# Phenotypic Characteristics And Selective Indices of Bambara Groundnut Landraces for Intercropping With Sorghum in Botswana

*S. K. Karikari*
*Department of Crop Science and Production*
*Botswana College of Agriculture, Faculty of Agriculture*
*Private Bag 0027*
*Gaborone, Botswana*

## Abstract

*The purpose of the study was to identify phenotypic characteristics and indices for selecting Bambara groundnut for intercropping. Three landraces, namely, Diphiri Cream (Dip C), OMotswasele6 (OM6) and National Tested SeedRed (NTSR) were intercropped with sorghum varity 'Segaolane' during 1995/96 and 1996/97 seasons in 3:1, 2:2, 1:3 ratios. The competitive relationship between sorghum and Bambara groundnut was determined by the Relative Crowding Coefficient (k) and Relative Yield Total (RYT). The suppression of Bambara groundnut growth and yield was significantly greater as the population of sorghum in the intercrops increased. The RYT values were higher for DipC than OM6 and NTSR, indicating that DipC could be developed as an ideotype Bambara groundnut for intercropping under semi-arid conditions such as those that pertain in Botswana and areas with similar climate.*

## Introduction

Bambara groundnut (Vigna subterranea (L) Verdc) is an important pulse crop in semi-arid Africa because of its potential as a food security crop (Doku and Karikari, 1971), and high nutritive value (Poulter and Caygill, 1980; Obizoba and Egbuna, 1992; Brough and Azam-Ali, 1992; Amarteifio et al., 1997). According to Collinson et al. (1996), it displays a range of traits conferring drought tolerance. It is, therefore, suited to low input farming systems, and this makes it popular amongst farmers with limited resources. Bambara groundnut is commonly intercropped with cereals in Botswana. Karikari (1996), Brink et al. (1996), showed that 67% of farmers intercrop with sorghum.

Increasing empirical evidence indicates that improved productivity and net income per hectare from intercropping are higher than their respective monocultures (Santa-Cecilia and Vieira, 1978; Willey, 1979; Shivay and Rathi, 1996). More important, for the resource poor farmers, is the greater stability of total production under intercropping (Francis and Sanders, 1978; Rao and Willey, 1980; Ofori and Stern, 1987; Karel et al., 1980, Govinden et al., 1984; Ayeh, 1988; Karikari et al., 1999). Spencer (1987) proposed the concept of stability under heterogeneous state of intercropping and the instability under homogeneous state in monocultures. Evidence of stability has been recognised in many intercropping systems (Donald, 1963; Norman, 1971; Stoop, 1986; Marshall and Brown, 1973; and Reddy *et al*., 1990). However, improved crop seeds used by farmers in intercropping have been selected for their good performance based on monoculture. Conscious selection of cultivars specifically adapted to intercropping systems have received low priority in national breeding programmes and in the international agricultural centres. It has, thus, been assumed that the best cultivars selected in monoculture would be optimum in intercropping systems, which is usually not the case (Davis, 1989; Davis and Woolley, 1993). According to Temple (1976), this explains in part, why yields of such crops are low under intercropping. Plant types used specifically for intercropping depend on the extent of the genotype x cropping systems arrangement and interaction (Francis et al., Osiru and Willey, 1972; 1978; Kass, 1978; Obuo et al., 1978, Willey, 1979; Ocaya et al., 2001). According to Donald (1963), the productivity of the plant and its competitive ability are distinct characteristics. A number of studies with other crops have indicated that competitive ability is negatively related to yield in monoculture (Jennings and Aquino, 1968 ), whereas it is positively related to yield in polyculture (Haizel, 1974, Kass, 1978). There is considerable scope to study the relative performance of crops used in intercropping with the aim of identifying traits associated with yield under intercropping (Ntare, 1989; Nelson and Robichaux, 1997) and breeding for intercropping (Hamblin and Zimmermann, 1986; Smith and Francis, 1986). The research reported here was conducted to investigate the relationship between productivity and competitive ability of Bambara groundnut landraces with a view to identifying specific plant characters which could be used for developing ideotypes suitable for intercropping.

