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Effects of Intra-Row Spacing of Pearl Millet (*Pennisetum glaucum* (L.) R.Br.) and Cropping Systems on Growth and Yields of Soybean-Pearl Millet Intercrop, in the Southern Guinea Savanna, Nigeria. (Part II)

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ABSTRACT

Field experiments were separately conducted from June to November, in year 2012 at the Research Farm, University of Agriculture, Makurdi, Nigeria and at a Farm in Ibi, Nigeria, to evaluate the effects of intra-row spacing of pearl millet and cropping systems on growth and yields of soybean-pearl millet intercrop, as well as assessing the yield advantages of the intercropping system. The experiment was a 2 x 4 factorial combination of treatments, fitted in a randomized complete block design (RCBD), with four replications. The cropping systems constitute the soles and the intercrop, while the intra-row spacing of pearl millet into soybean were at 15 cm, 20 cm, 25 cm and 30 cm. Results of study showed that sowing pearl millet into soybean at the intra-row spacing of 30 cm produced the highest pearl millet yields of 4.7 t ha^{-1} and 4.9 t ha^{-1} respectively, at Makurdi and Ibi locations, as well as producing the highest soybean yields at both locations. In Makurdi, intercropping pearl millet with soybean significantly ($P \leq 0.05$) decreased yield of pearl millet by 32.4 % and that of soybean by 29.4 % compared to sole cropping of the component crops, while at Ibi, intercrop yields of pearl millet and soybean were respectively reduced by 35.9 % and 30.0 % compared to their sole yields. Sowing pearl millet into soybean at the intra-row spacing of 30 cm also gave the highest total intercrop yields, highest land equivalent coefficient (LEC) values, highest land equivalent ratio (LER) values of 2.97 and 2.71 and highest percentage (%) land saved (66.3 % and 63.1 % respectively, recorded at Makurdi and Ibi locations). The implication of study showed that it is most advantageous having both crops in intercrop when pearl millet was sown into soybean at the intra-row spacing of 30 cm. This should therefore, be recommended for the southern guinea savanna, Nigeria.

Keywords**:** spacing; intercropping; pearl millet; soybean; Nigeria

1. INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R.Br) is one of the most important cereals and a staple grain for over 150 million people in West Africa and India (FAOSTAT, 2012). In recent times, pearl millet has drawn a lot of attention as a replacement for maize and sorghum because of its ability to produce grains on a wide range of soils and harsh production environments (Dewey *et al*., 2012).

Filardi *et al*. (2005) had indicated that it is a high yielding crop, drought tolerant and holds features to salvage food shortages in Nigeria. Pearl millet production in Nigeria grew from 2.6 million metric tonnes in 1961 to over 6.6 million metric tonnes in 2004 (Oluwasemire *et al*., 2002). The country has a world share of 4.5 % of the quantity of millet production (FAOSTAT, 2009). On a dry weight basis, the crop contains carbohydrate 67 g, protein 12 g, fat 5 g, mineral 2 g, fiber 1 g, moisture 12 g, calcium 42 mg, phosphorus 242 mg and iron 8 mg (FAOSTAT, 2012).

Soybean (*Glycine max* L. Merril) is a leguminous vegetable that grows in tropical, subtropical and temperate climates (Dugje *et al*., 2009). It contains more than 36 % protein, 30 % carbohydrate, vitamins and minerals. It also contains 25 % oil, which makes it the most important crop for producing edible oil (IITA, 2009). More than 2.6 million metric tonnes of soybeans were produced worldwide in 2007, of which 1.5 million metric tonnes were in Africa, with Nigeria been the largest producer in sub-saharan Africa (IITA, 2009).

Pearl millet and soybean are popular crops among farmers in the southern guinea savanna ecology of Nigeria, were these crops are grown for subsistence and for cash (Jahanzad *et al*., 2011). Studies have been conducted on sole pearl millet and sole soybean as affected by intra-row spacing (Hiebsch *et al*., 2009; Shinggu *et al.*, 2009; Kamal *et al*., 2013). In the southern guinea savanna of Nigeria, literature also abound on the effect of intra-row spacing of maize on yields and yield components of crop mixtures such as maize-egusi melon, maize-soybean and sorghum-soybean (Moueneke *et al*., 2007; Egbe 2010; Ijoyah *et al*., 2013), but documented scientific information on yield response of similar low growing plant such as soybean in intercrop with tall growing plant such as pearl millet as affected by the intra-row spacing of pearl millet is lacking, as well as their responses to intercropping compared to planting them as soles.

The study was therefore undertaken at Makurdi and Ibi, locations in the southern guinea savanna agro-ecology of Nigeria, with the aim to evaluate the effects of intra-row spacing of pearl millet and cropping systems on growth and yields of soybean-pearl millet intercrop, with the objectives to:

1. Identify the appropriate intra-row spacing of pearl millet that will maximize yields of soybean-pearl millet intercrop.
2. Determine the growth and yield effects of pearl millet and soybean to intercropping.
3. Evaluate the yield advantages of the intercropping system.

