Nutrient Cycling in Agroecosystems **46**: 215–223, 1997.

Response of cassava and maize to fertilizer application, and a comparison of the factors affecting their growth during intercropping

F.O. Olasantan[1], H.C. Ezumah[2] & E.O. Lucas[3]
[1]*Department of Horticulture, University of Agriculture, Abeokuta, Nigeria;* [2]*International Institute of Tropical Agriculture, Ibadan, Nigeria;* [3]*Department of Agronomy, University of Ibadan, Nigeria*

Received 8 January 1996; accepted in revised form 12 August 1996

Key words: cassava, fertilizer, intercropping, maize, paleustalf

Abstract

A field experiment was conducted on a Paleustalf to examine the effect of fertilizer application and the possible yield limiting factors in a cassava-maize intercropping system. Application of N-fertilizer significantly increased maize grain and cassava root yields as well as N, P and K concentrations of both crops compared with application of non-N fertilizer or with the unfertilized controls. Intercropping, with or without fertilizer application, led to a decrease in the root yield and N, P and K concentrations of cassava, but had no significant effect on nutrient concentrations and grain yield of maize. Growth analysis revealed that from 20 weeks after planting to harvest in cassava and during the flowering to harvest in maize dry matter accumulation in both crops was similar in intercropping. However, during the same period, the mean crop growth rate in cassava was less than a fourth of the mean crop growth rate in maize. It was concluded that the main factor limiting total yield in a cassava-maize intercropping system is the depression of early cassava growth by vigorous maize component, which reduces the amount of assimilate allocated to cassava roots.

Introduction

Cassava and maize are the staple foods of most people in sub-saharan Africa. Cassava is a staple for 160 million people or 40% and maize for 200 million people or 50% of the population, mostly in west and central Africa (Anon, 1988). In Nigeria, both crops are often intercropped under humid and sub-humid conditions. Cassava may be planted early with maize when the rains begin but often it may be planted later in the season, so as to minimize competition with the cereal which is more sensitive to soil fertility and moisture (Okigbo, 1980). Maize is usually one of the first crops grown in mixtures and cassava the last crop harvested before the rotation is allowed to return to bush fallow. Cassava harvesting often occurs between 36 and 60 weeks after maize harvesting. Under all comparable conditions the root yield of cassava has always been depressed while the grain yield of maize is unaffected, although cassava has sufficient time to recover after short-duration crops are harvested (Tsay et al., 1988). The indeterminate growth habit of cassava means that vegetative growth continues after maize is harvested (i.e. during the period of root bulking), and thus may compete with the growth of the roots for assimilate supply. This has been mentioned as an important process determining cassava root yields (Fukai & Trenbath, 1993), although critical evaluation of this contention seems to be lacking.

Nutrient availability during intercropping and/or after maize harvest might be another yield limiting factor. Although cassava has the ability to extract P efficiently from low-P soil through mycorrhizal symbiosis (Howeler, et al., 1987), root development may be affected if other soil nutrients such as N and K are deficient. Hagens & Sittibusaya (1990) reported that without adequate K fertilization cassava yields declined after several years of continuous cropping in Thailand due to K depletion. In many soils cassava requires some application of N and K fertilizers for maximum root yields (Howler, 1991; Obigbesan & Fayemi, 1976) and a lack of K may affect its response to N or P (Anon, 1975). However, under very fertile conditions, a low cassava harvest index may result due to excessive vegetative growth after the maize harvest (Mutsaers et al., 1993). The objective of this study was to examine the effect of fertilizer application, and to compare factors that affect the yields of cassava and maize during intercropping.

Materials and methods

The experiment was conducted on an oxic Paleustalf at the International Institute of Tropical Agriculture, Ibadan (7.30°N, 3.54°E), Nigeria in the 1989/1990 and 1990/1991 cropping seasons. The rainfall pattern is bimodal with peaks in July and September. A total of 1270 mm rain fell in 1989, 1150 mm in 1990 and 1410 mm in 1991, nearly 80% of which was received during June - October. Mean monthly minimum and maximum temperatures ranged from 21 - 24 °C and 27 - 37 °C, respectively, and solar radiation from 10 - 23 MJ m^{-2} day^{-1}. The soil of the experimental field has 1.45% organic carbon, 0.14% total N, 9.0 mg kg^{-1} (Bray-1) available P, with 3.11, 0.73 and 0.32 meq 100 g^{-1} Ca, Mg and K, respectively, and a pH of 5.6 at 0.15 m depth.

