Influence of spatial arrangements on performance of a yam-maize-pepper intercrop

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Abstract

Spatial arrangement of plants is critical in determining the growth and yield of intercrops. The productivity of three spatial arrangements of yam (*Dioscorea rotundata* var. Denteh), maize (*Zea mays* var. Obaatanpa) and pepper (*Capsicum frutescens* var. Kokuromotie) in intercrop was studied at Kintampo in the forest savanna transition zone of Ghana from 1996 to 1997. The intercrop row arrangements were one row of yam alternate with one row of maize/pepper relay, two rows of yam alternate with two rows of maize/pepper relay and one row of yam-pepper alternate with one row of maize. There were also the sole crop arrangements of yam, maize and pepper. Yields of the intercropped components were lower than their sole crops. However, the intercrops were more productive than the sole crops as shown in the Land Equivalent Ratios (LER) which ranged from 1.86 to 2.31 and Crop Performance ratio (CPR) from 1.44 to 1.69. The competitive ratios for the crops showed that yam was more competitive followed by maize and pepper but the influence of the dominated crops (maize and pepper) on the intercrop performance was not significant since the population of yam in all treatments was kept constant. A consequence of the intercrop competition was that maize and pepper components showed differences in plant height and the extent of leaf conductance was also higher than the sole crops. The result of the study showed that one row of yam/pepper: one row of maize, planted the same time, proved superior to the other two spatial arrangements where pepper came in as a relay crop.

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Introduction

Multiple cropping of cereals-legumes, cereals-cereals, cereals-vegetables, vegetables-legumes, root crops-legumes, etc. are very common in the tropics but the extent of these cropping practices in the tropics are not exactly known (Rao, 1984). In Africa, only a few farmers practice sole cropping in spite of the attention it has received from research and extension services (Lightfoot & Taylor, 1987). These cropping systems are used to maximize production and diversify crops from a parcel of land either in time or space than would be obtained by one crop. However, the possibility that multiple cropping may increase productivity and make more efficient use of resources has not received much research attention, probably due to the difficulty in managing and analyzing two or more different crops.

Studies have established that many intercropping systems may give higher and more stable yields than their component crops grown as sole crops (Marchiol *et al.*, 1992; Ahmed & Rao, 1982; Willey & Rao, 1981). For example, intercrops of sorghum and groundnut have shown yield advantages of between 25 and 40 per cent (Wahua &Miller, 1978). In terms of yield stability and monetary returns in intercropping, Rao & Willey (1980) observed that in a particular "disaster" area, sole pigeon pea would fail once in 5 years, sole sorghum once in 8 years, but intercropping of pigeon pea and sorghum would fail only once in 30 years. These and other related observations give credence to intercropping proving superior to their component sole crops.

For all the important attributes and the benefits that intercropping can provide to developing sustainable agriculture, more emphasis continues to be placed on sole crops in most agricultural and extension work. The main hindrance is due to the complexity of the system and the difficulty in managing the simultaneous exploitation of two or more crops of sometimes highly contrasting biological cycles (Azam-Ali *et al.*, 1990). This has discouraged most scientists from looking critically at their performance in relation to the capture and use of resources. The main thrust of this system is the efficient use of resources. In most cases, the other crop could use resources not used by one species. Such complementarity explains most of the advantages derived from the intercropping system (Willey, 1979).

A good knowledge of how the intercrop utilizes resources and the extent to which the micro-environment of the system differs from the component sole crops can give a scientific basis for choosing materials for the system, for there is enough evidence that high yielding materials in sole cropping do not give the same performance when grown in intercrop (Francis *et al.,* 1976). Thus, Zimmermann *et al.* (1984) and Rao & Willey (1980) emphasized the need for selecting specific genotypes for intercropping system. Crop performance in multiple systems is determined by factors such as choice of variety and agronomic practices. In Ghana, maize *(Zea mays)* yields in intercrop on farmers' fields have shown a reduction of 20-35 per cent (GGDP, 1987-90). Such yield decrease has been attributed to differences in spatial arrangement and relative planting dates.

Most of the work reported on yams *(Dioscorea* spp.) has been on sole cropping. However, socioeconomic studies have revealed that yams grown in the Sahel of Africa and Latin America are in multiple systems (Degras, 1993). Being a long-duration crop, which utilizes the potential growing period, yam is suitable for intercropping with early maturing crops such as maize and pepper *(Capsicum* spp.). Because maize and root crops such as yam constitute the dominant mixtures in many traditional intercropping systems, most researchers have tended to ignore the other components of the system, mostly vegetables. Observation has shown that when properly managed, yam-maize-pepper could make an efficient use of available resources to give higher productivity. The objective of this study was to assess the performance of a yam-maize-pepper intercrop under different spatial arrangements.

