Effects of row spacing and weed infestation on yield of bambara groundnut, *Vigna subterranea* (L.) Verdc. in South Africa

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Bambara groundnut, *Vigna subterranea* (L.) Verdc. is an important grain legume crop in Africa. The production of bambara is limited by farmers' poor cultural practices as well as weed interference. The effect of row spacing on yield of bambara and weed interaction has so far not been studied in detail. Therefore, this paper reports on the effects of row spacing on the performance of bambara and weed suppression. The trials were conducted in two seasons. A popularly grown bambara cultivar, SB 7-1, was planted under field conditions at the Agricultural Research Council-Grain Crops Institute (ARC-GCI) research station in Vaalharts, South Africa, in the 2009 and 2010 cropping seasons. The treatments consisted of four row spacings (45, 60, 75 and 90 cm apart), laid in a randomised complete block design for each year. The plots were weeded twice, at 1 and 2 months after planting. Weed incidence, abundance, biomass and dry matter were determined immediately after each weeding. Grain and fodder yields were taken at maturity. Results showed significant differences ($P \leq 0.05$) among the row spacings for fodder and grain yields, and weed total biomass and dry matter. Row spacings of 45 and 60 cm exhibited lower weed biomass and dry matter than 75 and 90 cm, and consequently produced higher grain yield. Mean yield decreased with increasing row spacing during the two seasons from 2079 kg/ha^{-1} at row spacing of 45 cm to 1017 kg/ha^{-1} at row spacing of 90 cm. The study found that planting bambara at row spacings of 45 or 60 cm is optimum for maximum yield with minimum weed interference.

Keywords: Biomass, dry matter, grain yield, plant density, *Vigna subterranea*, weeds

Bambara groundnut, *Vigna subterranea* (L.) Verdc. is an important grain legume in most rural households of South Africa. It is a cheap source of plant protein (Baudoin and Mergeai 2001; Iriti and Varoni 2017). The haulm and leaves are rich in nitrogen and potassium, and therefore are an important source of animal fodder (Karikari 1971). Bambara is believed to have originated from West Africa (notably Nigeria and Cameroun) (Begemann et al. 1997; Heller et al. 1997). It is the third most important crop among the grain legumes of the African lowland tropics after groundnuts and cowpeas. It is tolerant to drought and has the ability to produce a reasonable yield even when grown on poor soils (Mabhaudhi and Modi 2013; Chai et al. 2016). Bambara can tolerate water stress better than soybean, groundnut and other cereals. This characteristic makes bambara a versatile crop in rural and drought-prone areas, where rainfall is erratic and there is no irrigation to augment dryland production. Bambara, like most legumes, fixes atmospheric nitrogen (Musa et al. 2016) to reduce its nitrogen demand. This makes it suitable for intercropping systems with maize, millet, sorghum, cassava and yam.

However, the bambara groundnut has become less important in many parts of Africa because of the expansion of other groundnut production. The world production is estimated at 330,000 t annually, of which about half is produced in West Africa. The main producing countries are Nigeria, Ghana, Chad, Cameroun, Niger, Togo and Benin (DAFF 2011). In South Africa, the main production areas are Limpopo, Mpumalanga and KwaZulu-Natal (DAFF 2011). Bambara is produced on a small scale in many parts of Africa, where it is classified as indigenous, underutilised and a neglected or orphan crop (Vietmeyer 1979); Begemann et al. 1997;

