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INFLUENCE OF CASSAVA (*MANIHOT ESCULENTA*) INTERCROP ON GROWTH AND FRUIT YIELDS OF PEPPER (*CAPSICUM* SPP.) IN SOUTH-WESTERN NIGERIA

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SUMMARY

In tropical Africa, pepper (*Capsicum* spp.) is grown as a rainfed crop, and its production is limited by the long, hot growing season. Field experiments were conducted in Nigeria to evaluate the effects of cassava (*Manihot esculenta*) on the growth and yields of three pepper cultivars and gross returns in 2001–2003. In Experiment 1, pepper (cv. Sombo) was planted between rows of cassava cvs Idileru (PI), Odongbo (PO) and TMS 30572 (PT). In Experiment 2, pepper cvs Sombo, Tatase and Atarodo, were mixed with TMS 30572 (MS, MT or MA). The growth environment for the intercropped pepper differed from sole crops of pepper. Radiant energy reaching the soil surface, maximum diurnal soil and canopy temperatures, and weed growth were lower with intercropping, with the lowest values being observed in the PI and PT intercrops. Similarly, soil moisture content and the number of earthworm casts were greater with intercropping, with the highest values also occurring in the PI and PT intercrops. In both experiments, fresh fruit yields of pepper depended on the duration of harvest, the number of fruits per plant and the weight of fruits. In Experiment 1, although the number of fruits and fruit yield of cv. Sombo were greater in the sole crop (SP) than the PO intercrop, the fruit yields in the PI and PT intercrops were similar to those of the SP plot. In Experiment 2, the number of fruits and yield of intercropped pepper cvs Tatase, Sombo and Atarodo were 25–28 % higher, on average, than in pure stands. Cassava tuber yield was not affected by intercropped pepper in either experiment. Total gross returns were greater than growing either pepper or cassava in monoculture. Increased total gross returns in the intercrops were obtained in the PI and PT treatments and in the MS and MA treatments without a significant reduction in pepper fruit yield. By promoting early fruit set and harvest, and bearing in mind the cumulative gross returns, mixing pepper and cassava enhanced the value of the vegetable, as early fresh pepper fruits command a premium price. It is concluded that pepper can be grown between cassava rows to provide a suitable environment for growth, but that this depends on the cassava cultivar. Using the less tall early cassava cultivar, with a relatively moderate leaf area index in a mixture with pepper is therefore recommended.

INTRODUCTION

Pepper is widely cultivated in the tropics, and is generally recognized in the international market for its high content of vitamins A and C. The main species, *Capsicum frutescens* (hot pepper) and *Capsicum annuum* (sweet pepper), constitute about 40 % of the vegetables consumed in Nigeria (Denton and Swarup, 1981).

In the humid tropics, pepper is grown as a rainfed crop, with annual rainfall totals of 650–1250 mm and relative humidities of 75–88 % providing suitable growing conditions. Rainfall greater than this range is detrimental, as it leads to poor fruit set and rotting of the fruits (Purseglove, 1977). Excess soil moisture causes shedding of

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leaves, flowers and fruits, while low plant-moisture status decreases fruit set (Tindall, 1983). Pepper grows better within an optimum temperature range of 16–26 °C and under partial shade at 50–60 % of tropical solar radiation than under full daylight (Messiaen, 1994). The adverse effects of high temperature on fruit set has been reported previously (Shelby *et al.*, 1978; Song *et al.*, 1976); fruit set decreased as temperature increased from 18–23 to 33 °C. Stoffella *et al.* (1988) reported that pepper grows best at 25 °C, and that growth rates decrease above this temperature. Rylski and Spigelman (1986) observed adverse effects of different night temperatures at constant day temperatures on the fruit set. With a 27 °C day temperature, Dorland and Went (1947) reported that fruit set was best at a night temperature of 12.5–15.5 °C, and that at 30 °C pepper failed to reach anthesis, but abscised at the bud stage. Quinn (1974) observed that the best temperature for growing pepper was 21.2 °C at night and 32.2 °C during the day. It appears, therefore, that a cool period or provision of shade is required in a hot location to maximize total productivity of pepper.

In tropical Africa, pepper production is limited by the long and hot growing season. Farmers attempting to increase production through early planting in pure stands risk losing the crop, because of hot weather and the adverse growing conditions. In West Africa, the period between January and April is the driest and hottest period, just before the first rains and beginning of farming activities. Tropical vegetables generally respond favourably to the microclimate modifications produced by crop mixtures, although the extent of yield enhancement varies with the component crops, the growing environment and the season (Messiaen, 1994; Olasantan, 1992). Growing pepper in mixtures may provide natural shade and a more favourable microclimate for the developing vegetable crop. The practice has been used to improve the microclimate, accelerate development, and increase the yield of many tropical vegetables, with the greatest relative benefits occurring during hot weather (Ikeorgu *et al.* 1989; Olasantan, 1988; Olasantan and Bello, 2004). In a cassava/okra intercrop, cassava provided shade and a favourable growing environment for soil organisms and the okra crop (Olasantan, 2001; Olasantan and Bello, 2004). Growth and yield responses of vegetables to intercropping with cassava vary with the cultivar, mixture components, fertilizer application, planting date, population density and the prevailing growing conditions (Ikeorgu *et al.*, 1989: Olasantan 1999, 2001). Intercropping with cassava may also provide a degree of weed and moisture-stress protection, and an insect-free growing environment, depending on the cassava cultivar and the conditions prevailing at the time of production (Olasantan, 2001; Olasantan *et al.*, 1994; Zoufa *et al.*, 1992).

