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EFFECT OF POPULATION DENSITY AND SOWING DATE OF PUMPKIN ON SOIL HYDROTHERMAL REGIME, WEED CONTROL AND CROP GROWTH IN A YAM–PUMPKIN INTERCROP

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SUMMARY

Pumpkin (*Cucurbita maxima*) is used for live mulch and edible apical shoots, seeds and fruits, and requires that a strategy for using it as ground cover in intercropping with food crops be developed while sustaining reasonable apical and fruit yields. Field experiments were conducted in 1999–2001 to investigate the effects of population density (5000, 10 000 and 15 000 plants ha^{-1}) and sowing date (March, April and May) of pumpkin on the soil hydrothermal regime, earthworm casts, weed control, and crop growth and yields in a yam–pumpkin intercrop. Growing pumpkin between yam mounds reduced maximum diurnal soil temperature by 4.3–8.1 °C, weeding frequency by 52 % and weed dry biomass by 50–67 %, while soil moisture was conserved by 48–62 g kg^{-1}, earthworm casts were increased by 58–68 % and yam tuber yield by 30–52 %, irrespective of population density or sowing date, compared with yam monoculture. Intercropping had no effect on the growth and fruit yields of pumpkin, but leaf area index and apical shoot and fruit yields increased by 30–49 % as the plant population increased to 10 000 plants ha^{-1}, beyond which there was no further significant increase. Furthermore, apical shoot and fruit yields were remarkably reduced when pumpkin was sown beyond April. Increasing pumpkin population up to 10 000–15 000 plants ha^{-1} reduced soil temperatures by 0.7–1.2 °C, weeding frequency by 15–35 % and weed dry biomass by 36–57 %, conserved soil moisture by 46–63 g kg^{-1}, and increased earthworm casts by 20 % compared to 5000 plants ha^{-1} in both cropping systems. Although the sowing date did not affect earthworm casts and weeding frequency, pumpkin sown in March or April reduced soil temperatures by 2.6–4.0 °C and weeds by 27 %, and conserved soil moisture by 15–37 g kg^{-1}, compared with May-sown plants. Intercropping pumpkin up to 10 000 plants ha^{-1} with yam at an optimal sowing date target in March-April is recommended for maximum development and productivity, and when pumpkin is used for live mulch in yam plots to reduce supra-optimal soil temperature, excessive evaporation and weed growth.

INTRODUCTION

Yams (*Dioscorea* spp.) are widely grown in the tropics. Nigeria remains by far the principal producer and accounts for 72–76 % of about 25 million t of the total world annual output (Coursey, 1967; Degras, 1993; Olasantan, 1999; Onwueme, 1978). Yams are the most nourishing plant in the diet of many inhabitants of tropical regions of the world, to such an extent that their very existence is centered on this crop (Degras, 1993). In West Africa, yam tubers are an important source of energy in the diets of millions of people and some livestock. However, despite their importance from a traditional point of view, yam cultivation has long been left in the hands of

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small-scale farmers, whose farming situation is characterized by low technological inputs, low agricultural outputs and lean financial resources. This has made it difficult for farmers to adopt improved agricultural inputs and to employ labour, which are the means through which crop production can be improved. It has further tended to decrease yam cultivation, and the crop is being replaced by cassava, even though the latter is less nutritious.

In West Africa, yams are grown mainly as a rainfall crop, with an annual rainfall of at least 1000 mm. They require an optimum air temperature range of 25–30 °C for normal growth and temperatures above 30 °C may retard tuber development; a cool period is often required in a hot location to maximize their productivity (Onwueme, 1978; Olasantan, 1999; Purseglove, 1977). Farmers in the tropics often include indigenous vegetables when intercropping with yams for many reasons besides the foods they provide. Sometimes, vegetables are included in the system for their ecological stability, and bio-cultural and sustainable attributes (Bunting, 1980; Hulugalle *et al.*, 1994; Okigbo, 1980). Intercropping okra and melon with cassava has been found to reduce weed growth, maximum diurnal soil temperatures and evaporative water losses, thus creating an appropriate soil micro-environment (Ikeorgu e*t al.*, 1989; Olasantan, 2001; Olasantan and Bello 2004). Zuofa *et al.* (1992) observed a reduction in weed growth by 37 % in a cassava–maize intercrop when compared with sole cassava, and a further reduction of 34–59 % when melon was included. Soil temperatures at 5 and 10 cm depths were 2.2–4.6 °C cooler, on the average, in a maize–melon intercrop than in sole maize stands (Olasantan, 1988).

