Assessing the Productive Efficiency of Bambara Groundnut and Sorghum Intercrops in Botswana

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Abstract

An intercropping experiment consisting of three rows of Bambara groundnut and one row of sorghum (I_1); two rows of Bambara groundnut and two rows of sorghum and one row of Bambara groundnut and three rows of sorghum (I_3) was grown together with sole crops of the components at the same intra-row spacing as in the intercrops. The productivity of each intercrop and sole crop component was determined in terms of a Crop Performance Ratio (CPR) defined as the productivity of an intercrop per unit area of ground compared with that expected from sole crops sown in the same proportion.

The results showed that CPR for total dry weight in the intercrops ranged between 1.05 to 1.28 while the reproductive yield ranged from 1.41 to 1.82. Intercropping system with high population of Bambara groundnut (50% and above) had reproductive yield advantage over that with low (less than 50%) Bambara groundnut population. This advantage was due to greater efficiency of light conversion brought about through improved LAI, petiole/internode ratio and canopy spread in the Bambara groundnut component of the intercrops compared to its sole crop component. Bambara groundnut and sorghum intercrop is compatible and therefore recommended for small holder farmers in Botswana and other areas of similar climate.

Keywords: Intercropping, crop performance ratio, small holder farmers,energy equivalent, Bambara groundnut, Botswana

Introduction

In recent years, research has provided increasing evidence that substantial yield advantages can be achieved from intercropping compared to sole cropping. The beneficial interaction that is most widely applicable in intercropping systems is the better use of environmental resources. This is often attributed to the fact that different crops can complement each other and achieve an improved yield stability (Sinoquet and Crux, 1995). The mechanisms through which yield stability is achieved are threefold. Two such mechanisms are better control of pests and the greater relative advantages under stress; where these occur, they can provide a useful buffer against low yields in adverse years. A third mechanism, and perhaps the most universally applicable one, is that if one crop fails or grows poorly, the other can compensate; such compensation clearly cannot occur if crops are grown separately (Willey *et al.*, 1983).

Bambara groundnut (*Vigna subterranea* (L) Verdc), known in the local Setswana language as *Ditloo*, is one of the most important leguminous crops grown by smallholder farmers in Botswana. Available estimates reveal that the crop is grown on 1,500 hectares of land from which a total yield of 40 tonnes of seed is obtained annually (von Rudloff, 1993). A survey carried out by Brink *et al.*, (1996) showed that production is on the increase. The potential of Bambara groundnut as a crop in Botswana and other dry areas lies in the fact that under less favourable growing conditions such as low fertility, high heat and limited amount of moisture, it yields a reasonable crop where other legumes such as groundnut and cowpea may fail (Karikari *et al.*, 1997). It is also highly nutritious. Sorghum (*Sorghum bicolor* (L) Moench) is the leading traditional crop well suited to Botswana conditions and is grown throughout the country. An estimated 300,000 hectares of land is planted annually (MoA, 1993).

Bambara groundnut and sorghum are grown as intercrops in Botswana (Appa Rao *et al.*, 1986). According to Karikari (1996), Bambara groundnut production in Botswana is concentrated in the northern and eastern parts where it is intercropped with sorghum, millet and maize. Brink *et al.*, (1996) showed that 67% of farmers in Botswana, intercrop Bambara groundnut fields with cereals, mainly sorghum.

According to Worman *et al* (1992), intercropping is recognised as an important farming practice under dryland conditions in Botswana. Intercropping minimizes risks of complete crop failure and ensures greater stability in crop yields in variable environments (Azam-Ali, 1995). Usually, the more variable the environment, the greater is the annual variability in crop yields. Often, this variability is reduced when crops are grown together because different species are not equally affected by environmental, insects, diseases and weed constraints (Bhatnagar and Davis, 1981; Rao and Shetty, 1977; Moody and Shetty, 1981). Intercrops may also provide increased physical protection of the soil against erosion and wind damage. In these cases, continuous ground cover for a greater proportion of the season may provide a more stable soil microclimate and bind soil aggregates together.

