of crops +→ = double cropping of crop association

Table 11. Phosphorus balance sheet for five selected cassava intercropped systems tested on an Inceptisol at CATIE, Turrialba, Costa Rica, 1975-1978.

System[a/]	(1) Applied P 1975-1978	(2) Soil P Initial	Final	(3) Plant P uptake[b/] S+L	R	Acc	(4) Loss of P from soil	(4+1)-(3) Loss of P from the system
	----------	----------	----------	Kg/ha	----------	----------	----------	----------
1-2 C	128	6	12	15	4	-	-6	103
6-2 M+C	128	4	6	15	2	32	-2	77
5-2 B+C	128	4	8	13	4	13	-4	94
16-1 B+C→Me	99	8	16	13	3	34	-8	41
16-2 B+C→Me	139	6	6	12	4	37	0	86
24-1 B+M+C+→SP	99	6	8	18	2	60	-2	17
24-2 B+M+C+→SP	139	4	12	22	2	66	-8	41

a/
C = cassava
B = beans
SP = sweet potato
Me = green maize
M = maize
→ = double cropping
+ = association of crops
+→ = double cropping of crop association

b/
S+L = stem plus leaves
R = roots
Acc = accompanying crop

Table 12. Potassium balance sheet for five selected cassava intercropped systems tested on an Inceptisol at CATIE, Turrialba, Costa Rica 1975-1978.

System[a/] T ST Cul.	(1) Applied K	(2) Soil K Initial	Final	(3) Plant K S+L	R	Acc uptake[b/]	(4) Loss of K from soil	(4+1)-(3) Loss of K from the system
	-----	-----	-----	Kg/ha	-----	-----	-----	-----
1-2 C	166	140	109	96	68		31	33
6-2 M+C	311	109	109	62	39	246	0	No loss
5-2 B+C	311	117	94	56	59	143	23	76
16-1 B+C→Me	187	109	117	55	51	277	-8	No loss
16-2 B+C→Me	336	140	101	52	57	311	39	45
24-1 B+M+C+→SP	166	101	125	78	34	450	-24	No loss
24-2 B+M+C+→SP	332	101	86	129	29	521	15	No loss

a/
C = cassava
M = maize
B = beans
Me = green maize
SP = sweet potato
→ = double cropping
\+ = association of crops
+→ = double cropping of crop association

b/
S+L = stem plus leaves
R = roots
Acc = accompanying crop

Table 13. Calcium balance sheet of five selected cassava intercropped systems tested on an Inceptisol at CATIE, Turrialba, Costa Rica 1975-1978.

System[a/]	(1) Applied Ca	(2) Soil Ca Initial	(2) Soil Ca Final	(3) Plant Ca uptake[b/] S+L	(3) Plant Ca uptake[b/] R	(3) Plant Ca uptake[b/] Acc	(4) Loss of Ca from soil	(4+1)-(3) Loss of Ca from the system
		----------Kg/ha----------						
1-2 C	-	2080	2040	120	12	-	40	-92 No loss
6-2 M+C	-	2160	1760	99	7	84	400	210
5-2 B+C	-	2160	2000	92	10	301	160	-243 No loss
16-1 B+C→Me	-	2400	1920	94	9	165	480	212
16-2 B+C→Me	-	1520	2000	81	10	180	-480	-209 No loss
24-1 B+M+C↔SP	-	2160	2200	107	7	81	-040	-235 No loss
24-2 B+M+C↔SP	-	2240	1960	129	9	82	280	60

a/ C = cassava; B = beans; SP = sweet potato; Me = green maize; M = maize; → = double cropping; + = association of crops; ↔ = double cropping of crop association

b/ S+L = stem plus leaves; R = roots; Acc = accompanying crop

Table 14. Magnesium balance sheet of five selected cassava intercropped systems tested on an Inceptisol at CATIE, Turrialba, Costa Rica 1975-1978.