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Mabhaudhi and Modi 2013; Chivenge et al. 2015). Despite the positive attributes of this crop, its production is limited by lack of improved varieties, poor cultural practices by farmers, weed infestation, and a lack of extended research on the crop because of the difficulty in its pre-breeding phase (Massawe et al. 2003a; Mohammed 2014). In a few provinces of South Africa, especially Mpumalanga, Limpopo and Kwazulu-Natal, the crop is intercropped with cereals to reduce the risk of crop failure due to drought since bambara is more drought tolerant than other companion crops. For this reason also, bambara is grown on marginal soils with low moisture and fertility status (Modi and Mabhaudhi 2013; Shareef et al. 2013; Cook 2017). In the last two decades, international funding for research on bambara has led to increased research work to generate basic information on agronomy, nutrition and improvement of bambara (Brough et al. 1993; Kocabas et al. 1999; Sesay and Yarmah 1996; Sesay et al. 2003; Collinson et al. 1999; Fleissner 2001; Massawe et al. 2002; Massawe et al. 2003a; Massawe et al. 2003b; Mwale et al. 2007). However, despite such increased research funding being made available, in South Africa, research on the crop has been neglected for decades. Bambara production is limited to smallholder farmers (Cook 2017) who produce the crop on a small scale for their family consumption with little or no harvest available for sale. As a result of the lack of research on this crop, basic agronomic information is still not available to guide farmers. Agronomic practices adopted by farmers in these production areas are still traditional and not suitable for mechanisation (Cook 2017). Furthermore, information about this crop is limited, especially regarding aspects of improved agronomic practices such as planting density, yield and how the crop interacts with weed interference (Senkondo et al. 2003; Sesay et al. 2003; Mabhaudhi and Modi 2013).

Weiner et al. (2001) reported that weed biomass in wheat decreases with increase in crop sowing density and spatial uniformity due to interference. Negative impact of weed interference has been documented on maize, wheat, soybean and *Hibiscus sabdariffa* (Filton 1976; Teasdale and Frank 1983; Acciares and Zuluaga 2006; Bradley 2006; Hussain et al. 2012; Hussain et al. 2014; Kajidu et al. 2015), but only limited information is available on the bambara groundnut.

The objective of this study was to investigate the effects of row spacing on the agronomic performance of the bambara groundnut, weed incidence, abundance and suppression. Research on manipulation of plant density and the effects on yield and other biotic factors such as weed interference, is crucial in order to generate enough information and a database for use by emerging farmers who may be interested to scale-up their production to commercial level.

Materials and methods

The field trial was conducted at the Agricultural Research Council-Grain Crops Institute (ARC-GCI) research station in Vaalharts, South Africa in 2009 and 2010. The treatments consisted of four row spacings (45, 60, 75 and 90 cm), which were laid in a randomised complete block design (RCBD) with three replications. The corresponding plant populations per hectare were: 222,222; 166,666; 133,000 and 111,111. The plots were weeded twice, at 1 and 2 months after planting. Weed abundance (population) was assessed on a rating scale of 1 to 5; where 1 = ≤ 10; 2 = 11 - 20; 3 = 21 - 30; 4 = 31 - 50; 5 = ≥ 51 weed plants/plot. Weed incidence of different weed species was taken before each weeding, while weed biomass and dry matter were determined after weeding. The biomass was determined by uprooting the weeds and shaking off all sand/soil on the weed samples from each plot, putting into sample bags and taken to the laboratory. The samples were then weighed using a digital weighing scale. The dry matter of the weeds was determined by drying the biomass from each plot in an oven at 72 º C until a constant weight was attained; the dry samples were weighed using a digital weighing scale. Weed species sampled were identified at the Weed Science Division at ARC-GCI, Potchefstroom, using the guides from common weeds of crops and gardens in Southern Africa (Botha 2001). The percentage water loss at first and second weedings were calculated using the relationship:

(WB-DM)/WB) * 100

where WB and DM are weed biomass and dry matter respectively. This gave an indication of weed suppression by the bambara canopy. At maturity, the plants were harvested manually using a digging fork. The pods were detached from the plants, gathered, put in paper bags and taken to the laboratory for air-drying. After air-drying for 2 weeks, the pods were shelled and the weight of the dry grains was taken. For the fodder yield determination, the bambara leaves with the haulm were left on the plots to air-dry for one week before their weights were taken. Harvest index was determined by dividing the corresponding weight of the grain by the fodder weight and grain weight of each plot. The harvest index was correlated with row spacing, grain and fodder yields.