2. MATERIALS AND METHODS

2. 1. Study locations and crop varieties

A field experiment was separately conducted from June to November, in year 2012, at the Research Farm, University of Agriculture, Makurdi, Nigeria, and at a Farm in Ibi, Nigeria to evaluate the effects of intra-row spacing of pearl millet and cropping systems on growth and yields of soybean-pearl millet intercrop. The soybean variety 'TGX 1448-2E' was obtained from the Seed Technology Centre, University of Agriculture, Makurdi, while the pearl millet local variety 'Amine' is popularly grown by farmers in Makurdi and Ibi locations. The crops adapt well to the environment of both locations.

2. 2. Experimental design, area and crop arrangement

The experiment was a 2 x 4 factorial combination of treatments, fitted in a randomized complete block design with four replications. The cropping systems constitute the soles and the intercrop, while the intra-row spacing of pearl millet into soybean were at 15 cm, 20 cm, 25 cm and 30 cm. The experimental area was 542.5 m^2 and consisted of 36 treatment plots. Each treatment plot had an area of 12.0 m^2, while the net plot was 2 m x 2 m (4.0 m^2). The experimental field was cleared, ploughed, harrowed and ridged. Each plot consisted of 4 ridges. The ridges were spaced 1 m apart. In sole pearl millet plots, the plants were sown at an intra-row spacing of 15 cm, 20 cm, 25 cm and 30 cm, respectively at 80, 60, 48 and 40 plants per plot (66,666, 50,000, 40,000 and 33,333 plants ha^{-1} equivalent). In the sole plots, pearl millet and soybean were sown in a single row on top of ridge, at their intra-row spacing, while in the intercrop plots, soybean was planted on top of the ridge, while pearl millet was sown by the side of ridge, but at the varied intra-row spacing. The crops were sown at same time in late June.

2. 3. Cultural practices

Three manual weedings, with the use of the native hoe were done at 3, 6 and 9 weeks after planting (WAP). Mixed fertilizer NPK 15:15:15 was applied at the rate of 60 kg N, 30 kg P_2O_5 and 30 kg K_2O ha^{-1} at land preparation by broadcasting (Ekpete, 2000). Urea (65 kg) was applied to pearl millet stands by side placement at 6 WAP. Soybean was harvested at 18 WAP, when the pods have turned brown and seeds are at the hard-dough stage with moisture content between 14 and 16 % (Dugje *et al*., 2009). Pearl millet was harvested at 12 WAP, when the leaves turned yellowish and fallen off which were signs of senescence and seed maturity.

2. 4. Data collected

2. 4. 1. Pearl millet

Days to attain 50 % flowering and days to maturity (taken by counting the number of days from when crop was sown to when 50 % plants flowered and matured), plant height (cm) at 50 % flowering (measured as the distance from the soil surface to the tip of the topmost leaf), number of tillers per plant, number of nodes per plant and internode length (measured using a 30 cm ruler, as the length of stalk between two nodes). The panicles of four plants in the net plot and averaged were used to measure the panicle length (cm) and panicle width (cm), The total plant biomass and grain yield (t ha^{-1}) were also taken by the process of panicles sundried for a week, threshed, winnowed and grains further sundried for three days and weighed using an electronic weighing balance in grams.

2. 4. 2. Soybean

Days to 50 % flowering and maturity, plant height at 8 WAP, number of branches per plant at 8 WAP, number of leaves per plant, number of pods per plant, number of seeds per pod, 100 seeds weight, total plant biomass and seed yield ($t \cdot ha^{-1}$).

2. 5. Statistical analysis

Analysis of variance (ANOVA) for factorial experiment was carried out on each observation for each location and the Least Significant Difference (LSD) was used for means separation ($P \leq 0.05$) following the procedure of Steel and Torrie (1980). Main treatment effects and the interaction were also determined.

2. 6. Evaluation of yield advantages

2. 6. 1. Land equivalent ratio (LER)

The LER was determined as described by Willey (1985) using the formula:

$$LER = \frac{Intercrop\ yield\ of\ crop\ A}{Sole\ crop\ yield\ of\ A} + \frac{Intercrop\ yield\ of\ crop\ B}{Sole\ crop\ yield\ of\ B}$$

2. 6. 2. Competitive ratio (CR)

The CR as described by Willey and Rao (1980) was determined using the formula:

$CR = Ls/Lp$, where; Ls: Partial LER for soybean; Lp: Partial LER for pearl millet.

2. 6. 3. Percentage (%) land saved

The percentage (%) land saved as described by Willey (1985) using the formula:

$$\%\ \text{land saved} = 100 - \left(\frac{1}{LER} X\ 100\right)$$

2. 6. 4. Aggressivity (A)

Aggressivity (A) gives a simple measure of how much the relative yield increase in component 'a' is greater than that for component 'b' as described by McGilchrist (1971) using the formula:

$$A = \frac{Mixture\ yield\ of\ 'a'}{Expected\ yield\ of\ 'a'} - \frac{Mixture\ yield\ of\ 'b'}{Expected\ yield\ of\ 'b'}$$

where:
A = 0: indicates that both crops are equally competitive;
A = -: indicates dominated component

A = +: indicates dominant component

2. 6. 5. Land equivalent coefficient (LEC)

The LEC as described by Adetiloye *et al*. (1983) was determined using the formula:

$LEC = La \times Lb$; where La: LER of main crop; Lb: LER of intercrop.

These calculations were used to assess the yield advantages of the intercropping system.