Pumpkin (*Cucurbita maxima*), because of its creeping growth habit, ability to tolerate shade and cool temperatures after establishment, and to cover the ground very rapidly, as well as its importance in the diets of the people in Nigeria, is often intercropped with yams (*Dioscorea* spp.), cassava (*Manihot esculenta*) and maize (*Zea mays*). The crop prefers areas of medium rainfall and does not grow well under very wet conditions. Pumpkin may be useful in biological weed and erosion control in tropical agriculture (Olasantan, 2007). Apical shoots and fruits of pumpkin are edible by humans and some livestock, and they are a good source of protein, vitamins and minerals (Purseglove, 1977). The economic importance of pumpkin is determined by foliage production, the size and quality of fruits, and the amount of apical shoots. Farmers will not entertain any production practice that has an adverse effect on these components. However, information is lacking on pumpkin grown in mixtures with food crops, despite its importance as a live mulch, and its edible seeds, fruits and apical shoots. Pumpkin is grouped among lost crops in Nigeria, because only a few farmers in the country grow it (Olasantan, 2007).

Cultivation of pumpkin as a live mulch to protect the soil surface, suppress weeds and erosion, and for reasonable apical shoot and fruit yields would involve planting it at appropriate population densities and sowing dates so that it can cover the soil within a short time. Farmers do not follow standard agronomic practices, and plant at varied population densities and sowing dates. Use of pumpkin as a live mulch and human food will sustain its use, productivity and conservation. Information on pumpkin as a live mulch and how its growth and apical shoot and fruit yields change if agronomic practices are varied is urgently required. This study was undertaken to investigate the effects of pumpkin population density and sowing date on the soil hydrothermal regime, weed control and crop growth and yields in a mixture with yam.

MATERIALS AND METHODS

Field experiments were carried out at the University of Agriculture, Abeokuta (7 °15′ N, 3 °25′ W; 159m asl), southwestern Nigeria during the 1999–2001 cropping seasons. The rainfall pattern is bimodal; it commences in March and is plentiful in July and September, with a short dry spell in August. The long dry period extends from November to March. During the experimental period, average total annual rainfall ranged from 950 to 1010 mm, and mean maximum air and soil temperatures varied from 28.7 to 37.7 and 28.5 to 36.7 °C, respectively (Table 1). The site of the experiments had been under fallow for about six years, and the vegetation comprised secondary forests, interspersed with dense undergrowth. The soil is an Oxic Paleudulf of the Iwo series with 83 % sand, 5 % silt and 12 % clay with a pH of 6. The site was cleared and yam mounds were made manually, simulating farmer practices.

Experiment 1 – Effect of intercropping and pumpkin population density

This experiment was conducted to investigate the effect of intercropping at three pumpkin population densities during the 1999 and 2000 cropping seasons. A split-plot layout with cropping system (sole pumpkin and yam–pumpkin intercrop) as the main plot treatments and pumpkin population density (5000, 10 000 and 15 000 plants ha^{-1}) as the sub-plot treatments in a randomized complete block design with three replications was used. One sole-yam plot was randomized within each block to act as a control for the intercropped yam.

Table 1. Rainfall and temperature data during the experimental periods in 1999–2001 at Alabata-Abeokuta, Nigeria.

	Rainfall (mm)			Air temperature (°C)			Soil temperature (°C)		
Month	1999	2000	2001	1999	2000	2001	1999	2000	2001
January	33	3	3	34.1	35.1	34.4	33.5	33.8	34.1
February	32	–[†]	9	34.1	36.7	36.2	34.3	35.5	35.5
March	49	111	80	32.8	35.0	37.7	33.6	36.7	36.4
April	43	31	105	32.8	34.4	34.1	34.4	34.5	35.1
May	67	74	154	32.5	32.8	33.0	34.5	33.4	34.4
June	121	140	136	31.0	31.0	31.1	32.3	32.4	32.1
July	344	69	136	28.9	29.6	29.9	30.6	31.5	33.1
August	156	267	58	28.7	35.7	29.0	30.1	29.4	28.5
September	80	205	199	29.3	30.2	29.8	30.2	30.3	31.4
October	78	48	55	30.6	34.9	32.2	30.6	32.6	31.0
November	3	–	18	32.7	35.2	34.9	33.7	34.9	33.4
December	3	–	–	34.5	34.4	35.2	34.5	34.8	34.0

[†]No rainfall.

White yam (*Dioscorea rotundata*) was chosen, and pieces weighing on average 0.35 kg were planted on mounds spaced 1 m × 1 m in early March, giving 10 000 plants ha^{-1} in both years. Dry *Chromolaena odorata* mulch at the rate of 12.5 t ha^{-1} was applied immediately on top of the mounds, and weighed down with topsoil to prevent desiccation of planting pieces and disparity in emergence. A local pumpkin (*Cucurbita maxima* cv. Elegede), with 5–6 months of growth and without branched tendrils, collected from farmer fields was selected. This variety is grown in the rainforest zone in southwestern Nigeria. The seeds were sown in early April at 1.5 m × 1.5 m spacing with four seeds per stand. The seedlings were thinned to 1, 2 and 3 $stand^{-1}$ three weeks after sowing (WAS) to achieve the required population densities. In the sub-plots of 10.5 m × 9.5 m, eight rows of pumpkin bordered 10 rows of yam with the rows 0.50 m apart. Sub-plot paths were 2 m wide to reduce the spreading of pumpkin vines from adjacent plots. Yam seedlings were staked to about 3.5-m height and vines were trained regularly. There was no fertilizer basal treatment or irrigation, and weeding was done manually. These methods simulated farmer practices. At each weeding, weeds from three 1-m^2 quadrats diagonally in each plot were collected, oven dried at 60 °C for 72 h and weighed. Surface earthworm casts were collected within the quadrats shortly before every weeding occasion, counted, weighed and oven dried at 105 °C for 24 h.