System[a/]	(1) Applied Mg	(2) Soil Mg Initial	(2) Soil Mg Final	(3) Plant Mg uptake[b/] S+L	(3) R	(3) Acc	(4) Loss of Mg from soil	(4+1)-(3) Loss of Mg from the system
	------	------	------	------	Kg/ha	------	------	------
1-2 C	47	384	312	44	6		72	69
6-2 M+C	50	312	288	41	3	58	24	-28 No loss
5-2 B+C	50	384	312	40	5	59	72	18
16-1 B+C→Me	11	384	336	33	4	46	48	-24 No loss
16-2 B+C→Me	47	312	336	35	5	54	-24	-71 No loss
24-1 B+M+C↔SP	11	456	192	38	3	32	264	202
24-2 B+M+C↔SP	47	384	192	48	4	33	192	154

a/ C = cassava; B = beans; SP = sweet potato; Me = green maize; M = maize; → = double cropping; + = association of crops; ↔ = double cropping of crop association

b/ S+L = stem plus leaves; R = roots; Acc = accompanying crop

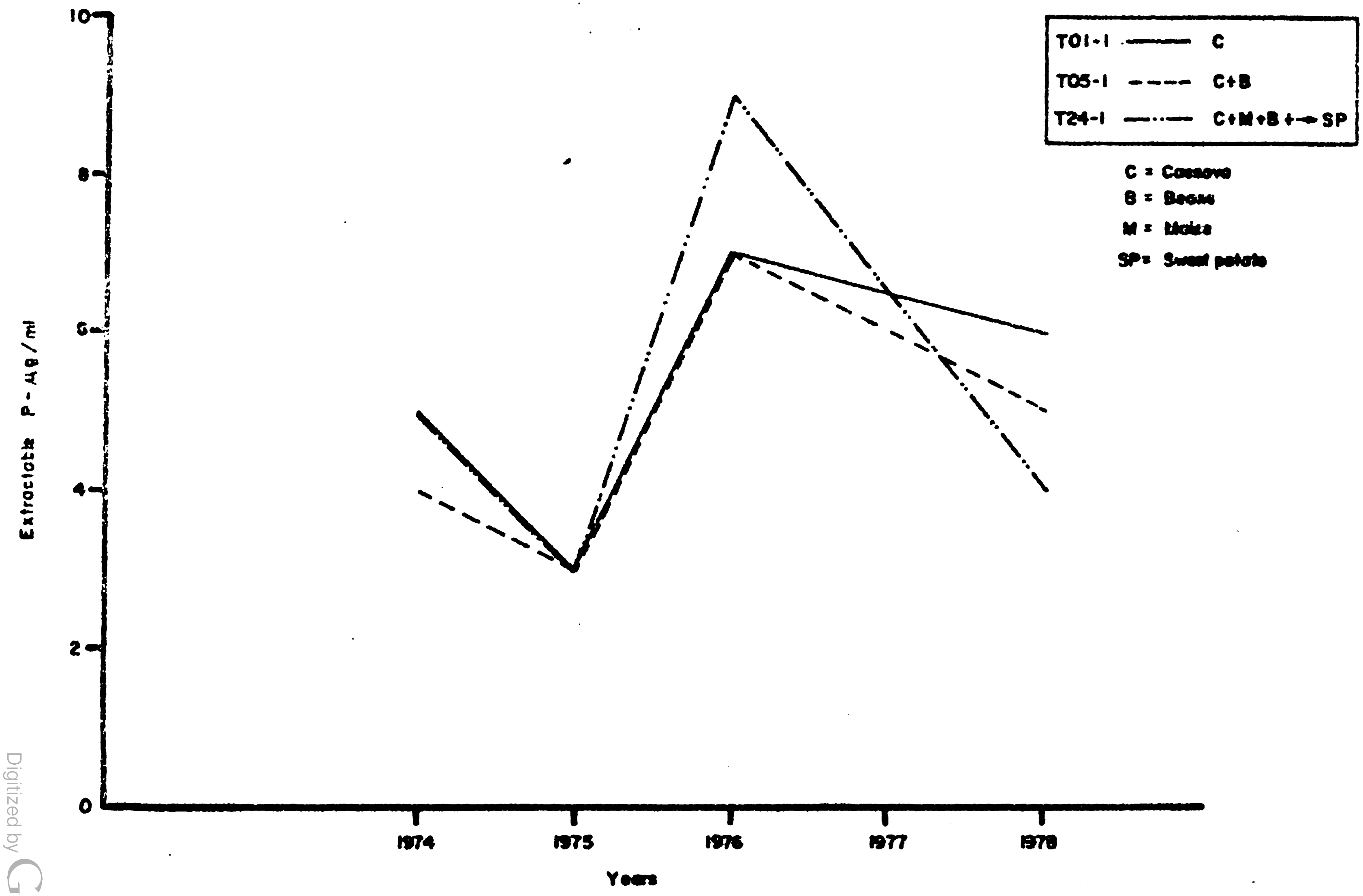

Fig. I Effect of time and cassava intercropped systems on the soil phosphorus content in the 0-30 cm horizon of an Inceptisol at CATIE, Turrialba, Costa Rica