3. RESULTS AND DISCUSSION

3. 1. Meteorological information for Makurdi and Ibi locations (June to November), in year 2012

The meteorological information for Makurdi and Ibi locations during the growth period of the two crops from June to November in year 2012 is presented in Table 1. Rainfall was regular from the months of June to October at the two locations of study. In both locations, the month of July recorded the highest amount of rainfall and highest number of rain days. The average relative humidity across locations was high. In Makurdi, the average monthly relative humidity ranged from 54.2 % to 79.8 %, while at Ibi, it ranged from 60.3 % to 78.5 %. The average monthly temperature for Makurdi ranged from 17.5 °C to 31.5 °C, while it ranged from 18.2 °C to 31.6 °C at Ibi location. In each location, the average solar radiation was about 6.0 hours.

3. 2. Physico-chemical properties of the soil of experimental sites before planting at Makurdi and Ibi locations, in year 2012

In Table 2, total nitrogen values were low, ranging from 0.08 % to 0.09 % at both study locations. The soil had a low level of available phosphorus, with a corresponding low level of potassium, ranging from 0.37 (Cmol kg^{-1} soil) to 0.49 (Cmol kg^{-1} soil) at both locations. The pH in water was slightly acidic to neutral. The textural class of soil at both study locations was sandy-loam.

Table 1. Meteorological information for Makurdi and Ibi locations, Nigeria (June to November) in year 2012.

Location/Months	Average monthly rainfall (mm)	Number of rain days	Average monthly temperature (°C)		Average relative humidity (%)	Average solar radiation (hrs)
Makurdi			**Min.**	**Max.**		
June	224.3	15	22.4	30.6	76.2	6.3
July	250.6	20	23.2	31.4	78.6	5.8
August	237.3	16	23.0	30.0	79.8	5.9

September	243.0	18	22.8	29.8	79.6	5.6
October	98.7	9	22.4	31.5	73.6	6.4
November	0	0	17.5	24.2	54.2	6.4
Ibi						
June	230.2	12	21.3	31.0	75.4	5.9
July	258.3	18	21.5	31.2	77.2	6.2
August	253.1	10	22.2	30.6	78.5	5.7
September	215.4	14	22.5	31.6	76.4	6.4
October	210.3	8	22.1	30.7	75.4	6.2
November	0	0	18.2	31.4	60.3	6.4

Sources: Air Force Base Meteorological Station, Makurdi, Nigeria.
Ministry of Agriculture (Zonal Office), Wukari, Nigeria.

Table 2. Physico-chemical properties of the soil of experimental sites before planting at Makurdi and Ibi locations, in year 2012.

Parameters	Quantity in soil	
	Makurdi	Ibi
Organic matter (%)	1.40	1.30
Nitrogen (%)	0.09	0.08
P_2O_5 (ppm)	4.1	3.5
K (Cmol kg^{-1} soil)	0.49	0.37
Sand (%)	69.3	76.3
Clay (%)	16.3	11.4
Silt (%)	14.4	12.3
pH (H_20)	6.1	6.3
pH(Kcl)	5.3	5.4
Textural class	Sandy-loam	Sandy – loam

Source: Soil Science laboratory, University of Agriculture, Makurdi, Nigeria.

3. 3. Growth and yield of pearl millet

3. 3. 1. Days to attain 50 % flowering and days to maturity

Although days to attain 50 % flowering and days to maturity were not significantly ($P \leq 0.05$) affected by the varied intra-row spacing of pearl millet in a soybean-pearl millet intercrop (Table 3), however, early days to attain 50 % flowering and maturity were recorded in closer intra-row spacing (15 cm and 20 cm) as compared to those recorded for the wider intra-row spacing of 25 cm and 30 cm.

The early days taken to attain 50 % flowering and maturity could be prompted by the higher plant density and intense competition for nutrients which could have occurred at the closer intra-row spacing of 15 cm and 20 cm. Getachar *et al*., (2012) reported similar findings in *Solanum tuberosum* in Ethiopia and attributed the result to intense competition in closely spaced plants, resulting in nutrient depletion, thus inducing early days to flowering and maturity.

3. 3. 2. Plant height (cm) at 50 % flowering

In both locations, the height of pearl millet significantly ($P \leq 0.05$) increased as the intra-row spacing of pearl millet increased from 15 cm to 30 cm (Table 3). The tallest height in both locations was obtained from pearl millet sown at the intra-row spacing of 30 cm.

The tallest plant height recorded at the widest intra-row spacing of 30 cm could be linked to lesser competition for available nutrients occurring at wider intra-row spacing. The result agreed with Mass *et al*. (2007) who reported increase in plant height at wider intra-row spacing in the south eastern coastal plains of America, but contradict that of Miko and Manga (2008) who reported increase in sorghum height at closer intra-row spacing. The reason for the contradiction in results could be attributed to the genetic potential of the varieties of the different crops used.

Table 3. Main effects of intra-row spacing of pearl millet and cropping systems on days to attain 50 % flowering, days to maturity and plant height (cm) at 50 % flowering, at Makurdi and Ibi locations, in year 2012.