The treatments consisted of two sole-cop cassava (CV.TMS 30572') given 0 or 30-30-30 K_g N-P_2O_5-K_2O ha^{-1}, two sole-crop maize (CV. TZESR-W') given 0 or 60-60-60 K_g of N-P_2O_5-K_2O ha^{-1} and five cassava-maize intercrops in a 1:1 row version with 0, 80-60-0, 80-0-60, 0-60-60 and 60-60-60 Kg of N-P_2O_5-K_2O ha^{-1}. Fertilizer rates were based on the recommendations given by National Accelerated Food Production Project. Nitrogen was applied as calcium ammonium nitrate and P and K as superphosphate and muriate of potash, respectively. The experiment was laid out in a randomized complete block design replicated thrice. The crops were planted on 11 and 12 May 1989 and on 30 and 31 May 1990 at the same site with the same treatment allocated to each plot. The land was prepared by disc-ploughing and ridging in 1989 and by spraying herbicides to kill weeks without reploughing in 1990. The size of each plot was 8 × 7 m. Cassava was planted at 1 m × 1 m giving 10,000 plants ha^{-1} and maize at 1 m × 0.25 m giving 40,000 plants ha^{-1} in both sole and mixed stands. Fertilizers were drilled into furrows at mid-interrow and covered with soil, two weeks after maize emergence. The plots were kept weed-free by hand.

Light interception was measured using 90-cm tube solarimeters (type TSL). Three solarimeters were used in mixed plot (two in sole plots), one position at right angle to plant rows at ground level, one at the top of cassava and one at the top of the maize canopy. Diurnal variation in soil temperature at 10 cm depth was measured with laboratory thermometers permanently installed at the centres of the plots. Gravimetric soil moisture content at 10 cm depth was determined by collecting soil samples adjacent to the thermometers and oven-dried at 105 °C for 24 h and weighed. All measurements were made at 8 weeks after planting (WAP).

Plant samples were taken during intercropping for both crops and after maize harvest for cassava for the determination of growth stage, leaf area, and fresh and dry weights of total above-ground biomass and of the tubers, grains and harvest index (HI). The shoot dry matter (including ears for maize) was determined by cutting two plants per plot for each crop from penultimate rows at every sampling occasion. Cassava leaf area (LA) was determined from the cut plants by the leaf dry weight method (Ramanujam & Indira, 1978) and maize LA from intact leaves of five plants per plot by the length-width method (Saxana & Singh, 1965). HI is the ratio of the fresh roots to total biomass in cassava and of the dry grains to total shoot dry mass in maize. Total N content of the youngest fully expanded leaves (without petioles) of cassava and ear leaves of maize was determined at 8 and 12 WAP for both crops and at 28 WAP for cassava by the Kjeldahl procedure using a Tacator Kjeltec Auto 1030 Analyser. The P and K contents were determined by the wet digestion method; the P content was subsequently determined by vanadomolybdate method and the complex was measured colorimetrically and the K content by flame photometry.

Results

Nutrient concentration

Cropping system had no significant effect on nutrient concentrations (averaged of the fertilizer treatments) in maize leaves in 1989 and 1990 (Table 1). In both years, the N, P and K concentrations in the leaves of sole maize were significantly higher with than without fertilizer both at 8 and 12 WAP. In the intercropping system, the N, P and K concentrations in the maize leaves were appreciably higher with N-fertilizer than

Table 1. Effects of intercropping cassava (C) with maize (M) and fertilizer application on the nutrient concentrations in the maize leaf tissue in two consecutive years