Cassava (*Manihot esculenta*)-based intercropping is a common practice in the sub-humid and humid tropics (Mutsaers *et al.*, 1993). Cassava is a tall crop of long-duration and with slow initial ground cover. It is also an indeterminate, drought-resistant crop, usually planted early, when the rains begin, or later in the season in wide-spaced stands. These are all characters particularly desirable in mixed systems for providing partial shade, producing shelter during dry conditions, and thus creating a more favourable environment for the developing intercrops. It is uneconomic to grow cassava alone for such a long period, but its favourable cultivation systems and growth habits provide

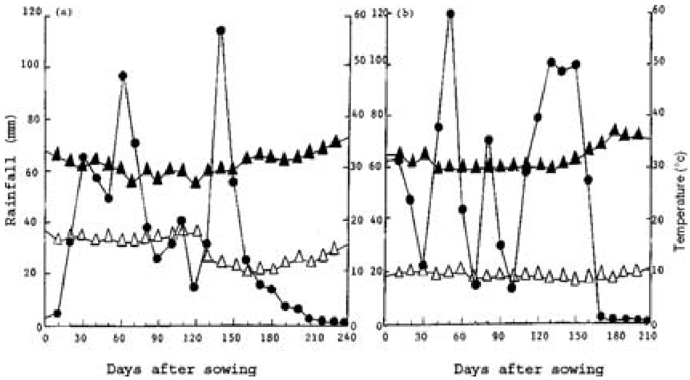

Figure 1. Mean 10-day values for rainfall, and minimum and maximum daily air temperatures, with time from sowing to maturity of pepper at Abeokuta in Nigeria in (a) 2001 and (b) 2002. Rainfall (●), minimum temperatures (△) and maximum temperatures (▲).

a good opportunity for intercropping with early maturing vegetables to diversify production and improve the starchy diets of the population.

Although cassava is grown as an intercrop in the tropics, there is still a dearth of information on the effect of cassava on the growing conditions for pepper. This study was therefore carried out to examine the effects of cassava on growth and fruit yields of three pepper cultivars and on gross returns.

MATERIALS AND METHODS

Two experiments were conducted between 2001 and 2003 at the University of Agriculture, Abeokuta (7°15′N, 3°25′E) in southwestern Nigeria. The area has a bimodal rainfall pattern, with peaks in July and September and a short dry spell in August. Figure 1 shows the weather data for the experimental period, measured at a meteorological station 2 km from the experimental site. In the experiments, pepper seedlings were grown for six weeks in a nursery shed provided with partial shade and 200 kg ha^{-1} N-P-K (15-15-15) compound fertilizer before transplanting. Foliar pests were controlled by spraying 400 ml ha^{-1} of Cymbush 10 EC (containing 100 g Cypermethrin) in 500 l of water at four and six weeks after sowing.

The first experiment was carried out in 2001 and 2002 to evaluate the effects of intercropping three cassava cultivars (Idileru, Odongbo, TMS 30572) of varying maturity dates and canopy types, and one hot pepper (cv. Sombo). According to Olasantan and Olowe (2006), Idileru (local) and TMS 30572 (improved morphotype) are both short and branching with dense canopies and take 250–360 d to mature, while Odongbo (local) is tall, non-branching with a sparse canopy, and takes 450 d to maturity. A 2 × 3 factorial (cropping systems × cassava cultivars) split-plot arrangement was fitted into a randomized complete block design with three replicates. The main plots were cropping systems (sole cassava cultivars and cassava/pepper intercrop) and the sub-plot treatments were cassava cultivars. The size of the main plot was

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12 m × 20 m and each sub-plot measured 12 m × 6 m. One sole sub-plot of cv. Sombo was randomized within each block to act as a control for the intercropped pepper.

Pepper seedlings were transplanted on 27 June 2001 and 20 July 2002 and cassava cuttings planted a day after the pepper seedlings had been transplanted. In the mixture, pepper was planted between cassava rows, with a constant arrangement of one row of pepper bordering one row of cassava with rows spaced 0.50 m apart. In both cropping systems, the row width of the cassava and pepper was 1.0 m. Intra-row spacing was 1.0 m for cassava giving 10 000 plants ha^{-1} and 30 cm for pepper giving 35 000 plants ha^{-1} with total intercrop plant density of 45 000 plants ha^{-1}. The crop arrangement and plant density used in the mixed stands simulated farmers' practice. The crops were not irrigated in either year. In all sub-plots containing pepper, a basal fertilizer of 80 N, 40 P_2O_5 and 50 K_2O kg ha^{-1} was drilled into furrows 15 cm away from pepper rows and covered with soil 1–2 weeks after transplanting pepper (WAT). The basal fertilizer was mainly applied to pepper, simulating farmers' practice. Sprouting of cassava stem cuttings was almost 100 % with number of shoots per planting piece varying from one to three. In both years, sole cassava plots were weeded thrice, and sole pepper or cassava/pepper intercrop plots, twice. At 12 WAT, weeds from three 1 m^2 areas were sampled from each plot, oven dried at 70 °C for 72 h and weighed for dry matter determination.

Soil temperatures at a depth of 10 cm and canopy temperatures were measured in all the plots with thermometers placed within the planted rows between 16:00 and 16:30 hours at 8–12 WAT in the first picking season, and at 30–44 WAT in the second picking season in each year. Light interception was measured on clear days at 10 and 34 WAT between 12:00 and 13:00 hours in 2002 using a Digital Micro-ammeter (Model 199.9 μa). Two light meters were used in each plot, one placed at ground level between the cassava and pepper rows and one at the top of both crops. Gravimetric moisture content was determined from soil samples collected at 0–10 cm depth adjacent to the thermometers and oven-dried at 105 °C for 24 h between 10 and 44 WAT in both years. In addition, surface earthworm casts were collected within three 1 m^2 quadrants in each plot on 14 January, counted, weighed and oven-dried at 105 °C for 24 h.

The second experiment was conducted in 2002 to evaluate the effect of intercropped cv. TMS 30572 on pepper cvs Sombo, Tatase and Atarodo. The three cultivars were selected for differences in maturity dates and growth habit. Tatase and Atarodo are the best *Capsicum annuum* cultivars while cv. Sombo is the best *Capsicum frutescens* widely grown in Nigeria (Olasantan, 1992). A split-plot arrangement with cropping systems (sole crop pepper and cassava/pepper intercrop) as the main plots and the three pepper cultivars as the sub-plots was fitted into a randomized complete block design with three replicates. One sole cassava sub-plot was randomized within each block to act as a control for the intercropped cassava.