	Days to attain 50 % flowering		Days to maturity		Plant height (cm) at 50 % flowering	
	Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi
Intra-row spacing						
15 cm	64.0	62.8	85.0	84.0	148.7	166.5
20 cm	64.0	63.4	84.3	85.0	175.6	184.6
25 cm	66.0	64.9	85.3	86.3	222.5	244.1
30 cm	66.0	64.9	85.8	86.5	240.9	275.5
LSD($P \leq 0.05$)	Ns	Ns	0.3	0.2	9.7	10.4

Cropping systems						
Sole pearl-millet	65.6	65.4	85.1	85.6	202.7	214.0
Intercropping	65.3	65.2	84.0	84.2	176.4	183.7
LSD($P \leq 0.05$)	Ns	Ns	Ns	Ns	12.1	14.0

Ns: not significant.

Table 4. Interaction of intra-row spacing of pearl millet x cropping systems on days to attain 50 % flowering, days to maturity and plant height (cm) at 50 % flowering, at Makurdi and Ibi locations, in year 2012.

Cropping systems	Intra-row spacing	Days to attain 50 % flowering		Days to maturity		Plant height (cm) at 50 % flowering	
		Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi
Sole pearl millet	15 cm	68.0	68.5	84.9	85.2	148.6	165.8
	20 cm	67.8	67.2	84.6	84.2	130.3	152.6
	25 cm	67.3	67.5	84.5	84.0	124.6	135.1
	30 cm	66.2	66.4	84.3	84.1	110.7	121.4
Intercropping	15 cm	66.9	67.2	85.9	85.7	127.2	129.3
	20 cm	66.0	66.4	84.8	84.6	120.1	120.0
	25 cm	66.3	66.6	84.1	84.2	113.2	115.1
	30 cm	66.1	66.0	84.0	84.1	95.7	99.2
	LSD ($P \leq 0.05$)	Ns	Ns	Ns	Ns	5.2	7.1

Ns: not significant.

Intercropping pearl millet with soybean significantly ($P \leq 0.05$) reduced the height of pearl millet (Table 3). The reduction in pearl millet height under intercropping could have been induced by the intense overcrowding effect of the component crops in the intercrop as compared to sole cropping for available nutrients. This view agreed with that of Madu and Nwosu (2001) who reported that yam planted sole, generally have greater efficiency in utilizing the growth environment. In Table 4, pearl millet sown into soybean at the intra-row spacing of 15 cm gave the tallest heights (127.2 cm and 129.3 cm, respectively at Makurdi and Ibi).

3. 3. 3. Number of tillers per plant

Number of tillers per plant significantly (P ≤ 0.05) increased as the intra-row spacing of pearl millet increased up to 30 cm. The highest number of tillers was obtained sowing pearl millet at the intra-row spacing of 30 cm at both locations (Table 5). Intercropping pearl millet with soybean significantly (P ≤ 0.05) reduced number of tillers (Table 5).

The reduction in the number of tillers per plant resulting from intercropping agreed with Silwana and Lucas (2005), who reported that intercropping reduced vegetative growth of the component crops.

Table 5. Main effects of intra-row spacing of pearl millet and cropping systems on number of tillers per plant, number of nodes per plant and internode length (cm), at Makurdi and Ibi locations, in year 2012.

	Number of tillers per plant		Number of nodes per plant		Internode length (cm)	
	Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi
Intra-row spacing						
15 cm	3.7	4.3	7.1	7.8	8.4	11.6
20 cm	4.2	4.5	8.7	8.8	12.8	15.8
25 cm	4.5	4.9	11.8	13.6	14.9	18.0
30 cm	4.8	5.4	13.0	15.8	15.9	19.7
LSD(P≤0.05)	0.2	0.1	1.3	0.7	0.8	1.2
Cropping systems						
Sole pearl millet	4.8	5.4	12.3	10.2	14.5	16.6
Intercropping	4.3	3.2	9.3	7.1	11.3	12.2
LSD (P ≤ 0.05)	0.3	1.5	2.4	1.6	2.1	2.7

The highest number of tillers (5.2 and 5.9, respectively recorded for Makurdi and Ibi) were obtained from intercropped pearl millet sown into soybean at the intra-row spacing of 30 cm (Table 6).

Table 6. Interaction effects of intra-row spacing of pearl millet x cropping systems on number of tillers per plant, number of nodes per plant and internode length (cm) at Makurdi and Ibi locations, in year 2012.

Cropping systems	Intra-row spacing	Number of tillers per plant		Number of nodes per plant		Internode length (cm)	
		Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi
Sole pearl millet	15 cm	3.5	3.9	6.8	6.9	8.5	13.4
	20 cm	4.0	4.6	7.6	9.2	12.2	15.3
	25 cm	4.3	5.0	12.4	12.8	12.8	15.8
	30 cm	4.8	5.6	14.2	17.6	14.2	16.6
Intercropping	15 cm	3.3	3.7	6.4	6.7	6.4	6.7
	20 cm	4.2	4.8	7.4	9.7	7.4	8.1
	25 cm	4.6	5.4	11.2	12.0	11.2	12.0
	30 cm	5.2	5.9	12.0	14.4	12.0	13.4
	LSD ($P \leq 0.05$)	0.2	0.1	0.5	2.1	0.5	0.3

3. 3. 4. Number of nodes per plant and internode length (cm)

The highest number of nodes per plant and longest internodes at both locations, were obtained sowing pearl millet at the intra-row spacing of 30 cm (Table 5). The tallest plants produced from the widest intra-row spacing of 30 cm could be attributed to the highest number of nodes and longest internode length obtained. The lowest competition for growth resources which might have occurred at the widest intra-row spacing of 30 cm could also be responsible for the highest number of nodes and longest internode length produced. Intercropping significantly ($P \leq 0.05$) reduced number of nodes per plant and the internode length (Table 5). Under intercropping, the highest number of nodes and longest internode lengths were obtained from pearl millet sown into soybean at the intra-row spacing of 30 cm at both locations (Table 6).