Cropping system	Fertilizer application (kg ha^{-1})			N (%)		P (%)		K (%)	
	N	P_2O_5	K_2O	8[z]	12	8	12	8	12
1989									
M	0	0	0	1.7b[y]	1.2c	0.22d	0.16c	1.6bc	1.8d
M	60	60	60	2.5a	1.6a	0.33a	0.18bc	2.5a	2 4a
C+M	0	0	0	1.6b	1.1c	o.23cd	0.16c	1.4c	1.9d
C+M	80	60	0	2.5a	1.5ab	0 32a	0.20ab	2.4a	2.2bc
C+M	80	0	60	2.2a	1.7a	0.26bc	0 18bc	2 6a	2.4a
C+M	0	60	60	1.7b	1 3bc	0.20d	0.17c	2.4a	2.1c
C+M	60	60	60	2.4a	1.5ab	0.29a	0.22a	2.5a	2.3ab
1990									
M	0	0	0	2.4cd	1.2bc	0 21b	0.21bc	2.2b	1.5de
M	60	60	60	2.8bc	1.4a	0.24a	0 27a	2.4a	2.0a
C+M	0	0	0	2.6c	1.1cd	0.17cd	0.19c	2.1bc	1.3e
C+M	80	60	0	3.3a	1.4a	0.20bc	0.28a	2.0c	1.5de
C+M	80	0	60	3.1ab	1.4a	0.16d	0 14d	2 4a	1.6cd
C+M	0	60	60	2.1d	1.0d	0.22ab	0.26a	2.2b	1.8abc
C+M	60	60	60	3.2ab	1.3ab	0.21b	0.25ab	2.3a	1.8abc

[z] Weeks after planting.
[y] Values within the same column within year with different letters differ significantly (p=0.05).

with PK or no fertilizer, both at 8 and 12 WAP in 1989. However, in 1990, application of N, P and K fertilizers did increase the N, P and K concentrations in maize leaves, respectively, compared with other treatments at both growth stages, but the increase was not always significant for P and K. In both years, nutrient concentrations in sole maize were similar to those in intercropped maize, with or without N-fertilizer treatment.

In 1989 and 1990, nutrient concentrations in cassava leaves (averaged over the fertilizer treatments) were higher in sole cropping than in intercropping, but the difference was significant only at 8 and 12 WAP (Table 2). In both years, sole cassava with fertilizer had higher N percentage than corresponding sole crop without fertilizer or intercropped cassava with or without fertilizer, both at 8 and 12 WAP. However, at 28 WAP percentage N in fertilized sole cassava did not always differ from that of fertilized intercropped cassava in either year. In 1989, fertilized sole cassava had higher P concentration at 8 and 12 WAP and K concentration at 12 and 28 WAP than corresponding unfertilized sole crop or intercropped cassava with or without fertilizer. In 1990, P concentration in fertilized sole and intercropped cassava did not differ from that of corresponding unfertilized cassava, but K concentration in both crops was appreciably higher than that of corresponding cassava without fertilizer in all three growth stages. In intercropping system, cassava with N, P and K-fertilizer application had 18, 20 and 12% more N concentration and 13, 7 and 15% more P at 8, 12 and 28 WAP, respectively, and 35% more K concentration only at 8 WAP in 1989 and, respectively, 22, 27 and 11% more N and 8, 28 and 18% more K concentration in 1990 than in other treatments. Fertilizer application did not show significant increase in the P concentration in cassava leaves in the second year.

Comparatively, both at 8 and 12 WAP in either year, the N percentage of cassava leaves was more than double that of maize leaves, while the P percentage in cassava exceeded that in maize by about 23%. However, the K percentage of maize leaves was very close to that of cassava leaves, especially with N-fertilizer, irrespective of cropping system.

Table 2. Effects of intercropping cassava (C) with maize (M) and fertilizer application on the nutrient concentrations in the cassava leaf tissue in two years