In 2002, the seedlings of cvs Tatase and Sombo were transplanted on 6 August and those of cv. Atarodo, on 15 August along with cassava cuttings. Main plots measured 8 m × 20 m and the sub-plots, 8 m × 6 m. The basal rate and source of N, P_2O_5 and K_2O, crop arrangement, spacing, planting population and cultural operations were the same as for Experiment 1. Ten pepper plants were sampled at 10 and 12 WAT to determine plant height, number of leaves and branches, and leaf area. Leaf area was estimated by its relationship with the weight of a known area of leaf to the total leaf weight using the linear equation of Ramesh and Singh (1989). The areas of 150 leaves of varying sizes were determined by graph paper tracing. The estimated regression line between leaf area (Y) and leaf dry weight (X) is:

$$Y = 9.05\ (1.60) + 83.16\ (7.34)X\ (r^2 = 0.78)$$

where figures in parentheses are *s.e.* of the coefficients of the variables.

On each occasion, all fully expanded leaves were detached without the petiole, weighed and oven-dried at 60 °C for 48 h to obtain total dry weight.

An additional determination of leaf area index (LAI), days to 50 % flowering and first fruit harvest, and harvest duration was made. The LAI was determined as:

$$\text{LAI} = \text{total leaf area (cm}^2\text{)/land area (cm}^2\text{)}$$

In each experiment, mature red fruits were harvested weekly from the centre 8 m × 4 m area (Experiment 1) and 6 m × 4 m area (Experiment 2) in each plot, to avoid between-plot interference, for yield determination. At harvest, the fruits of 120 plants from the inner-most planted six rows were counted, weighed and graded. Fruits without blemishes were regarded as marketable. The percentage fruit yield of pepper was determined as:

$$\text{Fruit yield (\%)} = \text{weekly fruit weight (t ha}^{-1}\text{)/total fruit weight (t ha}^{-1}\text{)} \times 100$$

Ten cassava plants from each plot were sampled at 12 weeks after planting to determine plant height, number of branches and leaves, leaf area and LAI. Leaf area was determined from its relationship with mid-lobe length using the linear equation described by Ramanujam and Indira (1978). Areas of 200 leaves of different sizes were estimated by graph paper tracing. The estimated regression line between leaf area (Y) and mid-lobe length (X) is:

$$Y = -156.64\ (10.21) + 23.07\ (1.58)\ X\ (r^2 = 0.88)$$

where figures in parentheses are *s.e.* of the coefficients of the variables.

At 18 and 15 months after planting in Experiments 1 and 2, respectively, 20 cassava plants were harvested within the centre rows to record the number of tubers and their weight, and the fresh tuber yield per hectare. Statistical analyses were conducted using the analyses of variance procedures according to the split-plot design of the Statistical Analysis System Institute (1990). Treatment means were presented with the associated standard error of the means (*s.e.*) at the 5 % probability level.

Table 1. Variation in soil moisture content and canopy temperatures with time (weeks) after transplanting in sole crop pepper (cv. Sombo) and mixed stands with three cassava cultivars in Experiment 1 at Abeokuta, Nigeria in 2001 and 2002.

	Soil moisture content (g kg^{-1})								Canopy temperature (°C)					
	2001				2002				2001			2002		
Treatment	10†	12	40	44	10	12	34	38	10	12	40	10	12	34
SP‡	117	107	135	132	87	102	98	95	29.9	28.9	28.6	28.9	28.6	28.4
PO	132	117	137	135	96	111	101	98	29.5	28.5	28.5	28.3	28.1	28.3
PI	140	128	139	141	104	125	105	105	28.3	28.1	27.5	28.1	27.7	27.2
PT	137	134	150	147	100	122	116	113	28.3	28.1	27.5	28.1	27.7	27.1
Intercrop (mean)	136	126	142	141	100	119	107	105	28.7	28.2	27.8	28.2	27.8	27.5
Sole crop Odongbo	131	122	137	138	94	118	101	100	28.6	28.3	28.0	28.1	28.3	27.9
Sole crop Idileru	135	131	138	141	95	120	103	100	28.3	28.3	27.5	28.1	28.3	27.3
Sole crop TMS 30572	136	130	138	141	95	121	102	106	28.1	27.9	27.9	27.9	28.1	27.5
Sole cassava (mean)	134	131	138	140	95	120	102	102	28.3	28.2	27.8	28.0	28.2	27.5
s.e.	5.9	5.5	4.6	4.5	4.9	4.6	5.4	5.6	0.14	0.11	0.22	0.17	0.18	0.25

†Weeks after transplanting pepper.
‡SP: Sole pepper cv Sombo. Intercrops – PO: cassava cv. Odonbgo/cv.Sombo; PI: cv. Idileru/cv. Sombo (PI); PT: cv. TMS 30572/cv. Sombo.

RESULTS

Weather conditions during crop growth

In 2001, minimum temperatures at various growth stages of pepper remained between 10 and 18 °C, whereas in 2002 the corresponding values were below 10 °C on several occasions and reached 8 °C in October (Figure 1). The maximum daily temperatures after planting were equal or greater than 30 °C in both years, but fell slightly to 28 °C in July and late August 2001. The differences between maximum and minimum temperatures, and the variations in minimum temperatures were greater in 2002 than 2001.

The total amount of rainfall during the growth of pepper was within the optimal range (953 mm) in 2001, but above optimal (1738 mm) in 2002, and during the second flush of fruiting in 2001 (Figure 1). However, during the vegetative growth, rainfall was sub-optimal in 2001 (483 mm), but optimal in 2002 (702 mm) between May and August. In contrast, during the reproductive phase, rainfall was sub-optimal in both years (i.e. 271 mm in 2001 and 501 mm in 2002 between September and December).