In addition to these and many other tangible management benefits, there is much evidence that the combined yield of species grown as intercrops may exceed that of their component species grown as sole crops under similar conditions (Willey, 1979; Willey and Rao, 1981; Ahmed and Rao, 1982). Reported yield advantages vary. For example, intercrops of sorghum and various legumes have typically shown yield advantages of between 25 and 40% (Willey and Osiru, 1972; Wahua and Miller, 1978). Despite these potential benefits, the biological and physical complexity of intercrops has deterred scientists from analysing their productivity in terms of the capture and use of resources. This paper describes the growth and yield of Bambara groundnut/sorghum intercrop and its component sole crops grown under dryland conditions in Botswana. The seasonal accumulation of dry matter and grain yield are analysed in terms of intercepted radiation for each species in the intercrop and comparable sole crops.

Materials and Methods

The experiments were conducted over a two year period during the 1993/94 and 1994/95 cropping seasons. Bambara groundnut landrace 'Gaborone cream' and sorghum variety 'Segaolane', were used. These varieties are among those recommended for growing by small holder farmers in Botswana (MoA, 1984; Karikari, 1996). The experiment was sited at the Botswana College of Agriculture gardens located at Sebele (latitude 24° 33'S, longitude 25° 54'E, altitude 994 m). The climate of Sebele is semi-arid with an average annual rainfall (30 year mean) of 538 mm (Bekker and de Wit, 1991). Most rain falls in a rainy summer season, which generally starts in late October and continues to March/April. Prolonged dry spells during the rainy season are very common and rainfall tends to be localized (Baker, 1987). Soils at Sebele are shallow, ferruginous tropical soils, mainly consisting of medium to coarse grain sands and sandy loams with a lower water holding capacity and subject to crusting after heavy rains. The soils at Sebele are deficient in phosphorus, have low levels of mineral nitrogen and very low organic matter content (Baker, 1987).

Each experimental plot was composed of four rows. The inter-row spacing was 30 cm with Bambara groundnut spaced 10 cm and sorghum at 20 cm along the row. This gave a pure stand crop of 34 and 17 plants m^{-2} for the Bambara groundnut and the sorghum, respectively. The combinations for intercrops I, 2 and 3 were 3 rows, 2 rows and 1 row Bambara groundnut to 1 row, 2 rows and 3 rows of sorghum, respectively. At any given population, a 'replacement series' technique was used to create a range of intercrops and sole crops of constant populations (de Wit, 1960). Optimum plant populations for cereals and legumes in Botswana under dryland conditions are similar (Jones, 1986), so in forming the 'replacement series' in the intercrops, Bambara groundnut and sorghum plants were considered equivalent to each other. Thus, for any sole crop and any intercrop stand, the total number of plants per unit area was the same.

The experimental site was disc-ploughed and harrowed twice to obtain a smooth tilth. Basal fertilizer 40 kg N ha^{-1} as lime ammonium nitrate (LAN) was applied prior to sowing. All plots were irrigated to ensure that the soil was at field capacity from sowing until crop establishment (21 days after emergence). Thereafter, all plants were left to grow on moisture stored in the soil profile plus any rain that fell during the season. The experimental design was a randomised complete block with four replications. Treatments were allocated to the plots randomly. Plot sizes were 1.5 x 5.0 m with paths of 0.5 m between plots. Sowing during the 1993 cropping season was done on 22 November, 1993 and during the 1994 cropping season, on 2 December, 1994. Two seeds were hand sown at 5 cm depth and at 21 days after emergence, the seedlings were thinned to one. The conventional manual hoe weeding was used to control weeds from the time of emergence till crop maturity. The following growth parameters were assessed; days to 50% flowering and leaf area index for Bambara groundnut and sorghum, plant height for sorghum, and petiole/internode ratio and canopy spread for Bambara groundnut. Traditional bird-scaring technique of shouting and throwing stones at birds were done to minimize bird damage to the sorghum; further sorghum losses were reduced by stooking until grain drying was complete 10 days after cutting. The crops sown in 1993 were harvested on 8 March, 1994 for sorghum and 17 April, 1994 for Bambara groundnut, while the 1994 crops were harvested on the 24 March and 30 April, 1995 respectively for sorghum and Bambara groundnut. At harvest the following yield and yield-related parameters were also assessed: total dry matter, grain yield, harvest index, 100 seed weight and shelling/threshing percentages for Bambara groundnut and sorghum.