The data were subjected to analysis of variance using SAS 9.3. Significance was determined at the $P \leq 0.05$. Treatment means that showed significant differences were separated using the Duncan Multiple range test. Plant spacing was correlated with other variables to generate a correlation matrix to determine if there were any relationships between the variables.

Results

The results show that the weed infestation comprised of both broadleaf weeds and grasses. The majority of the weed species were broadleaf weeds. Table 1 lists the weed species that were identified and recorded within the experimental plots. A total of 15 weed species were identified. The weeds were randomly distributed; however, their frequencies and abundance varied across plots (Table 1). On the basis of weed family, Poaceae exhibited the highest incidence, followed by Asteraceae and Amaranthaceae. The other families occurred only once in a plot. The abundance rating shows that *Tribulus terrestris* L. and *Tagetes minuta* L. were the most abundant with a population of over 51 plants per plot. This was followed by *Panicum maximum* Jacq. and *Schkuhria pinnata* Lam Cabr. with a score of 2 (11 - 20 plants/plot). The remaining weed species had less than 10 plants/plot with a score of 1. Table 2 shows that weed biomass at 1 and 2 months after planting (MAP) significantly ($P \leq 0.05$) increased with an increase in row spacing. The weed biomass obtained at 2 MAP was significantly lower than that obtained at 1 MAP. There was significant ($P \leq 0.05$) weed reduction (weed biomass-1 and weed biomass-2 (Table 2, Figure 1) in bambara plots spaced at 45 and 60 cm compared to the spacing of 75 and 90 cm, as shown in the total weed biomass and grand means.

Similarly, during 2009 and 2010, the mean weed dry matter showed significant differences, $P \leq 0.05$ (Table 3, Figure 1) between the narrower row spacings (45 and 60 cm) and the wider spacings (75 and 90 cm). Grain yield obtained from plots spaced at 45 and 60 cm were significantly ($P \leq 0.05$) higher than those obtained from plots spaced at 75 and 90 cm during 2009 and 2010. Grain yield ranged from grand mean of 1017 kg/ha^{-1} at row spacing of 90 cm to 2079 kg/ha^{-1} at row spacing of 45 cm (Table 4). The fodder yield varied significantly in the two seasons (Table 4). Fodder yield was higher during 2009 than in 2010. Mean fodder yield for the two years showed that plant spacing at 90 cm produced the highest fodder yield (Table 4 and Figure 1). Results show that the harvest index (HI) decreased with increasing plant spacing (Table 4).

The correlation matrix (Table 5) shows that grain yield and harvest index are strong and negatively correlated with row spacing, r = -0.87 and -0.99, respectively. Similarly, fodder yield was strongly and negatively correlated with harvest index (HI) (r = -0.73), while the grain yield was also strongly and positively correlated with the harvest index (r = 0.97). Fodder yields were positively and strongly correlated with row spacing and weed biomass (r = 0.68 and 0.82, respectively) (Table 5). Although the correlation of HI with weed biomass was positive, it was weak (0.41).

Table 1: Name, family and abundance rating of weed species identified in the study

Name	Incidence/family	Abundance (scale 1 - 5) *
Digiteria sanquinalis L. Scop	Poaceae	1
Panicum maximum Jacq.	Poaceae	2
Tragus berteronianus Schult	Poaceae	1
Schkuhria pinnata Lam Cabr.	Asteraceae	2
Chenopodium carinatum R. Br.	Chenopodiaceae	1
Senecio consanquineus DC	Asteraceae	1
Portulaca, oleracea L.	Portulacaceae	1
Tagetes minuta L.	Asteraceae	5
Commelina benghalensis L.	Commelinaceae	1
Gomphrena celosioides Mart	Amaranthaceae	1
Alternantera pungens H.B.K.	Amaranthaceae	1
Tragus racemosus L.	Poaceae	1
Malva paviflora L.	Malvaceae	1
Urochloa panicoides Beauv	Poaceae	1
Tribulus terrestris L.	Zygophyllaceae	5