Soil and canopy temperatures

In both years, soil and canopy temperatures were supra-optimal (28.5–33.6 °C in the soil and 28–31 °C under the canopy) at the early growth stages in sole pepper (SP), but these temperatures decreased by 1.5–2.5 °C later in the season (Table 1 and Figure 2).

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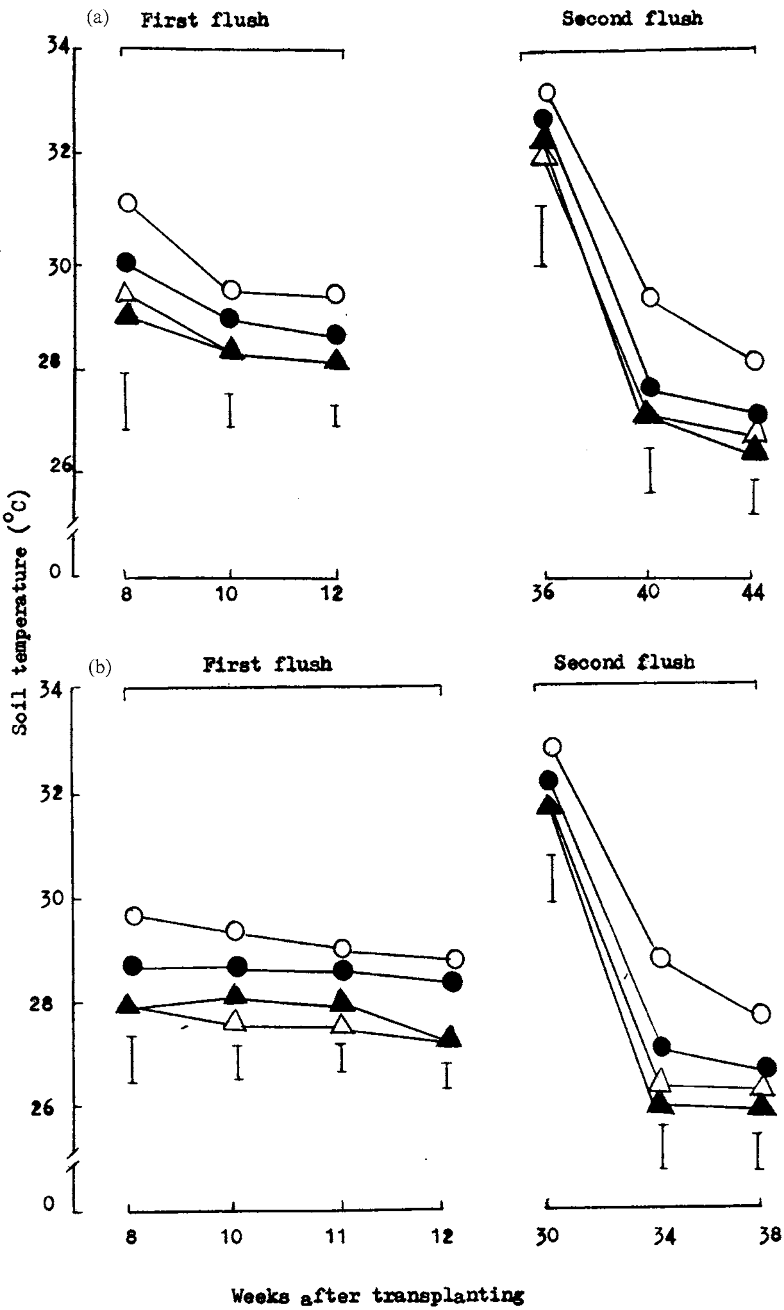

Figure 2. Daily maximum soil temperatures during the first and second flushes in sole pepper (SP) (○), and cassava cv. Odongbo/pepper (PO) (●), cv. Idileru/pepper (PI) (△) or cv. TMS 30572/ pepper (PT) (▲) intercrop in Experiment 1 at Abeokuta, Nigeria in (a) 2001 and (b) 2002. Bars are *s.e.* of treatment means.

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Table 2. Light interception, number of earthworm casts and weed biomass in sole crop pepper (cv. Sombo) and mixed stands with three cassava cultivars in Experiment 1at Abeokuta, Nigeria 1 in 2001 and 2002.

	Light interception (%)		No. of earthworm casts (m^{-2})	Weed biomass ($g\ m^{-2}$)	
	2002		2002	2001	2002
Treatment	10†	34	20	12	12
Sole pepper	39	58	29	358	235
PO‡	52	76	45	248	184
PI	55	76	56	207	166
PT	55	78	54	198	175
Intercrop (mean)	54	77	52	218	175
Sole crop Odongbo	42	65	42	278	206
Sole crop Idileru	46	72	43	258	177
Sole crop TMS30572	46	68	43	221	189
Sole cassava (mean)	44	68	43	252	191
s.e.	2.7	3.9	3.1	41	19

†Weeks after transplanting pepper.
‡Intercrops. PO: cassava cv. Odongbo/pepper; PI: Idileru/pepper; PT: TMS 30572/pepper.

In mixed stands, the soil and canopy temperatures under the cassava cvs Idileru/ pepper (PI) and TMS 30572/pepper (PT) remained within the range of 27.7–29.7 °C during the first picking season, and 26.4–32.6 °C during the second picking season. However, under the cassava cv. Odongbo/pepper intercrop (PO) temperatures remained at 0.5–1.5 °C higher than in the PI and PT intercrops in both seasons, except at the first measurement of soil temperature.

Soil moisture content

Soil moisture contents in the PO, PI or PT plots were greater, on average, by 10–27 g kg^{-1} during the first flush of the pepper harvest and 5–18 g kg^{-1} more during the second flush than in the SP plots, irrespective of sampling date in both years (Table 1). In mixed stands, however, soil moisture content was greater by 5–17 and 5–15 g kg^{-1} during the first and second flushes of pepper, respectively, in PI and PT than in the PO plots, and the difference was significant during the first flush at 10–12 WAT.