Leaf area index (LAI) was calculated by the formula LAI = $N_p n_s a_s$, where N_p is the number of plants per unit ground area, n_s the number of leaves per plant and a_s their mean leaf area (Squire, 1990). Canopy spread in Bambara groundnut was measured by taking the circumference of four inner plants at flowering, in two planes and averaging them. Final harvests were carried out on 2.5 m length in the centre of each row of the plots. Dry matter at harvest was determined after oven drying samples at 70°C for 48 hours. Pods of Bambara groundnut were harvested and dried for 7 days after harvest and then seeds were shelled and air dried for another 7 days. Seeds of sorghum were threshed and also air dried. Harvest index (HI) - the ratio of the economic yield (y-econ) to total plant biological yield (root weight not included) y-biol, was determined.

Data for the two years were combined after Bartett's test (Sokal and Rohlf, 1969) showed homogeneity of variance. Differences among growth, yield and yield-related components were analysed using the GLM procedure available from SAS (SAS Institute, 1990). The Duncan's Multiple Range Test (Steel and Torrie, 1980) was used to separate means where significant differences were observed. Precipitation data was from the Sebele Meteorological Station during both growing seasons from planting to harvest totalled 431.2 mm in 1993/94 and 384 mm in 1994/95. The 30 year average precipitation (November - April) for the location was 373.5 mm. Precipitation in 1993/94 was distributed more evenly throughout the growing season than in 1994/95 when approximately half of the growing season's rainfall occurred in the last 6 weeks of growth. To compare the biological output of the intercrop with that of its component species grown as sole crops, the Crop Performance Ratio (CPR) was used (Harris *et al.*, 1987; Azam-Ali *et al.*, 1990). For an intercrop composed of two species (a and b), the Crop performance Ratio for species a, ie CPRa, is given by:-

$$CPRa = Qia / (Pia * Qsa)$$

where Qia and Qsa are the productivity of species a, per unit area ($MJ.m^{-2}$) in the intercrop and sole crop respectively and Pia is the proportional sown area of the species a in the intercrop. For species b, Qib, Qsb and Pib represent similar terms. For both species together

$$CPRab = (Qia + Qib) / Pia * Qsa + Pib * Qsb)$$

Results and Discussion

The effects of intercropping on days to flowering and leaf area index in Bambara groundnut and sorghum, plant height in sorghum and petiole/internode ratio and canopy spread in Bambara groundnut are shown in Table 1. Sole crop Bambara groundnut flowered in a significantly shorter period than intercropped Bambara groundnut. Within the intercrops, Bambara groundnut in intercrop 3 flowered in significantly longer period than the one in intercrops 2 and 1. There was no significant difference in respective periods taken by Bambara groundnut in intercrops 1 and 2 to flowering. Also, flowering periods did not differ significantly between the sole crop and the intercrop sorghum. Leaf area index was affected by intercropping. The sole crop Bambara groundnut and Bambara groundnut in intercrop 3 had the lowest LAI which were significantly different from those in intercrops 1 and 2 which had the highest LAI. Sole crop sorghum also produced the highest LAI which differed significantly from the LAI in all the intercropped sorghum. However, within the intercrops, LAI of sorghum did not differ significantly. The mean differences in plant height between the sole and intercropped sorghum were not significant. The growth parameters; petiole/internode ratio and canopy spread for Bambara groundnut differed significantly between the sole crops and the intercrops being highest in intercrop 1 and 2 and declining in intercrops 3 and sole crops. Table 2 shows the effect of intercropping on dry matter and grain yield and yield components of Bambara groundnut and sorghum. Dry matter production in the intercrops was higher than in sole crop. One hundred seed weight was affected only in Bambara groundnut where seeds from intercrops 1 and 2 were significantly bigger than in the sole crop and intercrop 3. Between intercrops 1 and 2 and likewise between the sole crop and intercrop 3, seed sizes of Bambara groundnut did not differ significantly. Shelling percentage was affected in Bambara groundnut where the intercrops produced a significantly higher shelling percentage than the sole crop. Shelling percentage in sorghum between sole crop and intercrops did not differ significantly.