Cropping system	Fertilizer application ($kg\ ha^{-1}$)			N (%)			P (%)			K (%)		
	N	P_2O_5	K_2O	8[z]	12	28	8	12	28	8	12	28
1989												
C	0	0	0	3.8bc[y]	3.4c	3.6b	0.37b	0.35a	0.23ab	2.7ab	2.2b	1.4bc
C	30	30	30	4.6a	4.5a	3.6b	0.41a	0.35a	0.22bc	2.9a	2.4a	1.9a
C+M	0	0	0	3.5cd	3.4c	3.3c	0.29d	0.31bc	0.20d	1.9c	2.2b	1.4bc
C+M	80	60	0	3.9b	4.2b	3.7ab	0.33bc	0.32b	0.23ab	2.5b	2.1c	1.3c
C+M	80	0	60	3.9b	4.3b	3.8a	0.32cd	0.29d	0.21cd	2.7ab	2.2b	1.4bc
C+M	0	60	60	3.3d	3.6c	3.3c	0.31cd	0.30cd	0.24a	2.5b	2.1c	1.5b
C+M	60	60	60	4.1b	4.2b	3.7ab	0.36b	0.31bc	0.23ab	2.5b	2.2b	1 4bc
1990												
C	0	0	0	5.0b	3.5c	3.5d	0.29a	0.29a	0.18c	2.0c	1.7bc	2.0c
C	30	30	30	5.5a	5.4a	3.9bc	0.29a	0.26ab	0.18c	2.5a	2.6a	2.7ab
C+M	0	0	0	4.0c	3.5c	3.8c	0.20c	0.22bc	0.21a	1.8d	1.2d	2.2c
C+M	80	60	0	4.9b	4.3b	4.1b	0.22c	0.26ab	0.19b	2.1c	1.3c	2.2c
C+M	80	0	60	5.0b	4.3b	4.4a	0.26b	0.19c	0.18c	2.36b	1.9b	2.8a
C+M	0	60	60	4.1c	3.1c	3.9bc	0.22c	0.13d	0.19b	2.0c	1.7b	2.5b
C+M	60	60	60	5.2b	4.2b	4.0b	0.25b	0.22bc	0.19b	2.1c	1.4c	2.6ab

[z] Weeks after planting.
[y] Values within the same column within year with different letters differ significantly (p=0.05)

Table 3. Effects of intercropping cassava (C) with maize (M) and fertilizer application on grain yield, grain weight and harvest index of maize in two consecutive years

Cropping System	Fertilizer application ($kg\ ha^{-1}$)			Grainyield ($t\ ha^{-1}$)		Mean weight (g/100 grains)		Harvest index	
	N	P_2O_5	K_2O	1989	1990	1989	1990	1989	1990
M	0	0	0	2.1d[z]	1.9bc	22b	21b	0.38a	0.37bc
M	60	60	60	3.3a	2.4a	23a	22a	0.35bc	0.35de
C+M	0	0	0	1.9d	1.4d	22b	21b	0.34c	0.30f
C+M	80	60	0	2.7bc	2.1ab	22b	22a	0.36b	0.39a
C+M	80	0	60	2.8ab	2.2ab	23a	22a	0.38a	0.38ab
C+M	0	60	60	2.2cd	1.7cd	23a	22a	0.31d	0.34e
C+M	60	60	60	2.9ab	2.2ab	22b	22a	0.36b	0.36cd

[z] Values within the same column with different letters differ significantly (p=0.05)

Yield, root and grain weight

Cropping system generally did not have a significant effect on grain yield, mean grain weight and HI of maize with or without fertilizer treatments in 1989 and 1990 (Table 3). In both years, there were no appreciable differences in grain yield and mean grain weight between sole crop with fertilizer and the intercrop with N-fertilizer, but both produced significantly higher grain yield than sole crop without fertilizer or intercropped maize with PK or no fertilizer. Application of N-fertilizer significantly increased grain yield by 26-57% in both cropping systems and HI by 12 - 30% only in the intercropping system in both years. However, mean grain weight in intercropping system

Table 4. Effects of intercropping cassava (C) with maize (M) and fertilizer application on root yield, root weight and harvest index of cassava in two years

Cropping System	Fertilizer application (kg ha^{-1})			Root yield (t ha^{-1})		Mean root weight (g)		Harvest index	
	N	P_2O_5	K_2O	1989	1990	1989	1990	1989	1990
C	0	0	0	19c^z	18cd	292cd	288c	0.51c	0.57c
C	30	30	30	25a	23a	376a	365a	0.50c	0.56c
C+M	0	0	0	16d	13e	279d	266c	0 57b	0.62b
C+M	80	60	0	21bc	19cd	353b	346b	0.52c	0.64ab
C+M	80	0	60	22b	20bc	357b	346b	0.55b	0.63b
C+M	0	60	60	19c	17d	317bc	289c	0.57b	0.67a
C+M	60	60	60	22b	20bc	350b	349b	0.60a	0.67a

^{z} Values within the same column with different letters differ significantly (p=0.05)

was not markedly affected, while HI in sole stands actually decreased by N application.