At the base of centre mounds in all plots, thermometers were installed at a 15-cm depth to measure diurnal soil temperature in both sole and mixed stands. Adjacent to the thermometers soil samples were collected at 0–15 cm depth and oven dried at 105 °C for 24 h to determine the gravimetric soil moisture content. The depth for soil temperature and moisture measurement was chosen to investigate the hydrothermal variations experienced by the crops. Average soil temperature and moisture regimes were determined on clear days, 20, 21 and 22 June, 25, 26 and 27 July, and 22, 23 and 24 August 1999, and on 18, 19 and 20 June, 16,17 and 18 July, and 20, 21 and 22 August 2000. Measurements were taken at 16.00 hours local time when hydrothermal variations in both cropping systems were significant (Olasantan, 1988; Olasantan *et al.*, 1996).

Yam emergence and percentage survival of planted pieces per plot were determined 8–12 weeks after planting in each year. Five pumpkin plants per plot were sampled at 10 WAS for determination of number of leaves or branches per plant, leaf area, leaf area index (LAI), and vine length. Pumpkin leaf area (Y cm^2) was calculated by the non-destructive method proposed by Salau and Olasantan (2005):

$$Y = -122.45(7.76) + 19.41(0.56)X \quad r^2 = 0.96$$

where X is the leaf maximum width (cm). Pumpkin LAI was subsequently calculated as:

$$\text{LAI} = \text{Leaf area of plant (cm}^2\text{) plot}^{-1}/\text{plot area (cm}^2\text{)}.$$

Young apical shoots (30-cm long) of pumpkin were cut, counted and weighed every week, starting eight WAS and lasted until early September in each year. Mature

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pumpkin fruits were picked at seven months after sowing (MAS) while yam tubers of 45–48 plants from the six central rows per plot were harvested at nine months after planting (MAP), counted and weighed. Yam tubers without blemish and about 10 cm in diameter and 20 cm in length were regarded as ware tubers.

Experiment 2 – Effect of intercropping and pumpkin sowing date

This experiment was conducted to investigate the effects of intercropping and pumpkin sowing date during the 2000 and 2001 cropping seasons. The experiment was arranged in a split-plot layout fitted to a randomized complete block design with three replicates. The main plots comprised two cropping systems (pumpkin monoculture and yam–pumpkin intercropping) while the sub-plots of 10 m × 10 m corresponded to target pumpkin sowing dates (March, April and May). One sole-yam plot was randomized within each block to act as a control for the intercropped yam. The varieties of yam and pumpkin, cultural operations and data collection procedures were the same as for Experiment 1. Yam was planted in early February. Yam and pumpkin rows were 0.50 m apart, and the row width of each crop was 1.0 m, giving 10 000 plants ha^{-1} for either crop in sole and mixed stands. The soil hydrothermal regime was determined on clear days at 8, 12 and 16 WAS when the pumpkin had covered the ground on each sowing date in both years. Young apical shoots and mature fruits of pumpkin, and tubers of yam were harvested as in Experiment 1.

Data were subjected to analysis of variance procedures using a split-plot design for pumpkin and randomized complete block design for yam and soil hydrothermal regimes, earthworm casts and weed biomass in SAS (SAS, 1990). Where F values indicated significant differences, treatment means were compared using standard error (*s.e.*) of the means at the 5 % probability level. Simple linear correlation analyses were carried out to estimate the degree of association between crop growth and soil hydrothermal variables.

RESULTS

Weather conditions during crop growth

The total amount of rainfall during crop growth was within the optimal range (950–1010 mm) in the three years, with about two-thirds of the total occurring during the reproductive phase between June and October (Table 1). In all years, air and soil temperatures after planting were equal or greater than 31 °C, but air temperatures fell slightly to 28.7–29.9 °C in July and August and soil temperatures to 28.5–29.4 °C in August.

In each experiment, the pattern of responses of soil hydrothermal regime, earthworm casts, weed control, crop growth and yields of yam and pumpkin to treatments were similar in both years, and data were averaged over years and their values are presented separately for each crop. These parameters were affected by intercropping, pumpkin population density and sowing date, and their interactions.