* Abundance scale: 1 = ≤ 10; 2 = 11 - 20; 3 = 21 - 30; 4 = 31 - 50; 5 = ≥ 51 weed plants/plot

Table 2: Mean weed biomass per plot of four row spacings during 2009 and 2010 growing seasons

Plant spacing (cm)	Weed biomass at 1st weeding (g)		Mean	Weed biomass at 2nd weeding (g)		Mean	Total weed biomass (g)		Grand mean
	2009	*2010*		*2009*	*2010*		*2009*	*2010*	
45	535.3d	294.0c	414.7	52.1d	65.7d	58.9	587.3d	346.0d	466.7
60	877.5c	312.7c	595.1	105.4c	101.6c	103.6	983.0c	418.2c	700.6
75	1016.4b	578.0b	797.2	260.3b	142.9b	201.5	1276.8b	838.4b	1057.6
90	1203.0a	1239.7a	1221.3	399.1a	307.0a	353.0	1602.0a	1638.7a	1620.3
Mean	908.1	606.1		204.2	154.3		1112.28	810.3	
P-Level (P ≤ 0.05)	0.006	0.001		0.002	0.002		0.0002	0.001	

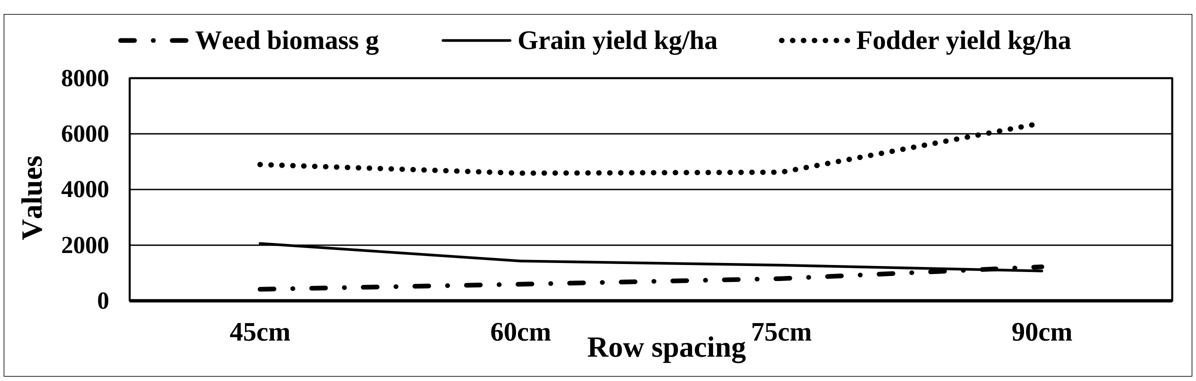

Figure 1: Plot of four row spacings with weed biomass, grain and fodder yields of bambara groundnut (combined seasons of 2009 and 2010)

Table 3: Mean percentage water loss, and dry matter of weed samples per plot of four row spacings during 2009 and 2010 seasons

Plant spacing (cm)	% water loss 1st weeding		Mean	% water loss 2nd weeding		Mean	Weed dry matter yield (g) 1st weeding		Mean	Weed dry matter yield (g) 2nd weeding		Mean
	2009	*2010*		*2009*	*2010*		*2009*	*2010*		*2009*	*2010*	
45	*64.6a*	*56.6a*	60.6	80.9a	69.1a	75.0	188.0d	182.3d	185.16	10.7c	16.7c	13.7
60	53.6a	49.b	51.3	73.5a	63.9a	68.7	352.0c	326.3c	339.15	27.0c	34.1c	30.6
75	46.4b	52.2a	49.3	49.0b	44.1b	46.3	531.7b	390.7b	461.17	95.7b	75.1b	85.4
90	42.2b	42.5b	42.3	62.8b	59.1a	60.9	664.0a	603.3a	633.66	147.4a	101.2a	124.3
Mean	51.7	50.0		66.5	59.0		433.92	375.7		70.2	56.8	
P-Level ($P \leq 0.05$)	0.005	0.001		0.0007	0.005		0.0003	0.001		0.00	0.007	