Cropping system had significant effects on cassava root yield, mean root weight and HI with and without fertilizer application in both years. (Table 4). Cassava grown alone produced higher root yield (19 - 38%) but lower HI (9 - 16%) than corresponding intercropped cassava, irrespective of fertilizer application. The increase in root yield of fertilized sole-crop cassava over that of the corresponding intercropped plants with N (and P or K) fertilizer application, though significant in two years, was only slight. Complete fertilizer application significantly improved root yield and mean root weight in both cropping systems and HI only in the intercropping system. In intercropping, application of N-fertilizer resulted in a significant increase of 38 - 54% in the root yield and 24 - 35% in the mean root weight.

In both years, intercropping with N-fertilizer application gave the highest grain and root yields in both crops, while non-N fertilizer application made only a slight improvement over the corresponding unfertilized mixtures.

Growth analysis and micro-environment

The micro-environment under sole-crop maize and in the intercropping system was similar with or without fertilizer treatments (Table 5). However, intercropping with and without fertilizer reduced mean daily soil temperatures by 1.3 - 2.0 °C and increased mean soil moisture by 1.1 - 2.0% and light interception by 15 - 26% compared with cassava grown alone. In both cropping systems, fertilizer application markedly increased light interception in both crops by 3 - 14%. Light interception and soil moisture content were lower and mean daily soil temperatures were higher under sole cassava than under sole maize.

The length of the pre-flowering period (before the start of root bulking) in cassava was prolong by 34 d by intercropping, hence the length of the subsequent period until harvesting was 214 d in sole cropping and 180 d in intercropping. Fertilizer application, however, had no significant effects on time from flowering (4 weeks after maize removal or 20 WAP) to harvest in cassava. Cropping system had no effect on pre-flowering period and the time from flowering to maturity in maize. However, fertilizer application prolonged the flowering to harvest period by 3 - 5 d for maize in both cropping systems. The establishment of an apparently close canopy was reached by both crops at a leaf area index (LAI) of 2, which in maize occurred around the time of anthesis (60 d), but in cassava was attained at about 150 - 180 d or 50 - 80 d after maize physiological maturity (Figure 1). At 8 and 12 WAP, the LAI (averaged over the two growth stages and the two years) of maize was considerably greater than that of cassava (1.57 compared with 0.50). The net assimilation rate (NAR) of maize during the same period was about 70% lower than that of cassava in both cropping systems with or without fertilizer application. Intercropping reduced NAR in cassava by 20 - 50%, particularly in the fertilized plots, but had no effects on NAR in maize (Table 5).

In both crops, dry matter accumulation from planting until harvest proceeded at a nearly constant rate, irrespective of fertilizer application (Figure 2), which was appreciably lower in cassava than in maize during the concurrent growth period. In sole cropping, dry

Table 5. Comparison of the development and growth of cassava and maize grown with and without fertilizer application in sole cropping and intercropping (means of two years)