Soil hydrothermal regime and earthworm activity

Soil temperatures and moisture content, and number of earthworm casts were similar in sole pumpkin and mixed stands, irrespective of population density or sowing date (Table 2). In both experiments, soil temperatures were supra-optimal (32.0–34.3 °C) at the early growth stages in sole yam, but later in the season the soil temperatures dropped by 4.3–8.1 °C in the intercrop treatments when compared with the sole yam. Also, soil moisture content was 48–62 g kg^{-1} and the number of earthworm casts was 58–68 % greater in mixtures than sole yam.

The effects of pumpkin population density on soil hydrothermal regime were similar in sole pumpkin and mixed stands. Doubling or tripling the plant population in sole stands reduced soil temperatures by 1.0–2.4 °C, and conserved soil moisture content by 34–45 g kg^{-1}. The corresponding values in the mixtures for soil temperatures and moisture content were 0.7–1.2 °C and 46–63 g kg^{-1}, respectively (Table 2). When the pumpkin population was increased from 5000 to 15 000 plants ha^{-1} earthworm casts were increased by 20 %. The variation in pumpkin LAI at varied plant populations accounted for 77 and 79 % of the variation in soil temperatures and moisture content, respectively (Table 3). Soil temperatures and moisture content, respectively, were negatively and positively related to the value of LAI. Variation in soil temperatures and moisture content, respectively, accounted for 98 and 99 % of the variation in earthworm casts. Earthworm casts were negatively related to soil temperatures and positively to moisture content.

The variation in soil temperatures and moisture content caused by varying the pumpkin sowing date was similar in sole pumpkin and in mixed stands (Table 2). Soil temperatures and moisture content during the early growth stages of yam were modified more by pumpkin sown in March than in April, which in turn was more than by plants sown in May. In both cropping systems, soil temperatures were cooler by 6.4–10.0, 6.0–8.6 and 3.0–6.0 °C when pumpkin was sown in March, April and May, respectively, relative to yam monocropping. The corresponding values for soil moisture content in March, April and May-sown plots were 33–89, 49–68 and 21–52 g kg^{-1}, respectively. Even though mixtures had more earthworm casts than sole yam, pumpkin sowing date did not affect the number of earthworm casts. Variation in pumpkin LAI at varied sowing dates accounted for 59 % and 56 % of the variation in soil temperatures and soil moisture content, respectively (Table 3). Soil temperatures and moisture content were negatively and positively related, respectively, to pumpkin LAI. Variation in soil temperatures and moisture content, respectively, accounted for 97 and 96 % of the variation in earthworm casts. Earthworm casts were negatively related to soil temperatures and positively to moisture content.

Weed growth

The experimental site was mainly infested with wild *Ipomea involucrata, I. mauritiana, I. vagans, Tridax procumbens, Elusine indica, Amaranthus spinosus, Talinum triangulare,* wild *Corchorus olitorus, Euphorbia hirta, Chromolaena odorata, Desmodium scorpiurus, D. tortuosum, Sesamum indicum and S. alatum,* which constituted over 90 % by weight of the total weed biomass. Weeding frequency and weed dry biomass were reduced significantly in sole pumpkin and mixed stands, compared with sole yam, in both experiments (Table 2). Four weedings were carried out in sole yam, but only on one or two occasions with

Table 2. Effect of cropping system, pumpkin population density and sowing date on variations in soil temperatures and moisture content, earthworm casts, number of weeding and weed dry biomass (mean of two years) in Experiments 1 and 2 at Abeokuta, Nigeria.

Cropping system	Plant density (ha^{-1})/ sowing date	Soil temperature (°C)			Soil moisture content ($g\ kg^{-1}$)			No. of earthworm casts (m^{-2})	No. of weedings	Weed dry biomass ($g\ m^{-2}$)
		June	July	August	June	July	August			
Experiment 1										
Sole yam	–	32.0	30.6	29.0	42	56	57	38	4.0	1149
Sole pumpkin	5 000	27.9	26.7	25.4	58	95	83	52	2.2	602
	10 000	26.3	25.4	25.0	87	119	103	58	1.7	377
	15 000	25.5	24.9	24.4	103	129	123	62	1.3	280
Mean		26.6	25.7	24.9	83	114	103	57	1.8	420
Intercrop	5 000	26.3	25.7	25.3	66	92	85	55	2.0	557
	10 000	25.8	25.1	24.7	91	120	114	60	1.7	358
	15 000	25.3	25.0	24.1	112	141	148	65	1.3	240
Mean		25.8	25.3	24.7	90	118	116	60	1.7	385
s.e.		0.33	0.31	0.29	8.7	8.6	9.0	1.5	0.37	35
Experiment 2										
Sole yam	–	34.3	32.7	30.7	42	54	53	40	4.0	1013
Sole pumpkin	March	24.7	26.3	27.0	122	87	81	64	2.2	526
	April	26.7	26.7	25.7	91	119	113	62	2.2	540
	May	29.3	27.3	24.3	63	92	130	63	2.0	612
Mean		26.9	26.8	25.7	92	99	108	63	2.2	559
Intercrop	March	24.3	26.0	26.7	131	111	82	67	2.2	455
	April	25.7	26.3	25.3	93	122	118	66	2.0	498
	May	28.7	26.7	24.7	70	112	136	68	1.8	574
Mean		26.2	26.3	25.6	98	115	112	67	2.0	509
s.e.		0.44	0.40	0.43	3.8	7.5	8.4	2.3	0.19	46