## Materials and methods

Field experiments were conducted during two consecutive growing seasons 1995/96 and 1996/97 at the Botswana College of Agriculture (BCA), Gaborone, Botswana Garden. The BCA is located at Sebele (24°33'S, 25°54'E, 994 m above sea level). The field was ploughed and harrowed to obtain a smooth soil tilth. Basal fertilizer 26 kg N $ha^{-1}$ from urea (46% N) and 140 kg $P_2O_5$ $ha^{-1}$ from Single Super Phosphate (9%P) were applied prior to sowing. Three Bambara groundnut landraces namely Diphiri Cream (DipC), OMotswasele 6 (OM6) and National Tested Seed Red (NTSR) with sorghum (*Sorghum bicolor* (L) Moench) variety 'Segaolane' were used. The features of the Bambara groundnut landraces using the Descriptors list (IBPGR/IITA/GTZ, 1987), have been described (Karikari, 1996) and genetic variability determined ( Karikari, 2000). The sorghum variety 'Segaolane' is a high yielding palatable porridge type, well adapted to Botswana conditions and recommended for growing by small scale farmers (DAR, 1987).

The experimental design was a randomised complete block with four replicates. Each 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 Bambara groundnut and sorghum, respectively. The combinations for the intercrops 1, 2 and 3 were 3 rows, 2 rows and 1 row of Bambara groundnut to 1 row, 2 rows and 3 rows of sorghum. A replacement series technique was used to create a range of sole crops and intercrops of constant populations. Accordingly, two Bambara groundnut plants were recognised as a crop unit for one sorghum plant. Treatments were allocated factorially to the plots. Each plot measured 1.5 x 5.0 m with 1 m alleys between plots. Two seeds were sown per station at 5 cm depth and seedlings thinned to one, 21 days after sowing. The plots were kept weed-free by manual hoeing.

Near the time of maturity, a traditional method of bird scaring was used to scare away quelea birds (*Quelea quelea*, family Ploceidae).

Five plants within each plot were tagged for growth analysis. The growth parameters assessed were leaf area index (LAI) at 50% flowering, shoot and root dry weights and root/shoot ratio at maturity. LAI was measured by the formula LAI = NpNsAs (Squire, 1990) where Np is the number of plants per unit ground area, Ns is the number of leaves per plant and As, their mean leaf area. Final harvests were carried on five plants in the inner row of each treatment. Dry matter at maturity was determined after oven drying at 70ºC for 48 hours. Pods of Bambara groundnut were harvested and dried for 7 days after which seeds were shelled and air dried for another seven days. Seeds of sorghum were threshed after harvesting and drying and also air-dried. Grain yield was converted to 12% moisture. Crop index (CI), i.e. the ratio of the economic yield to total biological yield was determined. Percentage grain yield reductions in the intercrops were calculated.

The competitive relationship between the two species were determined by the Relative Crowding Coefficient (K) of sorghum (s) with respect to Bambara groundnut (b) and is given by the equation of De Wit (1960) as:-

func Ksb``=``func{left({Ms over Ns}/ {Mb over Nb}right) / {Ps over Pb}}

where Ms and Mb are the yields of sorghum and Bambara groundnut respectively in the mixture and Ns and Nb, their corresponding numbers in the mixture and Ps and Pb, their respective yields in pure stand at the same overall density. In the replacement series, the ratio of the yield of a species in the mixed population (M) to its yield in pure stand (P) is represented as the Relative Yield (R). The Relative Yield Total (RYT) is thus the sum of the R values of the species in the mixture. The mean R values of the species of the corresponding RYT in mixtures of the three intercropping levels of the Bambara groundnut landraces were also computed.

Data for the two years were combined after Bartlett's test (Sokal and Rohfl, 1969) showed homogeneity of variances and were analysed using the General Linear Model of SAS (SAS Inst., 1990). Where the F-test indicated statistical significance ($P<0.05$), mean separations were accomplished using Fisher's Least significant Difference (LSD) test (Steel and Torrie, 1980) at 5% level of probability.