Light interception

Changes in light interception by sole and inter-crops during the first and second fruiting flushes in 2002 are shown in Table 2. At 10 WAT there was poor light interception in the SP and sole cassava (SC) plots when about 54–61 % of the light reached the ground. However, in the PO, PI and PT intercrops, light interception (52–55 % incident radiation) improved greatly. Light interception in the intercrop was greater by 15 and 10 % than in the SP and SC plots, respectively. At 34 WAT, during the second flush of fruiting, light interception was 58 % in the SP, 76–78 % in the intercrop, and 65–72 % in the SC plots.

Earthworm casts

Most of the earthworm casts collected were those of *Hyperiodrilus africanus*, the commonest species in the country (Hulugalle and Ezumah, 1991). The average number of earthworm casts in the PO, PI and PT intercrops were 45–56 m^{-2}, whereas the average estimated in the SP and SC plots were 29 and 43 m^{-2}, respectively (Table 2).

Weed growth

The sites of the experiments were mainly infested with *Tridax procumbens*, wild *Ipomea* spp. *Amaranthus spinosus*, *Talinum triangulare*, wild *Corchorus* spp., *Eleusine indica*, *Cynodon dactylon* and *Chromolaena odorata*, which constituted over 80 % by weight of the total weed population. In 2001 and 2002, weed biomass was significantly higher in the SP plots than in the corresponding PO, PI or PT plots at 12 WAT (Table 2). Weed biomass in the PO, PI and PT plots was lower than in the SP plots by 31, 42 and 45 % in 2001, and by 22, 29 and 26 % in 2002, respectively. In addition, weed biomass for the intercrops was lower than for SC by 6–20 %.

Vegetative characters of pepper

The interactions between cropping system and pepper cultivars on vegetative characters were not significant. In Experiment 1, the trends of growth responses to the treatments were similar in 2001 and 2002; the mean values for both years are therefore presented (Table 3). The plant height, number of leaves and LAI were significantly greater in the SP than the PO, PI or PT plots. The number of days to 50 % flowering and to first fruit harvest were influenced by the cropping system. Intercropping hastened flower production and fruit harvest. The timing of 50 % flowering and first fruit harvest was earlier by 5–9 days in PO, PI or PT than in the SP plot.

In Experiment 2, the growth responses of pepper to the treatments in both sole and mixed stands were similar. In both systems, cv. Sombo was the tallest with the most leaves and largest LAI, but with the shortest time to 50 % flowering and to the first fruit harvest. Cultivar Atarodo was the shortest with the smallest number of branches and LAI, and it was the last to reach 50 % flowering and first fruit harvest. Thus, in both cropping systems, cvs Tatase and Sombo produced flowers and fruits, and reached first harvesting date 10–23 days earlier than cv. Atarodo. However, cv. Sombo reached both 50 % flowering and first harvesting 9–14 days earlier than cv. Tatase, and the difference was significant in pure stands. All three pepper cultivars produced flowers and fruits about 7 days earlier in mixed stands than in the corresponding sole pepper plots.

Yield and yield components of peppers

In both experiments, fresh fruit yields of pepper cultivars depended on the duration of the harvest, the number of fruits per plant and the weight of the fresh fruits (Table 4). However, in Experiment 1, the number of fruits per plant determined fresh fruit yields

Table 3. Vegetative characters and days to 50% flowering and first fruit harvest of pepper in sole crop and mixed stands with cassava in Experiment 1 (mean of two years) and Experiment 2 at Abeokuta, Nigeria.

Treatment	Plant height (cm)	No. of branches plant^{-1}	No. of leaves plant^{-1}	Leaf area index†	Days to 50% flowering	Days to first harvest
Experiment 1						
SP‡	58	8	225	2.8	59	87
PO	52	8	195	1.9 (3.2)	51	82
PI	52	7	178	2.0 (4.2)	51	81
PT	51	7	164	2.1 (4.1)	52	82
Intercrop (mean)	52	7	179	2.2 (3.8)	51	82
s.e.	3.2	0.58	16	0.36	1.3	1.3
Experiment 2						
ST§	44	7	43	1.9	58	87
SS	55	8	166	2.1	49	74
SA	35	5	56	1.0	67	97
Sole pepper (mean)	45	7	88	1.7	58	86
MT¶	47	6	41	1.7 (3.6)	51	81
MS	59	6	145	2.0 (3.8)	42	67
MA	38	4	54	0.9 (2.7)	61	91
Intercrop (mean)	48	5	80	1.5(3.4)	51	80
s.e. (Cropping)	0.7	1.1	43	0.15	2.0	1.6
(Pepper cv.)	5.0	0.6	34	0.30	5.0	6.8
(Cropping × pepper cv.)	7.1	1.3	42	0.45	8.3	10.1

†Values in parentheses are combined intercrop LAI.
‡SP: Sole pepper cv Sombo. Intercrops – PO: cassava cv. Odonbgo/cv.Sombo; PI: cv. Idileru/cv. Sombo (PI); PT: cv. TMS 30572/cv. Sombo.
§Sole pepper – ST: cv. Tatase; SS: cv. Sombo; SA: cv. Atarodo (SA).
¶Intercrops – MT: Cassava cv. TMS 30572/cv. Tatase; MS: cv. TMS 30572/cv. Sombo; cv. TMS 30572/cv. Atarodo (MA).

more than fruit weight. In 2001, although the SP treatment produced a greater number of fresh fruits and yields of pepper than the PO intercrop, the fresh fruit yields in the sole crop were similar to those in the PI and PT intercrops. The trends were similar for 2002, although this time the PI intercrop produced a slightly higher fresh fruit yield than the SP treatment. In both years, the treatments had no effect on the duration or frequency of picking, but fruit yields in both cropping systems were larger in 2001 than 2002.