3. 3. 5 Panicle length (cm) and Panicle width (cm)

The longest panicle length and largest panicle width were produced sowing pearl millet at the intra-row spacing of 30 cm (Table 7). The reduced competition for growth resources at low plant densities could have induced the longest panicle length and largest panicle width. Mbah and Ogidi (2012) reported improved performance with low plant densities of component crops. Intercropping significantly ($P \leq 0.05$) decreased panicle length and panicle width of pearl millet (Table 7). In both locations, intercropped pearl millet sown into soybean at the intra-row spacing of 30 cm gave the longest panicle length and largest panicle width (Table 8).

3. 3. 6. Panicle weight (g) and grain yield ($t \cdot ha^{-1}$)

Sowing pearl millet at the intra-row spacing of 30 cm significantly ($P \leq 0.05$) produced the highest panicle weights of 80.8 g and 90.3 g, respectively at Makurdi and Ibi locations, as well as producing the highest grain yields of 5.1 t ha^{-1} and 5.3 t ha^{-1} respectively, for Makurdi and Ibi (Table 7).

The highest number of tillers and the largest panicle size produced sowing pearl millet at the intra-row spacing of 30 cm could be responsible for the highest panicle weight and highest grain yield. In addition, the lowest competition for growth resources at widest intra-row spacing of 30 cm could also be responsible. Muoneke *et al*. (2007) reported that yield was higher with decrease in maize population. Sowing pearl millet at the intra-row spacing of 30 cm significantly ($P \leq 0.05$) increased grain yield by 41.2 %, 29.4 % and 17.6 % respectively, compared to sowing pearl millet at the intra-row spacing of 15 cm, 20 cm and 25 cm at Makurdi location, and by 41.5 %, 28.3 % and 15.1 % respectively, compared to sowing pearl millet at the intra-row spacing of 15 cm, 20 cm and 25 cm at Ibi location.

Intercropping pearl millet and soybean significantly ($P \leq 0.05$) decreased grain yield of pearl millet by 32.4 % and 35.9 % respectively, at Makurdi and Ibi, compared to that obtained from sole cropping of pearl millet (Table 7). The lower yield obtained from intercropped pearl millet compared to sole cropping agreed with the result of Olufajo (1992) and Muoneke *et al*. (2007) who reported higher yield in sole cropping over intercropping. Intercropped pearl millet sown into soybean at the intra-row spacing of 30 cm gave the highest panicle weights and highest grain yields at both locations (Table 8).

3. 3. 7. Total plant biomass of pearl millet

Planting pearl millet at the intra-row spacing of 30 cm significantly ($P \leq 0.05$) produced the highest total plant biomass of 812.0 Kg ha^{-1} and 920.5 Kg ha^{-1} respectively, at Makurdi and Ibi (Fig. 1). Intercropping pearl millet with soybean significantly ($P \leq 0.05$) reduced total plant biomass of pearl millet at both locations (Fig. 1). The lowest plant density resulting from the widest intra-row spacing of 30 cm could be attributed to the highest total plant biomass obtained, while the intense competition for growth resources under intercropping could have been responsible for the significant reduction in total plant biomass.

Table 7. Main effects of intra-row spacing of pearl millet and cropping systems on panicle length (cm), panicle width (cm), panicle weight (g) and grain yields ($t \cdot ha^{-1}$), at Makurdi and Ibi locations, in year 2012.

	Panicle length (cm)		Panicle width (cm)		Panicle weight (g)		Grain yields (t ha^{-1}))	
	Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi
Intra-row spacing								
15 cm	42.5	53.9	1.3	1.5	45.9	54.0	3.0	3.1

20 cm	54.8	65.9	1.6	1.8	65.9	70.0	3.6	3.8
25 cm	63.1	70.3	2.3	4.0	72.9	79.9	4.2	4.5
30 cm	68.7	78.2	2.6	4.4	80.8	90.3	5.1	5.3
LSD ($P \leq 0.05$)	3.3	4.2	0.2	0.1	6.2	8.0	0.5	0.3
Cropping systems								
Sole pearl millet	62.7	68.4	2.4	3.8	77.4	79.8	3.4	3.9
Intercropping	56.4	54.0	1.6	1.8	68.2	66.0	2.3	2.5
LSD ($P \leq 0.05$)	4.1	6.3	0.5	1.2	5.4	8.2	0.6	0.4

Table 8. Interaction of intra-row spacing of pearl millet x cropping systems on panicle length (cm), panicle width (cm), panicle weight (g) and grain yields ($t \cdot ha^{-1}$), at Makurdi and Ibi locations, in year 2012.