	Cassava		Maize	
	Without fertilizer	With fertilizer	Without fertilizer	With fertilizer
Sole cropping				
Growth duration (days)	364	364	105	105
Time from flowering to harvest (days)	214	214	39	44
Mean daily soil temperature (°C) at 8 weeks	28.0	28.0	26.3	26.3
Mean soil moisture content (%) at 8 weeks	10.3	10.8	11.4	12.2
Light interception (%) at 8 weeks	29	32	41	55
Net assimilation rate (g cm^{-2} wk^{-1}, ±se)	0.17	0.21±0.12	0.05	0.06±0.004
Dry matter accumulation during the flowering (maize) or from 20 WAP (cassava) to harvest (g m^{-2}, ±e)	1580	2190±209	1060	1835±189
Mean crop growth rate during the flowering (maize) or from 20 WAP (cassava) to harvest (g m^{-2} d^{-1}, ± se)	7 4	10.2±0.9	27.2	41.7±3.5
Root or grain yield g m^{-2}, ± se)	1750	2305±188	200	285±27
Mean root or grain filling rate (g m^{-2} d^{-1})	8.2	10.8	5.1	6 5
Partitioning factor[y]	1.1	1.1	0.19	0.16
Intercropping				
Time from flowering to harvest (days)	180	180	41	44
Mean daily soil temperature (°C) at 8 weeks	26.7	26.0	26.7	26.0
Mean soil moisture content (%) at 8 wks	11.4	12.8	11.4	12.8
Light interception (%) at 8 wks	44	58	44	58
Net assimilation rate (g cm^{-2} wk^{-1}±se)	0 14	0.14	0.05	0.06±0.004
Dry matter accumulation during the flowering (maize) or from 20 WAP (cassava) to harvest (g m^{-2}, ± se)	1185	1785±209	1280	1775±189
Mean crop growth rate during the flowering (maize) or from 20 WAP (cassava) to harvest (g m^{-2} d^{-1},± se)	6.6	9.9±0.9	31 2	40 3±3.5
Root or grain yield (g m^{-2} ±se)	1460	2105±188	165	255±27
Mean root or grain filling rate (g m^{-2} d^{-1})	8.1	11.7	4.0	5.8
Partitioning factor[y]	1.2	1.2	0.13	0.14

[z] Flowering date was taken as the showing of the tassel in 50% of maize plants or opening of the flower in 50% of cassava plants.
[y] Partitioning factor is the ratio of the root or grain filling rate to the crop growth rate.

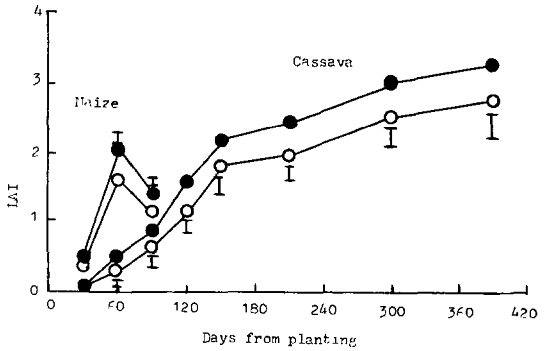

Figure 1. Leaf area index (LAI) of maize and cassava with 60 kg N-P_2O_5-K_2O ha^{-1} (•–•) and without fertilizer (o–o) application when intercropped (means of two years). Vertical bars represent the LSD ($p = 0.05$).

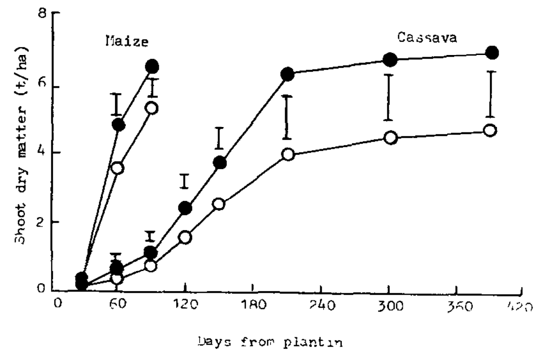

Figure 2. Shoot dry matter accumulation of maize and cassava with 60 kg N-P_2O_5-K_2O ha^{-1} (•–•)and without fertilizer (o–o) application when intercropped (means of two years). Vertical bars represent the LSD ($p = 0.05$)

matter accumulation from 20 WAP to harvest in cassava was about 20 - 50% greater than that of biomass from flowering to harvest in maize. In the mixed stands, however, dry matter production during the same period in cassava was similar to that of maize (Table 5). The rate of shoot dry matter production in cassava (Figure 2) follows a similar pattern to that shown by LAI (Figure 1) with values increasing to a peak after 5-6 months with or without fertilizer application. These values represent a crop growth rate (CGR) of 7-10 g m^{-2} day^{-1} during the last 6 - 7 months in both pure and mixed stands; this is considerably lower than the CGR reported for sole and intercropped maize during the last 6 - 8 weeks (Table 5). The mean CGR in cassava during the last 6 - 7 months was less than a fourth of the mean CGR in maize from flowering to maturity in both cropping systems, irrespective of fertilizer treatment. However, during the same period, the value of LAI in cassava was more than twice the value of LAI in maize. Another extreme difference between the two crops was in the mean root or grain filling rate. The mean root filling rate in cassava was almost twice that of the mean grain filling rate in maize in both cropping systems with or without fertilizer application. This is clearly shown by the comparative magnitude of the partioning factors for the two crops (Table 5).