## RESULTS AND DISCUSSION

The effect of cropping system on total shoot and root dry weights, root: shoot ratio and leaf area index are given in Table 1. Total shoot dry weight was lower in the sole crops compared to the intercrops. Within the intercrops, shoot dry weight increased significantly as population of Bambara groundnut decreased and sorghum, increased. The shoot dry weight differed significantly among the Bambara groundnut landraces being significantly lower in DipC, higher in NTSR with dry weight of OM6 being in between. Shoot dry weight was highest in NTSR and lowest in DipC because this character is related to the plant size but root dry weight was highest in DipC. Consequently, root/shoot ratio was highest in DipC. This is in agreement with observations made by Brouwer (1983) who found out that root/shoot ratio changes when soil moisture is in short supply because the plant responds by allocating a greater fraction of the assimilate to the structure whose function is to obtain the limiting resource, in this case, the roots.

Effect of cropping system on root dry weight also showed significant decline between the Bambara groundnut landraces with DipC having the highest, followed by OM6 and NTSR. Root dry weight decreased as sorghum population in the intercrops increased. Correspondingly, root/shoot ratio was significantly greater in DipC than OM6 and NTSR. Also, as the population of sorghum increased in the intercrops, root/shoot ratio within each of the Bambara groundnut landraces, generally declined between the 3:1 and the 2:2 ratios. The LAI of sorghum and DipC were affected significantly by cropping system but there was no effect of cropping system or landrace effect on OM6 and NTSR. In sorghum and DipC, LAI in sole crop and intercrop 1 were significantly higher than in intercrops 2 and 3. The interaction effect was not significant. The LAI did not differ significantly in OM6 and NTSR because the landraces used are known not to compensate for space (Karikari, 2000). Also, the inter-row spacing adopted was quite wide and, therefore, the more spreading landrace like NTSR had enough room to spread.

The effects of cropping system on grain yield and crop index are given in Table 2. Grain yield of over 2 t was obtained for the sole crop sorghum while sorghum intercrop yields were also quite high. In the Bambara groundnut landraces, grain yield of about 900 kg was obtained in the sole crop but intercrop yields were significantly reduced within the landraces and also as sorghum population increased in the replacement. Percentage yield reduction (Table 3) ranged from 23 - 41 in DipC as compared to between 72 and 95 percent reduction for OM6. The yield reduction in NTSR was between 52 to 81 percent. Again, as the population of sorghum in the intercrops increased in the replacement, grain yield decreased significantly within the intercropping treatments. Values of crop index (CI), in the sole crops were significantly higher than in the intercrops. Within the intercrops, significant decline was observed as the population of sorghum increased. The lowest CI was obtained in the 1:3 population where sorghum was highest. The grain yields of the Bambara groundnut landraces in monoculture were virtually identical but in association with sorghum, they differed significantly. With simultaneous planting, the Bambara groundnut had to withstand shading stress. In general, the most competitive landrace, DipC, gave the highest yield in association. Of fundamental importance to economic yield is the distribution of dry matter as affected by intercropping. The crop index being a proportion of the total dry matter of the plant which is allocated to grain production, is used as a measure of the economic efficiency of the biological system (Gupta, 1992). Higher CI values are shown in DipC than OM6 and NTSR. CI values were higher in the sole than in intercrops (Table 2). Within the intercrops, the differences were also significant because regular yield decline occurred at higher populations of sorghum in OM6 and NTSR. In DipC, the reduction was not significant within the populations in the intercrops.

The effect of cropping system on the Relative Crowding Coefficient of sorghum (Kbs) with respect to Bambara groundnut is given in Table 3. The Kbs values for DipC were about unity (mean 1.06 $\pm$ 0.13), while OM6 ranged from 0.52 - 0.75 (mean 0.62 $\pm$ 0.10) and NTSR 0.21 - 0.44 (mean 0.37 $\pm$ 0.10). The values decreased as the sorghum population increased emphasising the depressing effect of sorghum on Bambara groundnut. Thus, it was established that the competitive relationships between sorghum and Bambara groundnut was in favour of sorghum in all the three intercropping combinations. The mean Ksb for sorghum was 1.53 $\pm$ 0.09. On the other hand, the mean Kbs values for the Bambara groundnut landraces varied with a mean of 1.06 $\pm$ 0.13 in DipC, 0.62 $\pm$ 0.10 in OM6 and 0.37 $\pm$ 0.10 in NTSR. DipC is as equally competitive as sorghum, but OM6 and NTSR were out competed by sorghum with the competition intensifying as sorghum population in the intercrops increased.