Table 4: Mean grain and fodder yields of bambara groundnut obtained from four row spacings during 2009 and 2010 seasons

Plant spacing (cm)	Grain yield (kg/ha)		Mean grain yield	Fodder yield (kg/ha)		Mean fodder yield	Harvest index (HI)		Mean HI
	2009	*2010*		*2009*	*2010*		*2009*	*2010*	
45	2097.4a	2059.9a	2078.6	6329.9a	3458.6c	4894.2	0.33a	0.60a	0.42a
60	1642.7b	1428.5b	1535.6	4765.5b	4406.0b	4585.8	0.34a	0.32b	0.33b
75	1204.5c	1279.3c	1241.9	4897.1b	4340.7b	4618.9	0.24b	0.29b	0.27b
90	961.9d	1072.1d	1017.0	6558.1a	6214.0a	6386.1	0.14c	0.17c	0.16c
Mean	1476.6	1459.9	-	5637.7	4604.8	-	0.1	0.4	-
P-Level ($P \leq 0.05$)	0.006	0.006	-	0.04	0.04	-	0.05	0.04	-

Table 5: Correlation matrix of four row spacings with weed biomass, grain yield, fodder yield and harvest index of bambara groundnut obtained during 2009 and 2010 seasons

	Weed biomass	Grain yield	Fodder yield	Spacing	Harvest index
Weed biomass	1.00	-0.87	0.82	0.98	0.41
Grain yield	-0.87	1.00	-0.48	-0.94	0.97
Fodder yield	0.82	-0.48	1.00	0.68	-0.73
Spacing	0.98	-0.94	0.68	1.00	-0.99
Harvest index	0.41	0.97	-0.73	-0.99	1.00

Discussion

Results of the study showed that narrow row spacing performed significantly better than the wider spacings with respect to grain yield and weed suppression. Weed interference poses a serious threat to crop production as it reduces yield and quality of produce. Row spacing is important cultural practice in crop production as a tool to manipulate the plant density in relation to the utilization of available resource. Climate change can affect crop production but we have the opportunity to enhance water use efficiency and crop performance through crop selection and cultural practices such as row spacing, mulching and irrigation (Hatfield and Dold 2019).

In this study, weed incidence showed that ten of the weed species identified were broadleaf weed species, while the remaining five weeds species belonged to the grass families (Poaceae). This information is important in planning for weed control strategies, intervention and selection of post emergence herbicides that are suitable for the crop and weed mixtures or situation and abundance. In a situation where chemical control may be used to supplement manual weeding, selective herbicides for bambara which are effective for controlling both broadleaf and grass weeds should be advocated or recommended.

The total productivity of the crop and weed biomass during 2009 were significantly higher than that of 2010, probably due to better rainfall distribution in 2009. Amount of rainfall and its distribution are known to influence crops productivity, species richness and total biomass (Yan et al. 2015; Hatfield and Dold 2019). Results also indicated that rows spaced at 45 and 60 cm, which were narrower, were better able to suppress the emergence and weed growth. The weed production in terms of biomass was much higher at first weeding than at second weeding because of the well-developed canopy of bambara groundnut during the second month after planting, which suppressed the growth of weeds at narrower spacings (45 and 60 cm). These spacings are promising for use in bambara production not only for the optimization of plant population that will supress weeds germination and growth but also have high potential for higher grain yields.