Table 3. Correlation analysis between hydrothermal variables and leaf area index (LAI), earthworm casts and yam tuber yield in Experiments 1 and 2 at Abeokuta, Nigeria.

Variables	LAI ($n = 18$)	Earthworm casts (no. m^{-2}) ($n = 12$)	Tuber yield (t ha^{-1}) ($n = 18$)
Experiment 1			
Soil temperature (°C)	−0.77**	−0.98**	−0.96**
Soil moisture content (g kg^{-1})	0.79**	0.99**	0.79**
Dry weed biomass (g m^{-2})	−0.89**	–	–
Experiment 2			
Soil temperature (°C)	−0.59*	−0.97**	−0.99**
Soil moisture content (g kg^{-1})	0.56*	0.96**	0.99**
Dry weed biomass (g m^{-2})	−0.76**	–	–

* and ** significant at $p < 0.05$ and $p < 0.01$, respectively.

mixed stands. Weed dry biomass was 590–640 g m^{-2} (about 50–67 %) greater in sole yam than in either sole pumpkin or mixed stands.

Increasing the pumpkin population reduced the frequency of weeding and weed dry biomass in sole and mixed stands (Table 2). When the population was doubled or tripled, weeding decreased by 15–35 % and weed dry biomass in mixed stands decreased by 36–57 %. The situation differed when pumpkin was sown at different dates. Frequency of weeding was not affected by pumpkin sowing date, but the highest (574–612 g m^{-2}) and the lowest (455–526 g m^{-2}) weed dry biomass occurred when pumpkin was sown in May and March, respectively. Variation in pumpkin LAI accounted for 89 and 76 % of the variation in weed dry biomass at varied populations and sowing dates (Table 3). Weed dry biomass was negatively related to pumpkin LAI.

Growth and yield parameters of pumpkin

Intercropping did not affect the number of leaves or fruits per plant, LAI, fruit weight, and apical shoot and fruit yields of pumpkin, but affected vine lengths and the number of branches per plant compared with monocropping (Table 4). Stem vines of intercropped pumpkin elongated faster and produced fewer branches than those of monocropped plants.

Except for the number or weight of fruits, all measured growth and yield attributes were affected by pumpkin population density. The number of leaves or branches per plant was reduced, but LAI, vine length, and fresh apical shoot and fruit yields were increased when pumpkin was sown at 10 000–15 000 plants ha^{-1} compared with 5000 plants ha^{-1} in both cropping systems. However, LAI and fresh apical shoot and fruit yields increased by 20–49 % by increasing the plant population to 10 000 plants ha^{-1}, beyond which there was no further significant increase.

Sowing date significantly affected all growth and yield attributes of pumpkin, except for the number of leaves and vine length. The fresh apical shoot yield, LAI and fruit yields were greater by 8–17, 10–16 and 35–50 %, respectively, in pumpkin sown in March or April than in plants sown in May.

Table 4. Effect of cropping system, population density and sowing date on growth, fruit yield and components of yield of pumpkin (mean of two years) in Experiments 1 and 2 at Abeokuta, Nigeria.

Treatment	No. of leaves plant^{-1}	LAI	No. of branches plant^{-1}	Vine length (m)	Apical shoot yield (t ha^{-1})	No. of fruits plant^{-1}	Fresh fruit weight (g)	Fresh fruit yield (t ha^{-1})
Experiment 1								
Sole pumpkin	226	3.9	24	3.2	4.2	2.5	531	13.5
Pumpkin intercrop	223	3.7	19	3.7	4.1	2.4	527	12.5
s.e.	2.4	0.06	0.27	0.09	0.11	0.09	3.9	0.74
Pumpkin population ha^{-1}								
5 000	270	3.2	26	3.2	2.4	2.7	547	7.9
10 000	215	4.0	22	3.5	4.9	2.5	537	13.4
15 000	189	4.3	18	3.8	5.3	2.3	505	17.5
s.e.	6.1	0.21	0.47	0.08	0.25	0.41	4.8	0.91
Experiment 2								
Sole pumpkin	251	4.0	22	3.4	4.0	2.1	510	10.7
Pumpkin intercrop	250	3.8	18	3.7	3.7	1.9	516	10.0
s.e.	1.8	0.09	0.40	0.05	0.08	0.07	4.2	0.50
Pumpkin sowing date								
March	251	3.9	20	3.5	3.9	2.1	522	10.8
April	254	4.3	22	3.5	4.2	2.5	545	13.4
May	247	3.6	18	3.6	3.6	1.5	473	6.9
s.e.	3.6	0.87	0.14	0.04	0.04	0.07	4.6	0.42