The effects of intercropping on Crop Performance Ratio (CPR) and values for crop productivity for Bambara groundnut in the sole crop (Qsa) and intercrop (Qia) and sorghum in the sole crop (Qsb) and in the intercrop (Qib) is shown in Tables 3, 4 and 5. Because the sole crop values are multiplied by their sown proportions in the intercrop, this provides their expected productivity if unit area of ground had been sown with sole crops in the same proportions as in the intercrop. A value of CPR > 1 indicates an intercrop advantage and a CPR < 1, an intercrop disadvantage. The concept of using CPR to measure the relative performance of intercrops in terms of total dry matter and yield is used to assess their capture and use of solar radiation (Monteith, 1978; Azam-Ali, 1995). For this analysis, CPR is a more appropriate basis for calculating the biological advantage of an intercrop than the more conventional Land Equivalent Ratio (LER) because CPR compares the efficiency with which sole crops and intercrops use intercepted radiation to produce dry matter. CPR also takes into account, the relative durations of each species within the intercrop or sole crop systems (Hiebsch and McCollum, 1987). In order to calculate the energy equivalents of biomass for total dry matter and yield, the vegetative and reproductive dry weights of sorghum were multiplied by 17.51 (Passmore and Eastwood, 1986). For Bambara groundnut, the vegetative yield was multiplied by 17.51 (Passmore and Eastwood, 1986) and reproductive yield was multiplied by 18.26 (Brough and Azam-Ali, 1992). The mean energy equivalents of TDM and grain yield were similar. However, CPR was highest for intercrop 1, followed by intercrop 2 (Tables 3 and 4). The least CPR was achieved in intercrop 3 (Table 5). All the CPRs were greater than unity indicating that the intercrops were more efficient at capturing and using solar radiation than their constituent sole crops. The pattern of capture and utilisation of solar radiation favoured an intercrop combination where the population of Bambara groundnut was high or at least equal to that of

Table 1: Effect of intercropping Bambara groundnut and sorghum on the growth parameters of Bambara groundnut and sorghum

	Days to flowering		Leaf area index		Plant height (cm)	Petiole/ internode ratio	Canopy spread (cm)
	Bambara groundnut	Sorghum	Bambara groundn.	Sorghum	Sorghum	Bambara groundnut	Bambara groundnut
Sole crop Bambara groundnut	43.50c+	-	1.73b	-	-	8.51b	33.75b
Sole crop sorghum	-	72.50	-	3.02a	136.25a	-	-
Intercrop 1	56.40b	76.50	2.21a	2.88b	123.50b	9.15a	35.80a
Intercrop 2	59.32b	70.75	2.36a	2.58b	124.25b	9.81a	36.08a
Inntercrop 3	64.71a	74.00	1.70b	2.66b	126.50b	8.10b	32.62b

+Within colums, means followed by the same letter(s) are not significantly different by the Duncan's Multiple Range Test (at 0.05)

Footnote: Intercrop 1 = 3 rows Bambara groundnut : 1 rows Sorghum
2 = 2 rows Bambara groundnut: 2 rows Sorghum
3 = 1 row Bambara groundnut: 3 rows Sorghum