The Relative Replacement Rate (Bergh, 1968) was used to indicate the relative intensity. In the replacement series, the ratio of the yield of a species in the mixed population (M) to its yield in pure stand (P) is represented as the Relative yield (R) of the species. The Relative Yield Total (RYT) is thus the sum of the R values of all the species in the mixture. The mean R values of the species and the corresponding RYT values of the mixtures at the three intercropping patterns are presented in Table 4. In the 3:1 ratio, the RYT values were significantly higher which indicated a separation of their fields of exploitation. In the 2:2 and 1:3 ratios, the sorghum population increased and the RYT values declined progressively. The course of their Relative Replacement Rate in population, therefore, may be traced by plotting the ratios of their R values in the intercrops on a log scale against population as presented in Fig 1. Here, the lowest population in the intercrops was used as a reference point. Fig 1 confirmed that DipC maintained a uniform competitive ability under low (3:1), medium (2:2) and high (1:3) sorghum populations. OM6 and NTSR, on the other hand, had high competition under low rates and low competition under high rates as sorghum population increased.

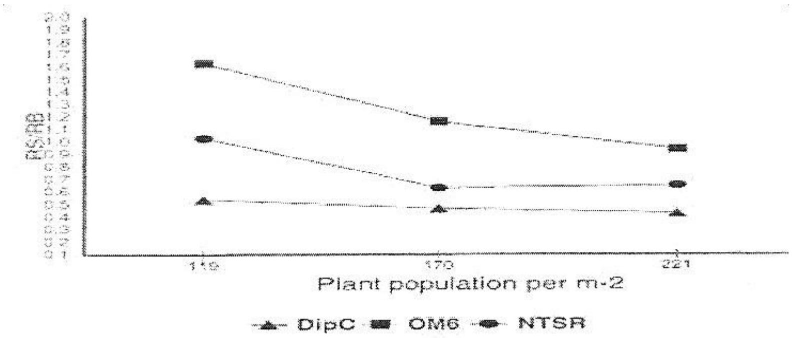


Figure 1. Relative replacement rate of sorghum (RS) with respect to Bambara groundnut landraces (RB) (RD, RO and RN = RB of DipC, OM6 and NTSR, respectively

## Conclusions and recommendations

From the results of this study, it can be concluded that DipC was the most competitive landrace, and more suitable for intercropping than OM6 and NTSR. The Kbs for DipC was above unity, while those for OM6 and NTSR wre below unity. Characters of DipC which might have increased its efficiency in intercropping were the high root/shoot ratio and high crop index. These characters may be related to the physiological tolerance under shade (Gupta, 1992). It is recommended that future breeding work on Bambara groundnut desirable for intercropping should incorporate high root/shoot ratio and crop index as important factors.

## References

Amarteifio, J. O., Sawula, G., and Gibbons, M. 1997. ***Composition of four landraces of Bambara groundnuts in Botswana***. Tropical Science 37: 143-145

Ayeh, E. 1988. ***Evidence of yield stability in selected landraces of bean*** (Phaseolus vulgaris). Experimental Agriculture 24:367-373

Bergh, J. P. van den 1968. ***An analysis of yields of grasses in mixed and pure stands***. Agricultural Research Report, Centre of Agricultural Publications and Documentation, Wageningen, No. 714

Brink, M., Collinson, S. T., and Wigglesworth, D. J. 1996. ***Bambara groundnut (Vigna subterranea) cultivation in Botswana. Report of a farmers' survey***. In proceedings of the International Bambara groundnut Symposium, pp 133-142.University of Nottingham, U.K., 23 - 25 July, 1996

Brough, S. H. and Azam-Ali, S. N. 1992. ***The effect of soil moisture on the proximate composition of Bambara groundnut*** (*Vigna subterranea* (L) Verdc). Journal of Science of Food and Agriculture 60: 197 - 203