Cropping system × population or sowing date interactions

The interactions between cropping system and population were not significant for any growth and yield components of pumpkin, except for the number of leaves and LAI (Table 5). The trends of response of the number of leaves per pumpkin plant and LAI to population density were not similar between cropping systems. The response of the number of leaves per plant to population density was greater in the mixtures than in sole stands while it was greater in sole pumpkin than in mixed stands for LAI at 10 000–15 000 plants ha^{-1}. The smallest number of leaves per plant and the highest LAI of pumpkin occurred in plots with 15 000 plants ha^{-1}.

The cropping system × sowing date interaction was not significant for growth, yield and yield components of pumpkin, except for the number of leaves per plant, LAI and apical shoot yield (Table 5). The patterns of response of the number of leaves per plant, LAI and apical shoot yield to sowing date were not the same for sole and mixed stands. The values with number of leaves, LAI and apical shoot yield were greater in the sole stands than in mixed stands in March-sown pumpkin. However, the values of these parameters were similar between cropping systems when pumpkin was sown in either April or May.

Emergence and yield components of yam

In both experiments, intercropping increased percentage emergence and the survival of planted pieces and tuber yield of yam compared with monocropping (Table 6). Although the numbers and weights of tubers per plant were not affected by cropping systems, they were greater in mixed stands with pumpkin than in sole yam plots. Percentage emergence and survival of planted pieces were 3–10 and 5–15 % greater, respectively, in the mixtures than in sole stands. Tuber yield was greater by 30–52 % in the intercrop than in sole stands in both years.

Even though percentage emergence and the survival of planted pieces were not affected by sowing date of pumpkin, they were increased by 6–10 % as the population increased to 15 000 plants ha^{-1}. However, both the population and sowing date treatments did not affect tuber yield of yam, but the highest value occurred when it was sown in April at 10 000 plants ha^{-1}. Variation in soil temperatures accounted for 96 and 99 % of the variation in tuber yield at varied population densities and sowing dates, respectively. Similarly, variation in soil moisture content accounted for 79 and 99 % of the variation in the tuber yield at varied population densities and sowing dates, respectively (Table 3). Tuber yield was negatively related to soil temperature and positively to moisture content.

DISCUSSION

In most mixed cropping systems studies, emphasis is usually not placed on the effects of component crops on the soil hydrothermal regime. However, the weather just before the beginning of cropping activities in January–March in West Africa is characterized by supra-optimal temperatures with a low diurnal variation, which often cause high natural evaporation and moisture stress. During this period soil organism activities, and water and nutrient absorption are usually impaired, organic matter

Table 5. Interaction effect of cropping system, population density and sowing date on growth, fruit yield and components of yield of pumpkin (mean of two years) in Experiments 1 and 2 at Abeokuta, Nigeria.

Treatment	No. of leaves plant^{-1}	LAI	No. of branches plant^{-1}	Vine length (m)	Apical shoot yield (t ha^{-1})	No. of fruits plant^{-1}	Fresh fruit weight (g)	Fresh fruit yield (t ha^{-1})
Experiment 1								
Sole pumpkin								
5 000	268	3.3	28	3.1	2.4	2.7	557	8.4
10 000	212	4.0	24	3.3	5.0	2.5	542	14.1
15 000	198	4.5	20	3.6	5.3	2.3	494	17.9
Pumpkin intercrop								
5 000	272	3.1	23	3.4	2.4	2.6	536	7.4
10 000	218	4.0	19	3.6	4.8	2.4	533	12.8
15 000	179	4.0	16	4.0	5.2	2.2	516	17.2
s.e	7.4	0.27	0.60	0.13	0.31	0.48	49	1.11
Experiment 2								
Sole pumpkin								
March	252	4.1	22	3.3	4.1	2.1	520	11.0
April	254	4.3	24	3.4	4.2	2.6	540	13.9
May	247	3.7	19	3.5	3.6	1.5	471	7.1
Pumpkin intercrop								
March	249	3.7	18	3.7	3.4	2.0	524	10.6
April	254	4.2	20	3.6	4.2	2.3	550	12.9
May	246	3.5	17	3.7	3.5	1.4	475	6.6
s.e.	4.9	0.16	0.59	0.08	0.12	0.13	13.1	0.81

Table 6. Effect of cropping system, pumpkin population density and sowing date on percent emergence and survival of planted pieces, ware tuber yield and components of yield of yam (mean of two years) in Experiments 1 and 2 at Abeokuta, Nigeria.