Dry matter increased with increasing row spacing due to less inter-row competition, giving the weeds opportunity to utilize the space and resources for dry matter production. This result corroborates the reports of Sesay et al. (2003) and Edje et al. (2003), who found that wider spacing produced more biomass and dry matter. However, the percentage water loss varied significantly ($P \leq 0.05$) across different row spacings, and the relationship was inverse. This indicates that more water loss was recorded from weeds obtained from plots at narrower row spacings (45 and 60 cm), which also shows that dry matter accumulation was higher among weeds that grew on plots with wider row spacings (75 and 90 cm). This observation probably suggests that weeds growing in plots with wider spacing took advantage of resources such as light, water and nutrients for more efficient production of assimilates and dry matter. Consequently, the impact of weed interference was higher from plots of wider row spacing, which led to yield reduction. Similar observations were made by Sesay et al. (2003); Edje et al. (2003); Weiner et al. (2001) who reported that total biomass and dry matter of bambara were higher at a lower planting density which were associated with wider spacings.

The fact that harvest index (HI) varied from 0.16 for 90 cm spacing to 0.42 for 45 cm spacing strongly suggests that grain yield of bambara groundnut decreased as the row spacing increased, which was due to three causes: (1) increased weed growth and interference as row spacing increased; (2) non-optimal plant population; (3) ability of bambara groundnut to partition assimilates for more grain production than fodder or biomass at narrower row spacings. This resulted in an inverse relationship of the harvest index with row spacing (r = -0.99). The result of this study confirms the findings of Collinson et al. 1999, who obtained a HI range between 0.05 and 0.46. Collinson et al. 1999 argued that HI could vary, depending on the severity of stress. Similar results were obtained in other crops, for instance, Hussain et al. (2014) reported that grain yield and harvest index of five wheat varieties were highest at lower row spacings (10 and 20 cm) than at 30 cm and broadcast. In this study, weed competition indirectly interfered with yield ability of bambara groundnut planted at wider row spacing; hence, reduced grain yield and HI. This observation also corroborates the results obtained by previous researchers on bambara groundnut, maize and soybean (Filton 1976; Teasdale and Frank, 1983; Ofori, 1996; Sesay and Yarmah 1996; Samani et al. 1999; Liu et al. 2003; Bradley 2006; Masindeni 2006; Zhou et al. 2010).

The application of the results from this study will be useful to the plant breeders in screening and selecting bambara genotypes for higher bambara grain yield at narrower row spacing, which will reduce weed interference and assist the breeder to identify and select plants with high yielding ability. To farmers, planting of bambara at narrow spacing will increase their profitability at a reduced cost of weed control.

Fodder yields were higher at wider row spacing and positively correlated with row spacing and weed biomass because at wider spacing, more biomass was produced possibly due to better light interception and utilization of other resources (space, nutrients and water). This result confirms the results obtained by Sesay et al. (2003); Edje et al. (2003); Masindeni (2006). The association of weed biomass with grain yield indicates that they are inversely related to row spacing. This implies that as row spacing increased, weed biomass increased while the grain yield decreased. On the other hand, the weed biomass was lower at narrow spacing, probably due to intra-specific competition as well as a suppressive effect of the canopy cover of bambara, which might have reduced light interception, weed emergence and growth (Collinson et al. 1999; Sial et al. 2001; Acciares and Zuluaga 2006). Planting in narrowly spaced rows should be recommended to smallholder farmers who always grow crops on marginal soils.

Conclusion

The study found that planting bambara groundnut at row spacings of 45 and 60 cm produced more grain yield with minimum weed interference. These spacings are regarded as the optimum for bambara production, while the wider row spacings (75 and 90 cm) exhibited lower yields due to higher weed interference. The wider the row spacing, the higher the weed abundance and the opportunity for weed growth and development, which impacted negatively on grain yield. To farmers, planting of bamara at narrow spacing will increase their profitability at a reduced cost of weed control. The results also provide advisory information to farmers regarding the fact that erect and less bushy bambara varieties can be planted at 45 cm row spacing, and the bushy and day-length sensitive cultivars can be planted at 60 cm row spacing. To the plant breeders in bambara breeding programme, the screening and selection for higher bambara grain yield should be done at narrower row spacing, which will reduce weed interference and assist the breeder to identify and select genotypes with high yielding ability.

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