Brouwer, R 1983. ***Functional equilibrium, sense or nonsense***. Netherlands Journal of Agricultural Science 31: 335 - 348

Collinson, S. T., Azam-Ali, S. N., Chavula, K. M. and Hudson, D. A. 1996. ***Growth, development and yield of Bambara groundnut (Vigna subterranea) in response to soil moisture***, Journal of Agricultural Science, Cambridge 126: 307 - 318

DAR (Department of Agricultural Research) 1987. ***Sorghum Agrifacts***, Ministry of Agriculture, Gaborone, Botswana, 5pp

Davis, J. H. 1989. ***Breeding for intercrops with special attention to beans for intercropping with maize***, In Waddington, S. R., Palmer, A. F. E., and Edje, O. T. (eds.) Research Methods for Cereal and Legume intercropping. Proceedings of a workshop on research methods for cereal/legume intercropping in Eastern and Southern Africa pp 37-40, CIMMYT, CIAT, Government of Malawi, Research Network Report No. 17

Davis, J. H. and Woolley, J. N. 1993. ***Genotypic requirement for intercropping***. Field Crops Research 34: 407-430

De Wit, C. T. 1960. ***On competition***. Versl. Landbouwk. Onderz 66: 8 - 12

Doku, E. V. and Karikari, S. K. 1971. ***Bambara groundnut, Economic Botany*** 25:225-262

Donald, C. M. 1963. ***Competition among crop and pasture plants***. Advances in Agronomy 15:1- 118

Francis, C. A. and Sanders, J. H. 1978. ***Economic analyses of bean and maize systems: Monoculture versus associated cropping***. Field Crop Research 1: 319 - 335

Francis, C. A., Prager, M and Laing, D. R. 1978. ***Genotypic x environment interactions in climbing bean cultivars in monoculture and associated with maize***. Crop Science 18: 242-246

Govinden, N., Arnason, J. T., Philogene, B. J. R and Lambert, J. D. 1984. ***Intercropping in the tropics: Advantages and relevance to the small scale farmer***. Canadian Journal of Development studies 5: 213-232

Gupta, U. S. 1992. ***Crop Improvement***. Volume 1: Physiological attributes. Westview Press, Colorado, U.S.A

Haizel, K. A. 1974. ***The agronomic significance of mixed cropping I, Maize interplanted with cowpea***. Ghana Journal of Agricultural Science 7: 169-178

Hamblin, J. and Zimmermann, M. J. O. 1986. ***Breeding common bean for yield in mixtures***. Plant Breeding Reviews 4: 245-272

IBPGR/IITA/GTZ 1987. ***Descriptors for Bambara groundnut***. International Board for Plant Genetic Resources. Rome, Italy

Jennings, P. R. and Aquino, R. C. 1968. ***Mechanisms of competition among phenotypes***. Evolution 22: 529 - 542

Karel, A. K., Lakhani, D. A. and Ndunguru, B. J. 1980. ***Intercropping of maize and cowpea: Effect of plant population on insect pests and seed yield***. In Keswani C. L. and Ndunguru, B. J. (eds). Intercropping pp 102-109. Proceedings of a Symposium on Intercropping in semi-arid areas, Morogoro, Tanzania 4-7 August, 1980. IDRC, Ottawa, Canada.

Karikari, S. K. 1996. ***The status of Bambara groundnut genetic resources in Botswana***. SACCAR Newsletter No 34 12- 16, June, 1996

Karikari, S. K. 2000. ***Variability between local and exotic Bambara groundnut landraces in Botswana***. African Crop Science Journal 8 (2): 145 - 152

Karikari, S. K., Chaba, O., and Molosiwa, B. 1999. ***Effects of intercropping Bambara groundnut on pearl millet, sorghum and maize in Botswana***. African Crop Science Journal 7 (2):143-152

Kass, D. C. L. 1978. ***Polyculture cropping systems***. Review and analysis. Agricultural Bulletin, Cornell Institute 32: 1-69