Materials and methods

Location, experimental design and crop management

The experiment was conducted in 2 consecutive years from 1996 to 1997 at Kintampo (3ꞌ 8° N, 43ꞌ 1° W) in a forest savanna transition zone of Ghana. The trial was sited on Denteso series *(Dystric gleysol-* FAO Classification) which is a colluvial soil found on middle to lower slope (Smith, 1962). The profile consists of about 30 cm of grayish brown sand overlying moderately deep sand. They are porous with rapid permeability. There were six treatments, namely two rows of yam alternate with two rows of maize-pepper relay (2Y2M-P); one row of yam alternate with one row of maize-pepper relay (1Y1M-P); yam and pepper in the same row alternate with one (1) row of maize (1Y-P1M); sole maize (SM); sole yam (SY); sole pepper (SP).

The design used was randomized complete block with three replications. Yam setts were hand-sown in rows 100 cm apart in mounds between January and February of each year with a north-south orientation. Maize seeds were interplanted in April. Pepper seedlings were transplanted in the sole pepper plots and yam-pepper-maize cropping pattern (i.e. 1Y-P1M) the same time as maize.

In treaments where pepper was relayed with maize, transplanting was done 10 days before maize harvest. In all cases the age of pepper at transplanting was 5 weeks. Maize and pepper were planted at 80 cm × 40 cm. An area of 4 m × 4 m was marked out in the centre of each plot for data collection on growth and development and yield data were taken from six central rows without the end plants. Nitrogen fertilizer was applied to maize at a rate of 50 kg/ha 1week after planting and 42 kg/ha 6 weeks after planting. The field was hand-weeded four times during the season. To prevent build up of yam pests the site was changed but within the same locality.

Growth and yield measurements

Between May and September each year, data on plant height (for maize and pepper) and stem diameter (for all crops) were taken at 2-week intervals. Yield for maize and pepper (planted simultaneously) were taken at 120 days after sowing while yam and relayed pepper were harvested 9 months after planting of yam.

Radiation measurement

Intercepted Photosynthetic Active Radiation (PAR) in each plot was measured with Sunfleck Ceptometer (model SF. 80) at 30, 45 and 60 days after planting maize. To measure the PAR transmitted by the canopy, the Sunfleck Ceptometer was placed horizontally above the crops to record the incidence flux density. The Ceptometer was then placed below the canopy perpendicular to the crop rows. This is similar to the method described by Marshal & Willey (1983). All measurements were taken at solar noon on cloudless days.

Stomata resistance

An automatic porometer (Delta T Devices) was used to measure stomata resistance of leaves in the crops at 30, 45 and 60 days after planting maize. Three leaves were selected at random and average values recorded. Measurements were made at the mid-portion of a leaf parallel to the mid-rib. The resistance of the abaxial and adaxial surfaces of the leaves was recorded separately. Measurements were made between 1200 h and 1400 h GMT.

Estimation of intercrop productivity and competitiveness

The biological productivity of the intercrops per unit of ground area were assessed as a ratio of intercrop to sole crop using the Land Equivalent Ratio (LER) defined by Willey (1985) for an intercrop comprising of three species "a", "b"and "c", $LER_{abc} = LER_a + LER_b + LER_c$. The differences in yield per unit area as a result of resource uptake were assessed using Crop Performance Ratio (CPR). For each species the productivity in the intercrop was expressed as partial CPR. For species "a", $CPR_a = Q_{ia} /(P_{ia} \times Q_{sa})$, where Q_{ia} and Q_{sa} are the productivity per unit area in the intercrop and sole crop, respectively and P_{ia} is the proportion of the intercrop area sown with species "a". A CPR > 1 implied an intercrop advantage (Azam-Ali *et al.*, 1990).

Changes in the competitive ability of the two crops in the intercrop were measured and compared with the sole crop using competitive ratio (CR) defined by Willey & Rao (1980). $CR = (L_a \times Z_a) / (L_b \times Z_b)$. Z_a and Z_b are proportion of species "a" and "b" in the intercrop. L_a and L_b are LER for specie "a" and "b". CR > 1 means higher competitiveness relative to the other crop.

Results

Seasonal variation

A summary of climatic conditions during the growing periods is shown in Table 1. The general pattern of rainfall and temperature during the period January-October was similar during the 2 years, with moderate rainfall and sunshine. The mean monthly temperature ranged between 28 °C and 35 °C. The total rainfall was 1064.2 mm and 1001.5 mm for the 2 consecutive years.

Crop yields and land equivalent ratio

A summary of productivity of the intercrop is presented in Table 2. For both years, the intercrops gave yield advantages from 86 to 131 per cent. Differences obtained in the plant populations did significantly affect the yields.