Cropping Systems	Intra-row spacing	Panicle length (cm)		Panicle width (cm)		Paride weight (g)		Grain yields ($t\ ha^{-1}$)	
		Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi
Sole pearl millet	15 cm	44.3	51.3	1.6	1.5	53.4	56.1	3.3	3.6
	20 cm	53.3	65.1	1.9	1.9	65.0	79.2	4.0	4.3
	25 cm	70.1	75.4	2.4	2.9	78.4	89.1	4.5	4.9
	30 cm	78.2	82.5	3.6	4.5	86.0	105.1	5.0	5.9
Intercropping	15 cm	42.1	49.2	1.3	1.3	42.6	51.3	3.2	3.3
	20 cm	59.2	61.3	1.6	1.7	62.9	74.9	3.8	4.0
	25 cm	66.4	70.3	2.2	2.4	74.2	82.2	4.2	4.8
	30 cm	74.2	78.6	2.6	3.8	78.4	94.3	4.7	4.9
LSD ($P \leq 0.05$)		5.4	6.1	0.2	0.3	3.0	5.4	0.04	0.06

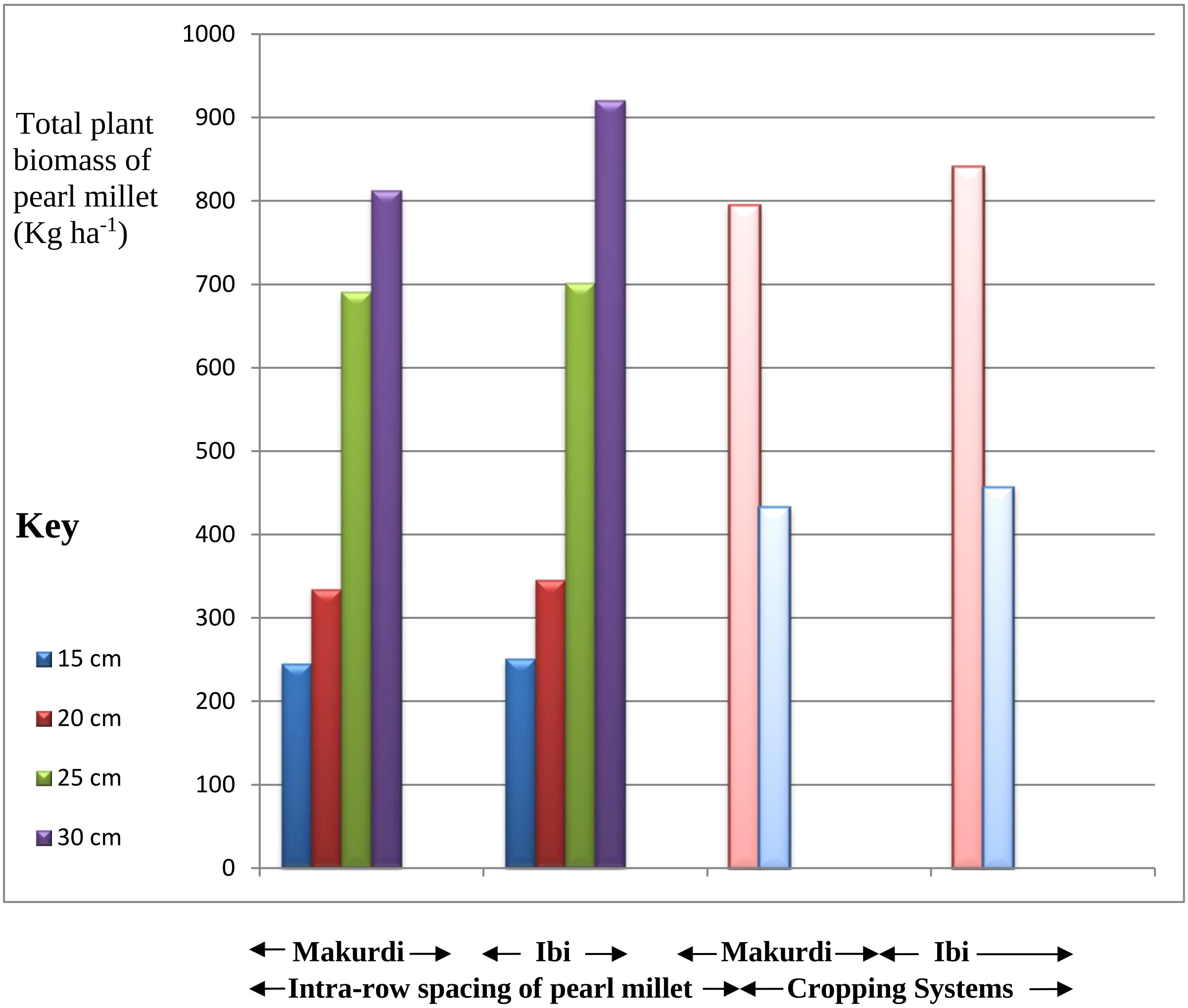

Fig. 1. Main effects of intra-row spacing of pearl millet and cropping systems on total plant biomass (Kg·ha^{-1}) of pearl millet at Makurdi and Ibi locations, in year 2012.

3. 4. Growth and yield of soybean

3. 4. 1. Days to attain 50 % flowering and days to maturity

Though days to attain 50 % flowering and days to maturity for soybean were not significantly ($P \leq 0.05$) affected by the intra-row spacing of pearl millet, however, intercropping pearl millet and soybean significantly ($P \leq 0.05$) reduced days to attain 50 % flowering and days to maturity for soybean (Table 9).