Cropping system	Pumpkin population/ sowing date	Emergence/ plot (%)	Survival of planted pieces/ plot (%)	No. of plants harvested plot^{-1}	No. of tubers plant^{-1}	Weight tuber^{-1} (kg)	Tuber yield (t ha^{-1})
Experiment 1							
Sole yam	–	83	80	45	1.3	2.4	20.3
Yam intercrop	5 000	86	85	48	1.5	2.6	26.5
	10 000	90	88	48	1.4	2.6	26.8
	15 000	96	94	48	1.5	2.5	25.7
	Mean	91	89	48	1.5	2.6	26.3
s.e.		2.8	2.9	0.64	0.23	0.42	4.4
Experiment 2							
Sole yam	–	88	85	45	1.1	2.0	12.3
Yam intercrop	March	95	93	48	1.3	2.2	18.3
	April	98	96	48	1.2	2.3	19.0
	May	92	90	48	1.3	2.2	18.5
	Mean	95	93	48	1.3	2.2	18.6
s.e.		0.64	2.2	0.64	0.03	0.08	3.9

decomposition is accelerated, and crop growth is reduced (Lal and Greenland, 1977; Lopez *et al.*, 2004). In the present study, pumpkin served as a live mulch and was found to reduce the maximum diurnal soil temperatures and excessive evaporation that usually characterize the early cropping season in West Africa, and thus conserved soil moisture and increased earthworm activities in the mixtures. This modification was greater when pumpkin was planted in March or April and at 10 000–15 000 plants ha^{-1} than planting it in May and at 5000 plants ha^{-1}. In mixed stands, the soil temperatures (24.1–29.3 °C) were close to optimal for yam growth and the soil moisture and earthworm casts were increased by 40–62 g kg^{-1} and 30–40 %, respectively, compared with sole yam plots. This could be due to increased LAI and the rapid ground cover of March or April-sown pumpkin at the higher plant densities. The amounts of radiant flux reaching the soil surface and evaporation were then reduced and rainwater infiltrating into the soil profile was increased. When selecting edible cover crops to protect soil surface from destructive rains, erosion, insolation, overheating and evaporation, as well as to conserve soil moisture, pumpkin should be considered in tropical agriculture. This finding agrees with previous reports that mixed cropping is sometimes used in the tropics to protect the soil surface against solar radiation, evaporation and erosion (Bunting, 1980; Olasantan, 1988; Okigbo, 1980).

Furthermore, mixed cropping is acceptable in the tropics because of its effectiveness in reducing the need for weeding (Akobundu, 1981; Olasantan *et al.*, 1994; Silwana and Lucas, 2002). The pumpkin sown in March or April and at 10 000–15 000 plants ha^{-1} had greater ability to suppress weeds and to maintain favourable environments because of its extensive, rapid spreading canopy cover, and subsequently greater reduction in the amount of ground level light available for weeds than in plots sown in May and at 5000 plants ha^{-1}. Intercropping at higher pumpkin densities with yam reduced frequency of weeding to one or two occasions only and weed dry biomass by about 70 %. This is because the extensive, spreading foliage of pumpkin stopped the emergence of weeds and smothered those that eventually emerged. In the mixtures, pumpkin largely utilized the solar radiation, water and nutrients, which presumably, otherwise would have been wasted and/or used by weeds in the yam inter-mound space. Earlier studies have reported good suppression of weed growth by melon in mixtures with cassava and maize as a result of improved ground cover (Olasantan, 1988; Zuofa *et al.*, 1992). Even though weeding frequency in sole yam increased, weed growth would lead to more competition for growth factors with yam, which was already competing with the weeds for growth resources before they were removed. In the mixtures, there had not been any competition between pumpkin and yam, because pumpkin apical shoots were removed on a weekly basis. Leaf harvest in pumpkin started when the plant was in full growth; the young shoots as well as the whole leaves with their petioles were removed. This was a form of defoliation that made pumpkin less competitive and harmful than the weeds that infested the experimental plots.

In tropical agriculture, growing pumpkin between yam mounds is a valuable cropping option to modify the hydrothermal regime and to diversify production. Intercropping with pumpkin at any target plant population and sowing date did not affect the growth of the pumpkin or the tuber yields of the associated yam. The disparity in growth habit and development in relation to resource requirements and utilization of both crops in time and space dimensions could in part explain this. Pumpkin thrived well with low soil moisture early in the growing season, and had largely developed an extensive, creeping canopy in July-August when yam tuber initiation commenced, but tuber bulking was yet to be maximal. Pumpkin is a spreading type of cucurbit that can tolerate shade, grow for about 5–6 months and has the tendency to re-grow as long as adequate water is available during its production. After the leaves had withered, the green fruits were left on the plots to mature further before they were collected, simulating farmer practice. Through this practice, pumpkin had a greater influence on the hydrothermal regime of the associated yam before the tubers were harvested. Moreover, after pumpkin physiological maturity, yam development was enhanced by the residual soil nutrients and moisture. The really important thing about the growth habit of pumpkin is that it drops almost all the leaves when the fruits reach physiological maturity. Some of the nutrients removed by the pumpkin during crop association would also be released into the soil by decomposition of the sloughed-off leaf residue for the yam to utilize.