Discussion

The considerable difference in growth and yields shown between cassava and maize in this study is typical of the differences generally found wherever these crops are intercropped under comparable conditions. However, the shoot dry matter accumulation in cassava from 20 WAP to harvest and in maize during the flowering to maturity period is similar because the dry matter accumulation of cassava was rapid after maize harvest. Fertilizer application did indeed increase growth, yields and nutrient concentrations of both crops over the years. The N and P concentrations of cassava leaves were about 50 and 23% greater than that of maize leaves, respectively, but the K percentage in both crops is similar in either cropping system, especially with N fertilizer application. The nutrient concentrations in maize or cassava leaves agree with those reported by Agboola (1972) and Obeke et al., (1982). This suggests that under the prevailing conditions the availability of nutrients, especially N, during intercropping and after maize harvest (i.e. when dry matter accumulation in cassava increased rapidly) was likely to be a growth limiting factor.

The enhanced crop performance in the intercropping system with applications of NPK, NP, and NK as compared to those of PK suggests that nutrient combinations without P or K did not limited the growth of either crop as much as those without N. The absence of any differences in the growth of both crops between mixed stands with NPK and NP or NK fertilization may partly reflect the soil of the experimental site, which has a high level of exchangeable K (Moormans et al., 1975). Cassava has the ability to extract P efficiently from low-P soils through mycorrhizal association (Howeler et al., 1987), reducing its response to applied P; associated maize probably used both native soil P and added P. In addition, there could be residual effects of P and K (immobile nutrients in soil) of the previous cropping. The greater effect of N application over that of P and K in terms of crop performance confirms our earlier findings (Olasantan et al., 1994).

The comparative analysis of the growth of cassava and maize under different fertility conditions in the intercropping system suggest the presence of other possible yield limiting factors. Despite the different phenology of cassava and maize, the mean daily temperature, mean soil moisture and percentage light interception prevailing during intercropping and under sole-crop maize in the present experiment were quite similar (Table 5). This suggest that inclusion of maize with cassava modified the growth environment of cassava more than that of maize, which should contribute to the validity of the comparison between the two crops. Pre-root bulking period was prolonged in cassava while phenological development in maize was not affected by intercropping. This could be an adaptation mechanism of cassava to intercropping stress. The effects of intercropping with maize on the micro-environment of cassava have been reported in our earlier paper (Olasantan et al., 1996).

With and without fertilizer application, the dry matter accumulation in cassava was slow during crop association (Figure 2) because of the initial slow growth rate and poor development of the leaf canopy during the early growth stages compared with that of maize (Figure 1). However, the above-ground dry matter produced in cassava from 20 WAP to harvest was rapid and was similar to that of the maize during the flowering to harvest in the intercropping system (Table 5). This is possibly because maize had been harvested and this period lasted longer in cassava, so compensating for cassava's initial lower mean crop growth rate. The LAI of cassava was considerably greater than that of maize during the respective periods (Figure 1). Higher assimilate partitioning in shoot and root of cassava after maize harvest would assist in maximizing light interception and in the utilization of soil recourses, respectively.