The longer days taken to attain 50 % flowering and days to maturity for sole soybean as compared to intercropped soybean contradict the results of Ijoyah *et al*. (2012) who reported longer days to attain 50 % flowering and maturity for intercropped soybean in a soybean-maize intercrop. The conflict in results could be due to the growth habit of component crops and possibly the arrangement of crops in the intercrop.

3. 4. 2. Plant height (cm) at 8 weeks after planting (WAP)

The plant height of soybean at 8 WAP significantly ($P \leq 0.05$) increased as the intra-row spacing of pearl millet increased up to 30 cm (Table 9). The tallest soybean height produced at the widest intra-row spacing of 30 cm contradict the result of Ibeawuchi *et al*. (2005) and Ijoyah *et al*. (2010) who reported that tallest okra heights were produced from closer intra-row spacing of 15 cm. The conflict in results might be attributed to the growth habit of component crops in the intercrop.

Intercropping pearl millet with soybean significantly ($P \leq 0.05$) produced taller soybean plants than that obtained from soybean planted as sole (Table 9). The competition for light from the higher plant densities in the intercrop might have induced taller soybean plants compared to soybean planted sole.

Sowing pearl millet into soybean at the intra-row spacing of 30 cm produced the tallest soybean plants of 82.4 cm and 85.8 cm respectively, at Makurdi and Ibi locations (Table 10).

Table 9. Main effects of intra-row spacing of pearl millet and cropping systems on days to attain 50 % flowering for soybean, days to maturity and plant height (cm) at 8 WAP, at Makurdi and Ibi locations, in year 2012.

	Days to attain 50 % flowering for soybean		Days to maturity		Plant height (cm) at 8 WAP	
	Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi
Intra-row spacing						
15 cm	54.5	55.6	94.2	93.1	70.5	65.0
20 cm	56.2	56.0	95.0	93.6	75.1	73.2
25 cm	56.1	56.4	96.0	95.1	79.4	78.8
30 cm	54.0	56.4	96.4	95.0	83.2	85.4
LSD ($P \leq 0.05$)	Ns	Ns	Ns	Ns	2.7	3.1
Cropping systems						
Sole soybean	56.2	56.8	94.1	94.6	71.1	73.0
Intercropping	54.4	53.6	92.0	92.2	80.3	81.4
LSD ($P \leq 0.05$	0.6	0.4	0.3	0.6	5.0	3.6

WAP: weeks after planting; Ns: not significant.

Table 10. Interaction of intra-row spacing of pearl millet x cropping systems on days to attain 50 % flowering for soybean, days to maturity and plant height (cm) at 8 WAP, at Makurdi and Ibi locations, in year 2012.

Cropping systems	Intra-row spacing	Days to attain 50 % flowering for soybean		Days to maturity		Plant height (cm) at 8 WAP	
		Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi
Soybean - pearl millet	15 cm	54.7	54.6	94.2	94.4	59.4	62.0
	20 cm	54.9	54.9	94.1	94.0	65.8	68.4
	25 cm	55.8	55.6	95.4	95.0	74.3	76.4
	30 cm	54.5	55.6	95.2	94.8	79.5	80.0
	LSD ($P \leq 0.05$)	Ns	Ns	Ns	Ns	4.1	3.0

WAP: weeks after planting.
Ns: not significant.

3. 4. 3. Number of branches per plant at 8 WAP, number of leaves per plant and number of pods per plant.

Table 11. Main effects of intra-row spacing of pearl millet and cropping systems on number of branches per plant at 8 WAP, number of leaves per plant and number of pods per plant, at Makurdi and Ibi locations, in year 2012.

	Number of branches per plant at 8 WAP		Number of leaves per plant		Number of pods per plant	
	Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi
Intra-row spacing						
15 cm	6.4	6.7	46.4	46.9	51.4	52.0
20 cm	7.2	7.4	51.5	53.2	59.0	62.4
25 cm	7.6	7.9	57.8	59.3	68.1	70.2
30 cm	8.2	8.6	65.3	64.1	82.6	85.1
LSD ($P \leq 0.05$)	0.2	0.1	Ns	Ns	5.6	6.4

Cropping systems						
Sole soybean	7.5	7.8	64.8	62.7	80.2	85.4
Intercropping	6.3	6.6	44.2	41.9	58.0	56.0
LSD ($P \leq 0.050.5$)	1.1	0.8	10.1	13.4	12.0	15.6

WAP: Weeks after planting: Ns: not significant.

Although, number of soybean leaves was not significantly ($P \leq 0.05$) affected varying the intra-row spacing of pearl millet, however, the number of branches per plant at 8 WAP and number of pods per plant significantly ($P \leq 0.05$) increased as the intra-row spacing of pearl millet increased up to 30 cm (Table 11). The significant increase recorded in the number of branches per plant as intra-row spacing of pearl millet increased up to 30 cm agreed with the work of Ibeawuchi *et al*. (2005) who reported that the mean branch number was significantly greater at wider intra-row spacing. It could be that the wider intra-row spacing might have enhanced a greater utilization of sunlight in branching. The highest number of pods obtained from soybean in intercrop with pearl millet sown at the intra-row spacing of 30 cm could be linked to the highest number of branches produced. This view supports Ijoyah *et al*. (2010) who reported that the number of pods would depend on the intensity of plant.