In Experiment 2, yield responses of the three pepper cultivars were similar for the two cropping systems, except for harvest duration (Table 4). However, the numbers of fruits per plant and total fruit yields in mixed stands were higher, on average, by 25–28 % than in pure stands. In mixtures, the MS (cv. Sumbo) and MA (cv. Aorado) treatments out yielded the MT (cv. Tatase) treatment. In both systems, cv. Atarodo produced the smallest weight of fruits and had the smallest number of fresh fruit harvests. In pure stands, cv. Sombo had the longest harvest duration, while in mixed stands it was cv. Atarodo.

Table 4. Harvest duration, frequency of fruit harvest, fruit yield and yield components of pepper in sole crop and mixed stands with cassava in Experiment 1 and Experiment 2 at Abeokuta, Nigeria in 2001 and 2002.

	Harvest duration (days)		Frequency of harvest†		No. of fruits plant^{-1}		Weight of 100 fruits (g)		Fresh fruit yield (t ha^{-1})	
Treatment	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
Experiment 1										
SP‡	215	188	13	13	165	72	110	117	5.8	3.0
PO	208	185	15	13	127	57	105	118	4.3	2.3
PI	215	185	15	15	151	67	104	130	5.1	3.1
PT	215	189	14	12	152	65	101	117	5.4	2.7
Intercrop (mean)	213	186	15	13	143	63	103	122	4.9	2.7
s.e.	5.5	2.5	0.48	0.75	16	3.1	3.7	5.5	0.65	0.35
Experiment 2										
ST§		245		17		7		976		2.4
SS		293		20		21		463		3.4
SA		275		14		27		256		2.9
Sole pepper (mean)		271		17		18		565		2.9
MT¶		259		16		9		947		3.0
MS		266		17		29		378		4.1
MA		276		15		36		300		3.8
Intercrop (mean)		267		16		25		542		3.6
s.e. (Cropping)		9		1.5		10		18		0.25
(Pepper cv.)		10		1.6		8		98		0.37
(Cropping × pepper cv.)		15		2.0		11		121		0.52

†Total number of harvests taken during the entire season, i.e. in both flushes.
‡SP: Sole pepper cv Sombo. Intercrops – PO: cassava cv. Odonbgo/cv.Sombo; PI: cv. Idileru/cv. Sombo (PI); PT: cv. TMS 30572/cv. Sombo.
§Sole pepper – ST: cv. Tatase; SS: cv. Sombo; SA: cv. Atarodo (SA).
¶Intercrops – MT: Cassava cv. TMS 30572/cv. Tatase; MS: cv. TMS 30572/cv. Sombo; cv. TMS 30572/cv. Atarodo (MA).

Fruit yield patterns and gross returns

In Experiment 1, fresh fruit yield patterns of pepper in both 2001 and 2002 were similar, and mean values for the two years are therefore reported. However, the patterns of fresh fruit production differed in the two experiments (Figure 3). In Experiment 1, the peak of yields occurred between 14 and 19 WAT in the first flush and between 38 and 49 WAT in the second flush. In Experiment 2, it was between 12 and 18 WAT in the first flush and 31 and 38 WAT in the season flush in the two cropping systems. In both experiments, however, the peaks of fruit production were higher in the first picking season than in the second. Fruit production declined in both experiments at 19–30 WAT (February–April), corresponding to the usual long dry spell and off-season production of pepper in Nigeria, but did not stop in Experiment 2, where there was a suggestion of a peak in fruit production by cultivar interaction. In the first picking season, cvs Tatase and Sombo reached peak fruit production earlier, on average by 10–23 days than cv. Atarodo. In the second season, cvs Atarodo and Sombo, especially cv. Atarodo, yielded more than cv. Tatase.

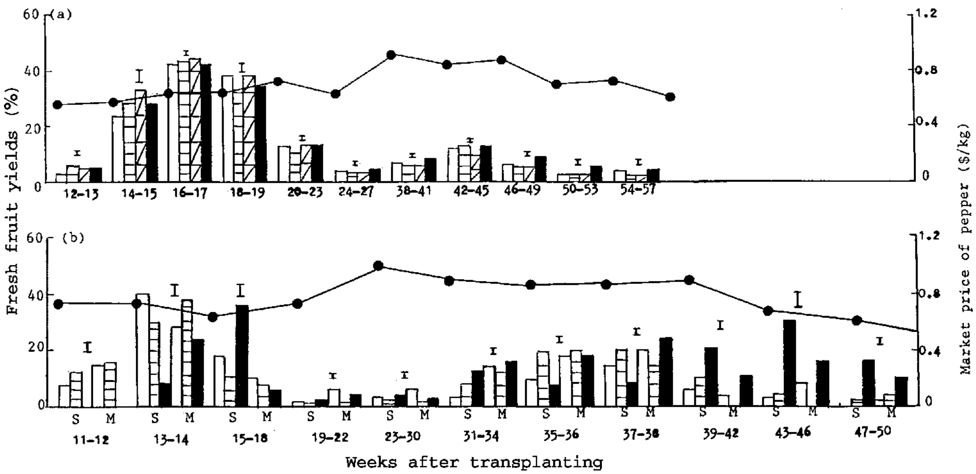

Figure 3. Fresh fruit yields (%) and market price (●) of peppers during the first and second flushes in sole pepper (SP, □), cassava cv. Odongbo/pepper (PO, ⊟), cv. Idileru/pepper (PI, ⊠) or cv. TMS 30572/pepper (PT, ■) in (a) Experiment 1 (mean of two years), and cv. Tatase (□), cv. Sombo (⊟), cv. Atarodo (■) in sole (**S**) and mixture (**M**) in (b) Experiment 2 at Abeokuta, Nigeria. Market prices from Ogun State Agro-Statistics Report for 1997–2002. Bars are *s.e.* of treatment means.