Table 2: Effect of intercropping Bambara groundnut and Sorghum on Dry Matter and grain yield and yield components of Bambara

	Total dry matter (Kg ha $^{-1}$)		Grain yield (Kg ha $^{-1}$)		Harvest index (%)		100 seed weight (g)		Shelling/threshing percentage	
	Bambara groundnut	Sorghum	Bambara groundnut	Sorghum	Bambara ground-nut	Sorghum	Bambara ground-nut	Sorghum	Bambara groundnut	Sorghum
Sole crop Bambara ground-nut	4556b+	-	902a	-	19.80a	-	50.55b	-	57.22b	-
Sole crop sorghum	-	5243c	-	2024a	-	38.60a	-	2.96	-	80.36
Intercrop 1	4762a	5297c	720b	1882b	15.11b	35.53b	58.77a	2.77	61.04a	75.94
Intercrop 2	4858a	5345b	693b	1725c	14.36b	37.27b	56.08a	2.92	62.19a	79.52
Intercrop 3	4568b	5407a	677b	1840bc	14.82b	34.03b	50.02b	2.85	60.17a	79.64

+ Within columns, means followed by the same letter(s) are not significantly different by the Duncan's Multiple Range Test (at 0.05)

Footnote: Intercrop 1 = 3 rows bambara groundnut: 1 row Sorghum
2 = 2 rows bambara groundnut : 2 rows Sorghum
3 = 1 row bambara groundnut : 3 rows Sorghum

Table 3: CPR of Total Dry Matter (TDM) and Reproductive Yield for Bambara Groundnut/Sorghum intercrop 1

	Qsb	Qsa	Qib	Qia	Qia + Qib	CPR
TDM (g m^{-2})	524.3	455.6	529.7	476.2	1005.9	1.28
TDM (MJ)	9.18	7.98	9.28	8.34	17.62	1.82
Yield (g m^{-2})	202.4	90.2	188.2	72.0	260.2	1.51
Yield (MJ)	3.54	1.73	3.30	1.38	4.68	1.31

Table 4: CPR of Total Dry Matter (TDM) and Reproductive Yield for Bambara Groundnut/sorghum intercrop 2

	Qsb	Qsa	Qib	Qia	Qia + Qib	CPR
TDM (g m^{-2})	524.3	455.6	534.5	485.8	1020.3	1.17
TDM (MJ)	9.18	7.98	9.36	8.49	17.85	1.22
Yield (g m^{-2})	202.4	90.2	172.5	69.3	241.8	1.47
Yield (MJ)	3.54	1.73	3.02	1.33	4.35	1.44

Table 5: CPR of Total Dry Matter (TDM) and Reproductive Yield for Bambara Groundnut/sorghum intercrop 3

	Qsb	Qsa	Qib	Qia	Qia + Qib	CPR
TDM (g m^{-2})	524.3	455.6	540.7	456.8	997.5	1.05
TDM (MJ)	9.18	7.98	9.46	8.00	17.46	1.15
Yield (g m^{-2})	202.4	90.2	184.0	67.7	248.1	1.44
Yield (MJ)	3.54	1.73	3.22	1.30	4.52	1.41

Note: Energy equivalents for TDM and yield (MJ) were calculated by multiplying the vegetative and reproductive components of sorghum by 17.51 (Passmore and Eastwood, 1986) and the vegetative component of Bambara groundnut by 17.51 (Passmore and Eastwood, 1986) and the reproductive component by 18.26 (Brough and Azam -Ali, 1992) sorghum (ie the 3:1 or the 2:2 ratio). Bambara groundnut intercepted more radiation per unit row in the intercrop than the sole crop. These gave a further advantage in reproductive yield which was a consequence of higher petiole/internode ratio and wider canopy spread.