Marshall, D. R. and Brown, A. H. D. 1973. ***Stability of performance of crop mixtures***. Euphatica 22: 405-412

Nelson, S. C. and Robichaux, R. H. 1997. ***Identifying plant architectural traits associated with yield under intercropping: Implications of genotype-cropping system interactions***. Plant Breeding 116: 163-170

Norman, D. W .1971. ***Crop mixtures under indigenous conditions in northern Nigeria***. In Ofori, I. M. (ed) Factors of Agricultural Growth in West Africa pp 130-145, Proceedings of International Conference held at University of Ghana, Legon, Ghana, 3 - 7 April, 1971

Ntare, B. R. 1989. ***Evaluation of cowpea cultivars for intercropping with pearl millet in the Sahelian zone of West Africa***. Field Crops Research 20: 31-40

Obizoba, I. C. and Egbuna, H. I. 1992. ***Effect of germination and fermentation on the nutritional quality of Bambara nut (Voandzeia subterranea (L) Thouars) and its milk products***. Plant Foods for Human Nutrition 42: 13-23

Obuo, J. E., Adipala E. and Osiru, D. S. O. 1998. ***Effect of plant spacing on yield of cowpea-sorghum intercrop***. Tropical Science, 38: 1- 7

Ocaya, C. P., Adipala E., and Osiru, D. S. O. 2001. ***Effect of spatial arrangement on growth and yield of cowpea in cow-pea maize intercrop***. Tropicultura 19(4) 184 - 187

Ofori, F. and Stern, W. R. 1987. ***Cereal-legume intercropping systems***. Advances in Agronomy 41: 41 - 90

Osiru, D. S. O. and Willey, R. W. 1972. ***Studies on mixtures of dwarf sorghum and beans (Phaseolus vulgaris) with particular reference to plant population.*** Journal of Agricultural Science, Cambridge 79: 531 - 560.

Poulter, N. H. and Caygill, J. C. 1980. ***Vegetable milk processing and rehydration characteristics of Bambara groundnut*** (*Voandzeia subterranea* (L) Thouars). Food and Agriculture 31; 1158 - 1163

Rao, M. R. and Willey R. W. 1980. ***Evaluation of yield stability in intercropping: Studies on sorghum/pigeonpea***. Experimental Agriculture, 16: 105- 116

Reddy, K. C., van der Ploeg, J. and Maga, I. 1990. ***Genotype effects in millet/cowpea intercropping in the semi-arid tropics of Niger***. Experimental Agriculture 26: 387-396

SAS Institute 1990. ***SAS/STAT User's Guide***. SAS Institute Inc., Cary, NC, USA

Santa-Cecilia, F. C. and Vieira, C. 1978. ***Associated cropping of beans and maize***. I Effect of bean cultivars with different growth habits, Turrialba 28: 19 - 23

Shivay, Y. S. and Rathi, K. S. 1996. ***Economics of intercropping of mustard with sugarcane***. Indian Journal of Agronomy 41: 485-488

Smith, M. E. and Francis, C. A. 1986. ***Breeding for multiple cropping systems***. In: Multiple Cropping Systems (ed Francis, C. A.) Pages 219-249. Macmillan, New York

Sokal, R. R. and Rohfl, F. J. 1969. ***Biometry. The principles and practices of statistics in Biological Research***. W. H. Freeman and Co.

Spencer, H. 1987. ***The principles of biology*** Volumes I and 2 John Wiley and Sons, New York

Squire, G. R. 1990. ***The physiology of Tropical Crop Production***. C. A. B. International, U.K.

Steel, G. B. And Torrie, J. H. 1980. ***Principles and procedures of statistics***. MacGraw Hill

Stoop, W. A. (1986). ***Agronomic management of cereal/cowpea cropping systems for major toposequence land types in the West African savanna***. Field Crop Research 14: 301 - 319

Temple, S. R. 1976. ***Adapting varieties for intercropped systems in the tropics.*** In: Multiple Cropping (eds Sanchez, P. A. and Triplett, G. B) Pages 235-254. American Society of Agronomy, Madison, Wisconson, USA.