Calculation of gross returns (assuming growers market their own product) for pepper highlights the importance of earliness of fruit harvest as well as total fruit yields, particularly in the mixed systems. For example, in Experiment 1, total fruit yield for the sole pepper was greater, on average, by 16 % than for the intercropped pepper, but because the fruit from the intercropped pepper was available earlier in the season, the cumulative gross returns of the intercropped pepper was only 2 % lower than for the sole pepper (Table 5). In Experiment 2, the average cumulative gross returns and fruit production in the pure stands for the SA and SS treatments were 21 and 42 %, respectively, greater than for the ST treatment. However, in mixed stands, the average cumulative gross returns for the MA and MS treatments were only 27 and 6 %, respectively, greater than for MT, yet fruit production with MA and MS was 27 and 37 % greater than with MT. In the first picking season the MT intercrop accelerated early fruit set, maturity, and availability of fruits for cv. Tatase. But the MA and MS intercrops resulted in high total fruit yields for cvs Atarodo and Sombo late in the picking season, thereby shifting the peak harvest period close to the peak in market prices, particularly during the second flush.

Growth and tuber yield of cassava

There were no significant interactions between cropping system and cassava cultivars on growth and tuber yield characters. In Experiment 1, responses to the cropping systems were similar in both years; mean values are therefore presented in Table 6. Cultivar Odongbo was taller, and produced, on average, a smaller LAI (50–52 %), fewer tubers per plant (25–36 %), and tuber yield per hectare (20–35 %) than cvs Idileru or TMS 30572. The corresponding values for cvs Idileru and

Table 5. Cumulative gross returns of pepper in monoculture and mixture in the first and second flushes, and the sum total of the intercrop gross returns in Experiment 1 (mean of two years) and Experiment 2 at Abeokuta, Nigeria.

Treatment	Gross returns ($ ha^{-1})† First flush	Pepper Second flush	Cumulative	Cassava	Total gross returns ($ ha^{-1})
Experiment 1					
SP‡	2026	809	2835	–	2834
PO	1609	591	2200	2058	4258
PI	2073	710	2783	2742	5525
PT	1917	813	2730	2817	5547
Intercrop (mean)	1866	705	2771	2539	5083
Sole crop Odongbo	–	–	–	2750	2750
Sole crop Idileru	–	–	–	3417	3417
Sole cropTMS 30572	–	–	–	4000	4000
Sole cassava (mean)	–	–	–	3389	3389
s.e.	104	52	147	272	437
Experiment 2§					
ST	1008	593	1601	–	1601
SS	1078	1190	2268	–	2268
SA	799	1134	1933	–	1933
Sole pepper (mean)	962	972	1934	–	1934
Sole crop TMS 30572	–	–	–	3000	3000
MT¶	1165	836	2001	3500	5501
MS	1079	1054	2133	3583	5716
MA	755	1778	2533	3583	6116
Intercrop (mean)	1000	1223	2222	3555	5778
s.e	68	163	129	140	742

†Values calculated as weekly price × weekly fresh fruit yield over the harvest period. Average retail sale prices from Ogun State Agro-Statistics Report, 1997–2002.
‡SP: Sole pepper cv Sombo. Intercrops – PO: cassava cv. Odonbgo/cv.Sombo; PI: cv. Idileru/cv. Sombo (PI); PT: cv. TMS 30572/cv. Sombo.
§Sole pepper – ST: cv. Tatase; SS: cv. Sombo; SA: cv. Atarodo (SA).
¶Intercrops – MT: Cassava cv. TMS 30572/cv. Tatase; MS: cv. TMS 30572/cv. Sombo; cv. TMS 30572/cv. Atarodo.

TMS 30572 were similar in both systems. In Experiment 2, average values for plant height, number of leaves, leaf area and LAI of cassava were also similar in both cropping systems. However, SC produced the lowest number of tubers and tuber yield, but the greatest weight per tuber. In the mixtures, the number of tubers, tuber weight and tuber yield were similar.

DISCUSSION

This study showed that earliness, yield and gross returns of pepper may be enhanced by planting in mixtures with cassava through the favourable changes in microclimate. Substantial variation in light interception, and air, canopy and soil temperatures during the growing seasons were favourably modified to benefit the growth of pepper

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Table 6. Growth characters and tuber yields of cassava in monoculture and mixture with pepper in Experiment 1 (mean of two years) and Experiment 2 at Abeokuta, Nigeria.

Treatment	Plant height (cm)	No. leaves plant^{-1}	Leaf area (cm^2)	Leaf area index	No. of tubers plant^{-1}	Weight tuber^{-1} (g)	Tuber yield (t ha^{-1})
Experiment 1							
Sole crop Odongbo	97	56	350	1.3	3.5	816	33
Sole crop Idileru	80	60	355	2.1	5.0	853	41
Sole crop TMS 30572	79	58	339	2.0	6.0	816	48
Sole cassava (mean)	85	58	348	1.8	5.0	828	41
PO‡	98	53	326	1.3	4.0	812	31
PI	83	62	375	2.2	5.0	824	41
PT	81	61	362	2.0	5.5	826	46
Intercrop (mean)	87	59	354	1.8	5.3	821	39
s.e. (Cropping)	3.0	1.5	4.1	0.01	0.11	5	0.71
(Cassava cv.)	4.4	3.2	8.5	0.17	0.27	13	2.1
(Cropping × cassava cv.)	5.4	6.8	17.0	0.21	0.35	15	2.6
Experiment 2							
Sole crop cassava	89	59	383	1.9	3.9	1056	36
MT¶	92	60	381	1.9	5.3	955	42
MS	90	58	366	1.8	5.8	981	43
MA	91	56	381	1.8	5.0	986	43
Intercrop (mean)	91	58	376	1.8	5.4	974	43
s.e.	1.3	1.7	8	0.06	0.81	43	3.4

‡Intercrops – PO: cassava cv. Odonbgo/cv.Sombo; PI: cv. Idileru/cv. Sombo (PI); PT: cv. TMS 30572/cv. Sombo.
¶Intercrops – MT: Cassava cv. TMS 30572/cv. Tatase; MS: cv. TMS 30572/cv. Sombo; cv. TMS 30572/cv. Atarodo.

in the mixture. The soil and canopy temperatures (26.4–28.4 °C) under the mixture, particularly in the PI or PT intercrops, were close to optimal for pepper. Growing pepper in mixtures modified its phenology, while intercropped pepper also flowered and fruited 5–10 days earlier than the sole crop. A similar effect of temperature and partial shade of tropical solar radiation on the growth of pepper has been reported previously (Messiaen, 1994; Shelby *et al.*, 1978; Song *et al.*, 1976).