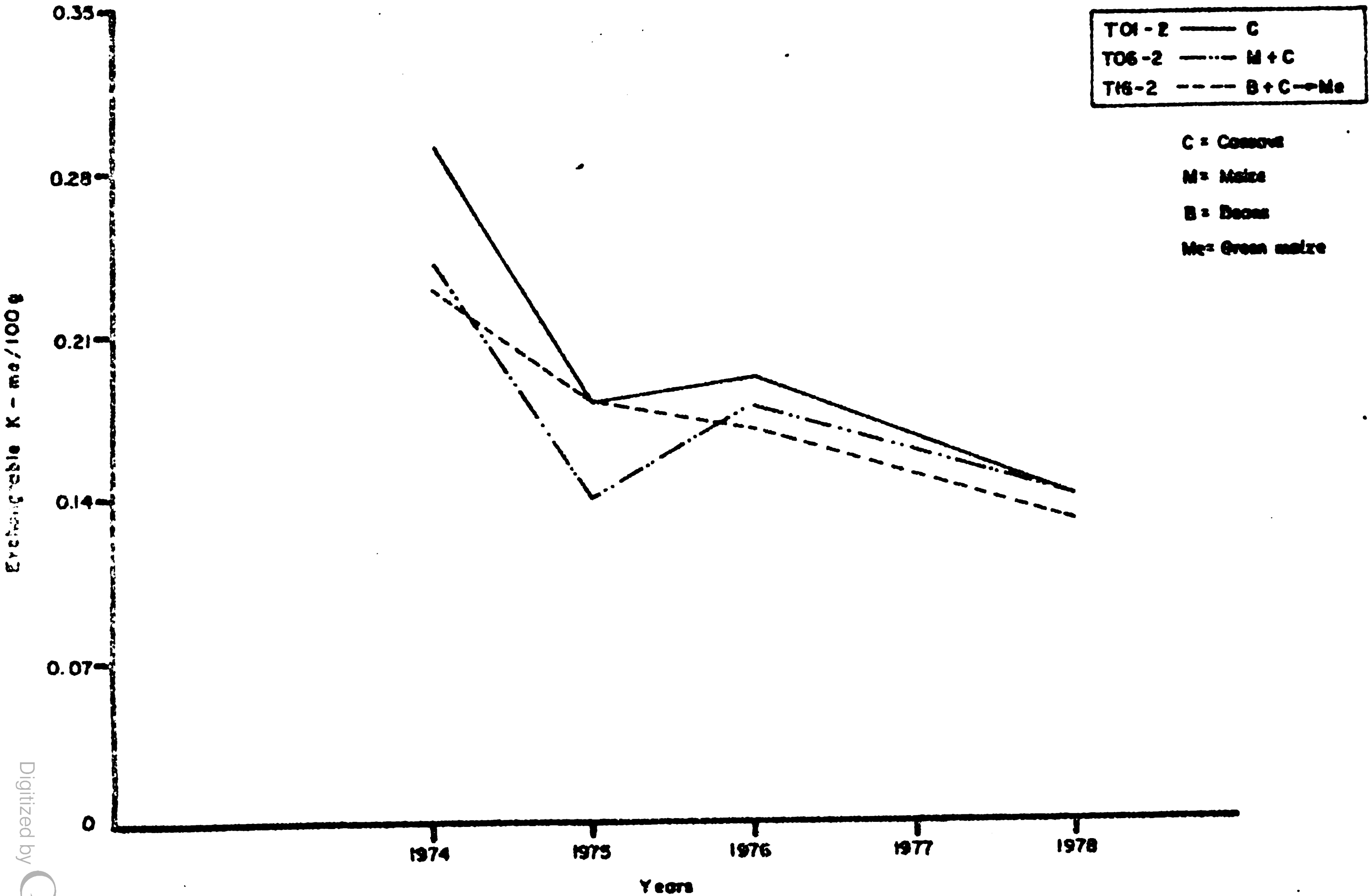

Fig. 2 Effect of time and cassava intercropped systems on the soil exchangeable potassium in the 0-30 cm layer of an Inceptisol at CATIE, Turrialba, Costa Rica