Willey, R. W. 1979. ***Intercropping: its importance and research needs***. I. Competition and yield advantages. Field Crops Abstracts 32: 1 - 10

**Table 1: Total shoot and root dry weights, leaf area index and root: shoot ratio of Bambara groundnut landraces and sorghum grown in sole and intercrops in Botswana**

| | Total shoot dry weight (kg $ha^{-1}$) | | | | | Total root dry weight (kg $ha^{-1}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Sorghum** | **DipC** | **OM6** | **NTSR** | **Mean** | **Sorghum** | **DipC** | **OM6** | **NTSR** | **Mean** |
| Sole crop | 5432 | 4556 | 6100 | 6861 | 5737.25 | 1206 | 946 | 710 | 504 | 841.50 |
| 3:1 | 5295 | 4762 | 5622 | 6580 | 5565.25 | 1322 | 731 | 612 | 433 | 774.50 |
| 2:2 | 5345 | 4858 | 5210 | 6210 | 5405.75 | 1346 | 677 | 544 | 394 | 740.25 |
| 1:3 | 5407 | 4568 | 5304 | 5590 | 5217.25 | 1361 | 681 | 520 | 408 | 742.50 |
| Mean | 5370 | 4686 | 5559 | 6310 | 5481.36 | 1309 | 759 | 597 | 435 | 774.69 |
| SD | 53 | 129 | 348 | 476 | 192.35 | 61 | 110 | 74 | 42 | 40.88 |
| CV% | 10.0 | 3.0 | 6.0 | 8.0 | 4.0 | 5.0 | 15.0 | 12.0 | 10.0 | 5.0 |
| LSD(0.05) | 44 | 61 | 112 | 208 | 131.20 | NS | 134 | 37 | 12 | 55 |

NS = Not significant

**Table 1: (continued)**

| | Leaf area index | | | | | Root:shoot ratio | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Sorghum** | **DipC** | **OM6** | **NTSR** | **Mean** | **Sorghum** | **DipC** | **OM6** | **NTSR** | **Mean** |
| Sole crop | 3.02 | 2.21 | 2.18 | 2.49 | 2.48 | 22.20 | 20.76 | 11.63 | 7.34 | 15.48 |
| 3:1 | 2.88 | 2.36 | 2.05 | 1.97 | 2.32 | 24.96 | 15.35 | 10.88 | 6.58 | 14.44 |
| 2:2 | 2.58 | 1.73 | 2.31 | 1.93 | 2.14 | 25.18 | 13.39 | 10.44 | 6.34 | 13.97 |
| 1:3 | 2.66 | 1.70 | 1.94 | 2.26 | 2.14 | 25.17 | 14.90 | 9.80 | 7.30 | 14.29 |
| Mean | 2.79 | 2.00 | 2.12 | 2.16 | 2.27 | 24.38 | 16.24 | 10.69 | 6.89 | 14.54 |
| SD | 0.17 | 0.29 | 0.14 | 0.23 | 0.14 | 1.26 | 2.66 | 0.67 | 0.44 | 0.57 |
| CV% | 26.0 | 15.0 | 7.0 | 11.0 | 6.0 | 6.0 | 16.0 | 6.0 | 6.0 | 4.0 |
| LSD(0.05) | 0.26 | 0.35 | NS | NS | NS | 2.24 | 3.65 | 1.04 | 1.25 | 1.76 |

*NS = Not significant*

**Table 2: Grain yield and crop index of Bambara groundnut landraces and sorghum grown in sole crops and intercrops in Botswana**