Intercrop competition and crop performance

The parameter considered under crop performance in Table 3 showed that the ratio was greater than one for all the intercrops, indicating an intercrop advantage. The intercrop competition among the crops also showed that yam was the most competitive crop among the three crops.

TABLE 1

Mean Monthly Temperature and Total Rainfall for Kintampo (1996 and 1997) from January to October

Month	Temperature 1996 (°C)	Rainfall (mm)	Temperature 1997 (°C)	Rainfall (mm)
Jan	33.3	8.1	33.4	0.3
Feb	33.9	32.0	35.6	-
March	34.1	72.2	35.4	93.2
Apr	32.9	99.2	32.4	183.7
May	32.3	203.1	31.1	183.7
June	30.0	232.9	29.3	153.0
July	29.2	107.4	28.0	74.2
Aug	28.3	76.4	28.3	78.0
Sep	28.9	106.7	29..0	99.7
Oct	30.0	126.2	30.9	197.6

For all combinations yam gave CR > 1.

Resource use and changes in growth and development

Changes in the fractional light interception and stomata conductance, as an indicator of resource use (Table 4) did not show significant differences among the different spatial arrangements of the intercrops. The crop height at 60 days after planting of maize showed that the intercropped plants were taller than their corresponding sole crop components. However, such differences were not significant.

TABLE 2

Plant Population, Yield and Land Equivalent Ratio

Treatments	Plant/ha			Yield (T/ha)			LER
	Maize	Yam	Pepper	Maize	Yam	Pepper	
1996							
2Y2M-P	39,708	8,240	31,541	3.04	8.34	0.43	1.95
1 YIM-P	40,125	8,440	25,416	2.67	7.70	0.51	1.86
1 Y-PIM	32,791	8,407	33,750	2.66	9.00	0.76	2.22
SY		9,860	-	-	9.90	-	-
SM	61,375	-	-	4.18	-	-	-
SP	-	-	41,944	-	-	1.13	-
Mean	34,799	8,737	33,162	2.47	8.74	0.70	-
SED	8,690	2,184	7,290	0.62	2.18	0.18	-
1997							
2Y2M-P	28,629	7,667	28,150	1.85	9.60	0.51	1.93
1 YIM-P	38,458	7,617	29250	2.55	9.63	0.58	2.22
1 Y-PIM	32,208	7J83	25,674	2.38	9.83	0.72	2.31
SY	-	9,167	-	-	11.13	-	-
SM	43,042	-	-	3.21	-	-	-
SP	-	-	41,940	-	-	1.04	
Mean	35,584	7,958	31,234	2.50	10.5	0.60	-
SED	7,116	1,592	6,247	0.63	2.63	0.15	-

TABLE 3

Changes in Intercrop Competition and Crop Performance Ratio

Treatment	Yield (T/ha)						Competitive ratio			
	Maize		*Yam*		*Pepper*					
1996	*Sole*	*Mixed*	*Sole*	*Mixed*	*Sole*	*Mixed*	*Ma:Yam*	*Ma:Pep*	*Yam:Pep*	*CPR*
2Y2M-P	4.18	3.04	9.9	8.34	1.13	0.43	0.87:1.15	-	2.21:0.45	1.55
1 YIM-P	4.18	2.67	9.9	7.74	1.13	0.51	0.82:1.22	-	1.73:0.58	1.44
1 Y-PIM	4.18	2.67	9.9	9.01	1.13	0.76	0.70:1.42	1.05:0.96	1.36:0.74	1.64
1997										
1	3.21	1.85	11.13	9.60	1.04	0.51	0.67:1.48	-	1.76:0.57	1.56
2	3.21	3.55	11.13	9.63	1.04	0.58	0.90:1.10	-	1.53:0.64	1.66
3	3.21	2.38	11.13	9.88	1.04	0.72	0.84:1.19	1.07:0.93	1.28:0.78	1.69

Ma - Maize
Pep - Pepper

TABLE 4

Changes in Light Interception and Leaf Conductance of the Cropping System at 60 Days after Planting of Maize

Treatment	*Fractional light interception*		*Stomata resistance* (ms^{-1})					
	1996	*1997*	*1996*			*1997*		
			Ma	*Yam*	*Pep*	*Ma*	*Yam*	*Pep*
2Y2M-P	0.81	0.83	2.10	3.20	-	2.32	1.89	-
1 YIM-P	0.86	0.88	2.42	2.68	-	-	1.89	1.90
1 Y-PIM	0.94	0.91	2.60	2.46	2.16	2.96	1.53	1.64
SY	0.93	0.90	-	2.98	-	-	2.05	-
SM	0.63	0.74	2.54	-	-	1.95	-	-
SP	0.38	0.42	-	-	1.34	-	-	0.93
Mean	0.76	0.78	2.41	2.83	1.75	2.28	1.84	1.29
SED	0.19	0.20	0.60	0.71	-		0.32	0.46