The results of this study also showed that the number of leaves or branches per pumpkin plant decreased as the population increased, but the LAI, apical shoot and fruit yields increased by 30–49 % at 10 000 plants ha^{-1}, beyond which there was no further significant increase. This could be due to mutual shading of leaves at 15 000 plants ha^{-1} that could have reduced the amounts of energy available for growth, since many of the leaves would be respiring more than they photosynthesized. Leaf production and size are normally affected by changes in light intensity and leaf water potential (Bjorkman and Holmgren, 1963; Wahua, 1985). Somewhat similar responses to changing population densities have been reported for a number of crop plants (Holliday, 1960; Olasantan, 2001; Silwana and Lucas, 2002; Wahua, 1985). Furthermore, production of apical shoots or fruits and their respective yields were reduced more when pumpkin was sown in March or May, especially in May, than in April. This could be due to quick establishment and increased leaf production and size for pumpkin sown in April caused by an increased soil moisture supply. In contrast, March-sown pumpkin experienced more drought and hotter environments (32.8–37.7 °C) which could lead to competition for soil moisture, while May-sown plants grew under wetter conditions (98–182 mm rainfall) than April-sown pumpkin during the planting and establishment stages (Table 1). This possibly enhanced the photosynthetic area of April-sown plants, and subsequently the amounts of assimilate available for apical shoots and developing fruit. Pumpkin grows well in areas of relatively warm temperatures and medium rainfall; it does not establish properly under too dry or wet conditions (Purseglove, 1977). In selecting pumpkin for both live mulch and apical shoot and fruit yields, attention should be paid to the optimum plant populations with maximum utilization of growth factors, and the optimum sowing dates.

In assessing the effect of intercropping, emphasis is mainly placed on full yield of the major crop and some yield of the minor component crop (Willey, 1979). In tropical agriculture, yam is grown as a major food crop, and its economic importance is measured by the size and weight of tubers, which determine total yield and often by the quality of the ware tubers. Similarly, the economic value of pumpkin is determined by the size and quality of the fruits and the amount of apical shoots. In this study, intercropping reduced the maximum diurnal soil temperatures and weed growth, and increased earthworm casts, and subsequently increased yam tuber yields, irrespective of pumpkin population density or sowing date. However, pumpkin plants sown in March or April produced greater numbers and weights of apical shoots and fruits than those sown in May. Also, increasing its population density beyond 10 000 plants ha^{-1} did not further significantly increase apical shoot and fruit yields. Hence, additional yields of pumpkin when sown in March or April and at 10 000 plants ha^{-1} should be taken into account in assessing the benefits of intercropping with yam. Suitable soil hydrothermal conditions and subsequently favourable environments for earthworms in the mixtures also enhanced the percentage emergence and survival of planted pieces, and the tuber yield of yam. A similar finding was reported in yam (Olasantan, 1999) and in cassava (Hulugalle and Ezumah, 1991; Olasantan, 2001; Olasantan and Bello, 2004; Olasantan *et al.*, 1996). Abundant earthworm casts in the mixtures could increase the enzymatic activities of soil micro-organisms, as well as their biomass (Lopez *et al.*, 2004).

These results indicate that in tropical countries where pumpkin is grown as a live mulch, and both the apical shoots and fruits are used as human food and animal feed, the optimum target for plant population is 10 000 plants ha^{-1}, while the optimal sowing date target is March-April for maximum development and production for ground cover and edible apical shoots and fruits. Pumpkin could be treated as a crop with three distinct economic values, the ground cover serves as live mulch, the seeds and fruit pulp are rich in oil and carbohydrate, and young apical shoots are rich in proteins, vitamins and minerals.

CONCLUSION

This study shows that intercropping pumpkin with yam is a valuable cropping option to diversify production, improve the soil hydrothermal regime, and suppress weed growth in tropical agriculture. Intercropping reduced supra-optimal soil temperatures and weed growth, conserved soil moisture and earthworm activity, which subsequently increased yam tuber yield, irrespective of pumpkin population density or sowing date. However, increasing the population density beyond 10 000 plants ha^{-1} in the mixtures did not further significantly increase growth and apical shoot and fruit yields of pumpkin. Also, the performance of pumpkin was reduced when it was sown after April. It is recommended that when pumpkin is to be used for both live mulch and apical shoot and fruit production, it should be intercropped up to 10 000 plants ha^{-1} with yam at a target optimal sowing date in March-April for maximum development and productivity.

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