| | Grain yield (kg ha$^{-1}$) | | | | | Crop Index | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Sorghum** | **DipC** | **O M6** | **NTSR** | **Mean** | **Sorghum** | **DipC** | **OM6** | **NTSR** | **Mean** |
| Sole crop | 2024 | 902 | 885 | 898 | 1177.25 | 37.26 | 19.80 | 14.51 | 13.09 | 21.17 |
| 3:1 | 1882 | 694 | 239 | 423 | 809.50 | 35.53 | 14.57 | 4.25 | 6.18 | 15.13 |
| 2:2 | 1725 | 584 | 118 | 402 | 707.25 | 32.27 | 12.02 | 2.26 | 6.47 | 13.26 |
| 1:3 | 1840 | 533 | 43 | 171 | 646.75 | 34.03 | 11.67 | 0.08 | 3.05 | 12.21 |
| Mean | 1868 | 678 | 321 | 474 | 835.19 | 34.77 | 14.52 | 5.27 | 7.20 | 15.44 |
| SD | 107 | 142 | 333 | 264 | 205.88 | 1.84 | 3.25 | 5.53 | 3.66 | 3.47 |
| CV% | 6.0 | 21.0 | 104.0 | 56.0 | 25.0 | 5.00 | 22.00 | 105.00 | 51.00 | 22.00 |
| LSD(0.05) | 167.5 | 53.0 | 71.0 | 102.0 | 125.0 | 3.08 | 5.17 | 6.20 | 6.20 | 3.77 |

**Table 3: Percentage reduction in grain yield and Relative Crowding Coefficients of Bambara groundnut and sorghum grown in sole and intercrops in Botswana**

| | Percentage yield reduction | | | | | Relative Crowding Coefficient | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Sorghum** | **DipC** | **OM6** | **NTSR** | **Mean** | **Sorghum** | **DipC** | **OM6** | **NTSR** | **Mean** |
| 3:1 | 7.02 | 23.05 | 72.99 | 52.90 | 38.99 | 1.42 | 1.09 | 0.75 | 0.44 | 0.93 |
| 2:2 | 14.77 | 35.25 | 86.67 | 55.23 | 47.98 | 1.51 | 0.98 | 0.60 | 0.36 | 0.86 |
| 1:3 | 9.09 | 40.90 | 95.14 | 80.95 | 56.52 | 1.65 | 0.95 | 0.52 | 0.21 | 0.83 |
| Mean | 10.29 | 33.06 | 84.93 | 63.03 | 47.83 | 1.53 | 1.06 | 0.62 | 0.37 | 0.86 |
| SD | 3.28 | 7.45 | 9.13 | 12.71 | 7.16 | 0.09 | 0.13 | 0.10 | 0.10 | 0.06 |
| CV% | 32.0 | 23.0 | 11.0 | 20.0 | 15.0 | 6.0 | 15.0 | 15.0 | 28.0 | 7.0 |
| LSD(0.05) | 5.22 | 6.27 | 8.11 | 7.48 | 5.31 | 0.15 | 0.12 | 0.06 | 0.07 | 0.04 |

*NS = Not significant*

**Table 4:** **Mean Relative Yields (R) of Bambara groundnut landraces and the corresponding Relative Yield Totals (RYT) in Bambara groundnut/sorghum intercrops in Botswana**

| | | DipC | | | OM6 | | | NTSR | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **RS*** | **RD** | **RYT** | **RS/RD** | **RO** | **RYT** | **RS/RO** | **RN** | **RYT** | **RS/RN** |
| 3:1 | 1882 | 694 | 1.70 | 2.71 | 239 | 1.12 | 7.87 | 423 | 1.40 | 4.45 |
| 2:2 | 1725 | 584 | 1.50 | 2.95 | 118 | 0.99 | 14.62 | 402 | 1.30 | 4.29 |
| 1:3 | 1840 | 533 | 1.50 | 3.45 | 43 | 0.96 | 42.79 | 171 | 1.10 | 10.76 |
| Mean | 1815 | 604 | 1.57 | 3.04 | 133 | 1.02 | 21.76 | 332 | 1.27 | 6.50 |
| SD | 66.36 | 67.18 | 0.09 | 0.31 | 80.75 | 0.07 | 15.22 | 114.17 | 0.12 | 3.01 |
| CV | 0.04 | 0.11 | 0.06 | 0.10 | 0.61 | 0.07 | 0.70 | 0.34 | 0.10 | 0.46 |
| LSD(0.05) | 61.50 | 50.32 | 1.03 | 1.55 | 77.31 | 0.06 | 14.33 | 46.05 | 0.15 | 3.71 |

**RS, RD, RO and RN = Relative yields of sorghum, DipC, OM6 and NTSR, respectively*