Discussion

In both years, the intercrops were more productive than the sole cropping. This is expressed by their LER's >1 and CPR's > 1 (Tables 2 and 3). The higher intercrop advantages indicated that the system was more efficient in terms of resources use than the sole crops. However, there were differences in the reproductive yields of the different spatial arrangements especially for maize. The differences shown by the intercrop advantages (LER and CPR) are consistent with similar observation by Azam-Ali *et al.* (1990). The differences in performance among the intercrop treatments could be accounted for by the differences in the plant populations, especially for maize and pepper. The population of maize and pepper in the intercrop changed from 45 to 80 per cent in the three treatments compared to the sole crops. The resultant yield shift ranged between 38 and 70 per cent for pepper, and 58 and 79 per cent for maize. Such differences gave rise to the differences in the intercrop competition.

Essentially, there was a reduction in yields of the component crops of intercrop compared to the sole crops due to intercrop competition. The net yield loss was in a range of 36 to 42 per cent. Assessment of the growing condition (i.e. rainfall and temperature) showed that the rainfall was adequate and well distributed (Table 1) to support growth and development of the crops. Therefore, the major factor responsible for the variation in intercrop yields was probably due to the changing degree of interactions between the interphase plants. The differences in plant height and stomata conductance between the intercrops and sole crops showed that spatial differences in intercrops could result in differences in performance (Tables 4 and 5). This condition usually results in physiological changes, which affect crop development.

The intercropped maize and pepper grew much taller than their component sole crops. However, the differences in height among the intercropped maize and pepper were not significant. This is reflected in the relative proportion of radiation intercepted by the different intercrop patterns. This condition suggests that radiation was not limiting as far as the intercrops were concerned. Therefore, root competition rather than shading might have contributed to the differences in the intercrop performance among the different spatial arrangements. Studies have shown that nutrient absorption in most crops (including yam, maize and pepper) is small during their early development, while at the time of full bloom the amount absorbed ranged between 60 to 100 per cent (Mittleider and Nelson, 1970). Thus, considering the differences in spacing and arrangements among the intercrops, it was likely that the maize and pepper planted the same time might have received lesser root competition from yam.

The stomata resistance (Table 4) was slightly higher for the intercrops than sole crops. This suggested an increase in resistance to gas exchange and reduction in water loss. Thus, there was a decrease in CO_2 diffusion which was likely to cause a reduction in photosynthetic rates (Boyer, 1976). This sequence of events might probably be the result of partial shading as observed in the different spatial arrangements depicted by the differences in plant height and stomata resistance.

An increase in the productivity of this intercrop may be ascribed to both spatial and temporal advantage. The combination of a long season crop (yam) and relatively short season crops (maize and pepper) enabled the system to utilize the potential cropping period shown in Table 1. By mixing such crops that differ in their requirements for resources, i.e. light, water and

TABLE 5

Plant Height and Stem Diameter at Physiological Maturity of Maize and Pepper

Treatment	*Plant height (m)*				*Stem diameter (cm)*					
	Maize		*Pepper*		*Maize*		*Yam*		*Pepper*	
	1996	*1997*	*1996*	*1997*	*1996*	*1997*	*1996*	*1997*	*1996*	*1997*
2Y2M-P	2.75	2.92	0.64	0.64	1.64	1.65	0.92	0.95	0.60	0.58
1 YIM-P	2.69	2.79	0.63	0.60	1.69	1.77	0.97	0.97	0.62	0.66
1 Y-PIM	2.71	2.82	0.67	0.68	1.72	1.73	0.96	0.99	0.68	0.77
SY	-	-	-	-	-	-	0.99	1.06	-	-
SM	2.69	2.80	-	-	1.86	1.91	-	-	-	-
SP	-	-	0.60	0.58	-	-	-	-	0.98	1.11
Mean	2.71	2.83	0.64	0.63	1.73	1.77	1.77	0.99	0.72	0.78
SED	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

space, it was likely that their demand for resources were at different times. Such complementarity for resource need by the crops is consistent with the finding of Willey (1979).

Comparison of the different cropping patterns indicated that the combination of yam and pepper in the same row alternating with maize showed higher and better intercrop advantages. This may have resulted from the efficient use of the available resources. Since maize and pepper were planted the same time in this cropping pattern, the two crops might have been subjected to less competition from yam. On the other hand, in the pattern in which pepper came in as a relay, there was greater competition from yam and it was also likely that the soil moisture at the time of transplanting was not very adequate. Transplanting was done between August and September. Therefore, to achieve higher intercrop advantage in a three-crop system such as described in this study, the best option will be a row of yam-pepper alternate with a row of maize.

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