The striking difference between the growth of cassava and that of maize was apparently due to the considerable difference in CGR and pattern of partitioning of dry matter to the different plant parts during their respective growth periods. The value of CGR was considerably smaller in cassava than in maize, irrespective of cropping system or fertilizer application. The pattern of development in cassava differs markedly from that of maize, in which there is more of a phasic development. In maize the photosynthetic system (leaves) develops first and the storage system (grains) is filled later. Thus, there is little competition for assimilates between the two systems. Therefore, the rate of dry matter production after flowering in maize is largely reflected in the rate of grain development. In cassava there is simultaneous structural growth and storage root development and thus demands simultaneous supply of assimilates to both sinks, which may lead to intensive competition between the two sinks. The difference between the two crops in the pattern of growth and partitioning of dry matter between the grains or roots and the vegetative parts resulted in cassava giving poor yields in the intercropping system. However, the rate of dry matter production and partitioning to the cassava roots after maize harvest depended strongly on availability of soil nutrients, particularly N. It is therefore concluded that the main factor contributing to poor root yield of cassava in intercropping with maize is that maize grows faster and competes more vigorously than cassava, and thereby impairs early growth and root bulking in cassava. Indeed, Mutsaers et al. (1993) suggested that cassava varieties characterized by vigorous recovery growth after maize harvest and probably a high HI will be the ones most suitable for intercropping with maize. It seems, however, that the breeding and selection of such desirable cassava genotypes has not yet been accomplished.

Acknowledgements

The authors are grateful to IITA, Nigeria for providing the facilities for the study. Thanks are expressed to Dr H J W Mutsaers and Dr D S O Osiru for their assistance during the period of study.

References

Agboola AA (1972) The relationship between the yields of eight varieties of Nigerian maize and contents of N, P and K in the leaf at flowering stage. J Agric Sci Camb 64: 641–644

Anonymous (1975) Annual Report for 1974. Centro International de Agricultural Tropical, Cali, Columbia

Anonymous (1988) Annual Report for 1988. International Institute of Tropical Agriculture, Ibadan, Nigeria

Fukai S & Trenbath RR (1993) Processes determining intercrop productivity and yields of component crops Field Crops Res 34: 247–271

Hagens P &Sittibusaya C (1990) Short and long-term aspects of fertilizer application on cassava in Thailand. In: R.H. Howeler (ed) Proceedings of the 8th Symposium, pp 244–259. Int Soc Trop Root Crops, Bangkok, Thailand

Howeler RH (1991) Long-term effect of cassava cultivation on soil productivity. Field Crops Res 26: 1–18

Howeler RH, Sieverding E & Saif S (1987) Practical aspects of mycorrhiza technology in some tropical crops and pastures. Plant Soil 100: 249–283

Moormans FR, Lal R & Juo ASR (1975) The soils of International Institute of Tropical Agriculture (IITA). IITA Techn Bull No. 3. Ibadan, Nigeria. 48 p

Mutsaers HJW, Ezumah HC & Osiru DSO(1993) Cassava based intercropping: a review. Field Crops Res 34· 431–457

Obigbesan GO & Fayemi AA (1976) Investigations on Nigeria root and tuber crops: Influence of N fertilizer on the yield and chemical composition of two cassava cultivars. J Agric Sci Camb 86: 401–406

Okeke JR, Kang RT & Obigbesan GO (1982) Effects of fertilizers and plant age on distribution of nutrients in Nigerian cassava (*Manihot esculenta* Crantz.). Exp Agric 18: 403–411

Okigho RN (1980) The importance of mixed stands in tropical agriculture. In: R.G. Hurd, P.V. Biscoe & C. Dennis (eds) Opportunities for increasing Crop Yields. pp 233–245 Ass of Appl Biol. Pitman Publ Univ. of Reading

Olasantan FO, Ezumah HC & Lucas EO (1996) Effects of intercropping with maize on the micro-environment, growth and yield of cassava. Agric ECO Environ 57: 149–158

Olasantan FO, Lucas EO & Ezumah HC (1994) Effects of intercropping and fertilizer application on weed control and performance of cassava and maize. Field Crops Res 39: 63–69

Ramanujam T & Indira P (1978) Linear measurement and weight methods for estimation of leaf area in cassava and sweet potato. J Root Crops 4: 47–50

Saxana MC & Singh V (1965) A note on leaf area estimation of intact maize leaves. Indian J Agric 10: 437–439

Tsay JS, Fukai S & Wilson GL (1988) Effects of relative sowing time of soybean on growth and yield of cassava in cassava/soybean intercropping Field Crops Res 19: 227–239