Furthermore, the mixture suppressed weed growth, increased earthworm casts, and maintained favourable soil and canopy environments. Difference in LAI may explain the discrepancy between sole cassava and intercrop plots. The ground cover provided by the associated pepper possibly reduced radiant flux to the soil surface and minimized water loss by evaporation during the daytime and the inversion of soil temperature at night. Intercropped pepper largely utilized the solar radiation, water and nutrients, which presumably, otherwise would have been wasted and/or used by weeds in the cassava inter-row space. It might be practical to grow pepper between cassava rows to enhance early fruit production to ensure a better market price and to help growers to avoid a glut on the market.

The response of pepper to the cropping system depended on the season, and the varieties of cassava and pepper. In Experiment 1, although the difference was not significant, cv. Sombo produced a greater number of fruits and fruit yield in pure stands than the intercrop in 2001, but similar fruit yields in both cropping systems in 2002. In Experiment 2, however, pepper produced more fruits and fruit yield in the intercrop than the sole crop in 2002. This suggests that in 2002 performance of pepper was enhanced in mixtures in both experiments. Some of the lower yields recorded in intercropped pepper in 2001 might possibly be due to variations in night temperature and poor light interception, which could cause flower and fruit abortion, and slower fruit set and development. The adverse effects of varied growing seasons on fruit set of pepper have been reported by Quinn (1974) and Rylski and Spigelman (1986).

In the mixtures, cv. Odongbo/cv. Sombo produced lower pepper fruit yield than cv. Idileru/cv. Sombo or cv. TMS 30572/cv. Sombo, and in several cases resulted in poorer yields than in the SP. In the PO intercrop, LAI, fruit yield (Tables 3 and 4) and cumulative gross returns of cv. Sombo (Table 5) were 5–15, 18–32 and 24–27 % lower, respectively, than in the PI or PT intercrop. This could be attributed not only to the facts that soil moisture content was less, and both soil and canopy temperatures were greater in the cv. Odongbo/cv. Sombo intercrop, but also that cv. Odongbo produced the tallest canopy and matured much later than cvs. Idileru and TMS 30572. All these are attributes that enhance competition for light, soil nutrients and moisture. Excess build-up of heat and low soil moisture may have interfered with flower formation and fruit set of pepper plants in the PO intercrop, particularly during the first picking season. Low plant-moisture status has been found to decrease fruit set in pepper (Tindall, 1983) and okra (Olasantan, 2005). In a previous study, cv. TMS 30572 provided more protection against heat and low soil moisture for okra production than did cv. Odongbo (Olasantan and Olowe 2006). Also, under moist and cool conditions, flower opening and availability of early fresh pods in okra were similar in monoculture and mixtures with cv. TMS 30572 (Olasantan, 2001; Olasantan and Bello, 2004).

In Experiment 2, there were variations in the pattern of fruit production of the three pepper cultivars. In both cropping systems, cvs Tatase and Sombo matured earlier (Table 3) and produced greater fruit yield (Figure 3) than cv. Atarodo during the first harvest season. However, during the second season, cvs. Sombo and Atarodo yielded more than cv. Tatase, and as a proportion of total fruit yield, cv. Atarodo yielded more than cvs. Tatase and Sombo (Figure 3). The benefits of earliness to cvs Tatase and Sombo were most apparent in the first picking season, whereas those of cv. Atarodo came in the second season. Overall, in both systems, cv. Sombo gave the highest fruit yields as a result of higher number of fruits per plant and large fruit (Table 4), and also similar fruit yields during the first and second harvest seasons (Figure 3), relative to the other two cultivars. This could be attributed to the differences in the maturity date and shade tolerance of the pepper cultivars. Cultivars Tatase and Sombo are early maturing, and they appeared to perform poorly under the shady conditions experienced during the second picking season. However, cv. Atarodo is a late-maturing pepper, and it may be that its higher fruit yield later in the season is due to inherent lateness in fruit production. Enhanced growth, accelerated fruit set and maturity of cvs Tatase and Sombo, particularly cv. Tatase, meant that fruits were available earlier in the season, thereby attracting high demand and prices, and cumulative gross returns. This ensured a better market price during November and December. Conversely, the peak harvest of cv. Atarodo in the second picking season coincided with the peak of market demand and prices for fresh fruits of pepper between April and July (Figure 3), also attracting high cumulative gross returns (Table 5). Prices and demand for pepper in Nigeria and in other coastal regions of West Africa are high in March–July, and then decline as the dry season and harmattan winds approach, and the bulk of local production comes onto the market between September and February. The gross returns for the pepper cultivars were recorded during the first and second flushes, respectively (Table 5). The increase in total gross returns obtained in the intercrops was much greater than the additional cost of materials and labour involved in their production and harvest (\$500 ha^{-1}). Total gross returns for the intercrops were 79–98 % greater than for pepper and 50–92 % than for cassava in monoculture. Bearing in mind the costs of materials and labour, growing peppers between cassava rows is more profitable than growing either crop in pure stands.

CONCLUSION

The results of the present study showed that earliness, fruit yield and gross returns of pepper may be enhanced in mixture with cassava through the favourable changes in the microclimate produced by the cassava. Mixing pepper and cassava enhanced early fruiting and availability of fruits of pepper as a result of improvement in the growing conditions, thereby attracting high demand and prices. It also enhanced an effective complementary biological approach for suppressing weeds, ensuring earthworm activity, and increasing total crop yields and gross returns. However, these attributes depended on growing conditions, and on the cassava and pepper cultivars. Intercropping pepper with a less-tall, early maturing cassava cultivar, with a relatively moderate leaf area index is recommended.

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