In this experiment, the CRP for dry matter was generally low (between 1.05 - 1.28). There was little increase in the overall productivity of dry matter of intercrop compared with the combined sole crops. The CPR for the reproductive yield was high (between 1.41 - 1.82) which meant that up to 80% more total grain yield was achieved by the intercrop when compared with exactly the same area under sole crops sown in the same proportions as the intercrop. The results are consistent with intercropping advantages reported for sorghum/groundnut intercrops (Baker, 1978; Bodale, 1980; Evans, 1980; Rao and Willey, 1980; Tarhalkar and Rao, 1981; Harris *et al*, 1987 and Azam-Ali *et al*, 1990). This improvement in yield reflects a reduced intra-specific competition between sorghum plants in the intercrop because individual plants were able to allocate more of their total dry matter to yield than in a sole crop. This may also be explained by the fact that the sorghum variety used in this experiment 'Segaolane' has smaller and more vertically disposed leaves and therefore allowed greater light penetration into the lower canopy strata and thus raised the CO_2 compensation point of the Bambara groundnut. The advantage of tall sorghum varieties with erect leaves for use in intercrops has already been documented (Tsunoda, 1959; Willey and Rao, 1981). Combining a tall C_4 and a short C_3 crop improved the efficiency of light use through leaf distribution confirming the findings of Natarajan and Willey (1981) and photosynthesis as observed by Crookston and Kent (1976). It was therefore possible to sow the Bambara groundnut more densely (34 plants m^{-2}) in order to attain the desired higher LAI and seed yield.

In this case, an increase in the productivity of a Bambara groundnut/sorghum intercrop could be ascribed to both a spatial advantage before the removal of the first species or to a temporal advantage between the removal of the first species and the harvest of the second. The spatial advantage was due to the differences in the height of the Bambara groundnut and sorghum. As observed by Osiru and Kariba (1979), plants with different heights make more use of light when intercropped than when monocropped. It has been observed by Broughan (1958) and Ojomo (1976) that if the leaves of the taller plants are vertical as in the case of sorghum and the leaves of the lower plants are horizontal, making use of dim light as in the case of Bambara groundnut, it is possible to utilize as much solar energy with intercropping as can be done with monocropping. In this experiment, where the number of plants of both sorghum and Bambara groundnut in the intercrop was equal to the total number in the monocrop, the upper portion of the sorghum which was above the leaves of the Bambara groundnut did not suffer from competition for light. The Bambara groundnut did benefit later when the sorghum was harvested. Baker (1978) made a similar observation with sorghum and groundnut in Nigeria. Also, in this experiment, the Bambara groundnut had 35 more days to mature after removal of the sorghum and this explains why the CPR for the grain yield increased by over 40% in the intercropping.

Conclusions and Recommendations

The greater yield from the Bambara groundnut/sorghum combination, was brought about by greater light interception over larger leaf area (determined by the LAI) and much higher and wider crop exposure to sunlight determined by the petiole/internode ratio and canopy spread. These two parameters have been used to determine dry matter conversion and hence productivity in Bambara groundnut (Karikari, 1972). The Bambara groundnut/sorghum combination provides an excellent example of the kind of spatial and temporal complementarity of resource use that occurs in intercropping in crops of different heights and temporal complementarity of differences in maturity periods of sorghum and Bambara groundnut and confirms the findings by Rao and Willey (1980) that in such a situation, the tall crop variety intercepts light early in the season with the short crop intercepting light, later.

The increase efficiency of the Bambara groundnut/sorghum intercrop and the corresponding high CPR occurred because Bambara groundnut was able to produce almost the equivalent of a full sole crop yield while growing in only 75:25 and 50:50% ratios. The growth factors which enabled this to be possible included a higher dry matter productivity, higher LAI, higher petiole/internode ratio and a wider canopy spread. An intercropping system consisting of Bambara groundnut and sorghum is worthy of recommendation to small holder farmers in Botswana and elsewhere with similar climatic pattern.

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