Table 12. Interaction of intra-row spacing of pearl millet x cropping systems on number of branches per plant at 8WAP, number of leaves per plant and number of pods per plant, at Makurdi and Ibi locations, in year 2012.

Cropping Systems	Intra – row spacing	Number of branches per plant at 8 WAP		Number of leaves per plant		Number of pods per plant	
		Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi
Soybean - pearl millet	15 cm	6.0	6.3	43.0	43.1	50.4	51.1
	20 cm	7.2	7.2	50.1	49.2	56.2	57.0
	25 cm	7.7	7.5	56.1	56.1	64.3	65.2
	30 cm	8.2	8.3	63.0	68.3	72.1	76.2
	LSD ($P \leq 0.05$)	0.3	0.2	Ns	Ns	2.5	3.2

WAP: weeks after planting
Ns: not significant.

The highest number of pods was obtained from soybean with pearl millet sown at the intra-row spacing of 30 cm (Table 12).

3. 4. 4. Number of seeds per pod, 100 seeds weight (g) and seed yield (t ha^{-1})

Intercropping pearl millet and soybean significantly ($P \leq 0.05$) reduced number of seeds per pod, weight of 100 seeds and seed yield of soybean, compared to planting soybean as sole (Table 13). The shading of pearl millet over soybean could be responsible for the reduction in the yield of intercropped soybean, as compared to the yield produced from soybean planted sole. Seed yield of intercropped soybean was significantly ($P \leq 0.05$) reduced by 29.4 % and 30.0 % respectively, at Makurdi and Ibi locations, compared to that obtained from sole cropping of soybean. Soybean sown with pearl millet at the intra-row spacing of 30 cm produced the highest number of seeds per pod, highest weight of 100 seeds and highest seed yields of 2.7 t ha^{-1} and 2.9 t ha^{-1} respectively, at Makurdi and Ibi locations (Table 14). The highest number of branches per plant and highest number of pods obtained from soybean in intercrop with pearl millet sown at the widest intra-row spacing of 30 cm could be responsible for the highest number of seeds per pod and highest seed yield.

3. 4. 5. Total plant biomass of soybean

Soybean sown with pearl millet at the intra-row spacing of 30 cm produced the highest total plant biomass of 947.6 kg ha^{-1} and 954.2 kg ha^{-1} respectively, at Makurdi and Ibi, significantly ($P \leq 0.05$) higher than the closer intra-row spacing of 25 cm, 20 cm and 15 cm (Fig. 2). Intercropping pearl millet with soybean significantly ($P \leq 0.05$) reduced the total plant biomass of soybean as compared to that obtained from soybean planted sole (Fig. 2). The higher plant density achieved under intercropping might have induced greater competition for growth resources, thereby reducing the total plant biomass of intercropped soybean.

Table 13. Main effects of intra-row spacing of pearl millet and cropping systems on number of seeds per pod, 100 seeds weight (g) and seed yield (t ha^{-1}), at Makurdi and Ibi locations, in year 2012.

	Number of seeds per pod		100 seeds weight (g)		Seed yield (t ha^{-1})	
	Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi
Intra-row spacing						
15 cm	4.2	4.6	9.8	7.2	1.4	1.3
20 cm	5.0	5.6	11.6	8.6	1.6	1.8
25 cm	5.8	6.8	14.8	10.4	1.9	2.5
30 cm	8.3	8.8	15.9	14.2	2.3	3.0
LSD ($P \leq 0.05$)	0.5	0.8	0.7	0.5	0.1	0.4

Cropping Systems						
Sole soybean	8.4	8.6	14.7	14.4	1.7	2.0
Intercropping	5.3	5.6	10.2	9.0	1.2	1.4
LSD ($P \leq 0.05$)	1.6	1.9	3.2	2.6	0.3	0.2

Table 14. Interaction of intra-row spacing of pearl millet x cropping systems on number of seeds per pod, 100 seeds weight (g) and seed yield (t ha^{-1}), at Makurdi and Ibi locations, in year 2012.

Cropping systems	Intra-row spacing	Number of seeds per pod		100 seeds weight (g)		Seed yield (t ha^{-1})	
		Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi
Soybean pearl millet	15 cm	4.2	4.4	9.7	8.4	1.4	1.3
	20 cm	4.7	4.8	12.2	10.1	2.0	1,8
	25 cm	5.6	6.0	15.3	13.6	2.3	2.2
	30 cm	6.2	6.5	18.4	15.2	2.7	2.9
LSD ($P \leq 0.05$)		0.3	0.1	2.3	1.4	0.05	0.03

Table 15. Sole crop yields, intercrop yields and total intercrop yields as affected by the main effects of intra-row spacing of pearl millet and cropping systems in a soybean-pearl millet intercrop, at Makurdi and Ibi locations, in year 2012.

Intra-row spacing of pearl millet	Sole crop yields (t ha^{-1})		Soybean		Intercrop yields (t ha^{-1})				Total intercrop yields (t ha^{-1})	
	Pearl millet				Pearl millet		Soybean			
	Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi
15 cm	3.0	3.1	1.4	1.3	3.2	3.3	1.4	1.3	4.6	4.6
20 cm	3.6	3.8	1.6	1.8	3.8	4.0	2.0	1.8	5.8	5.8
25 cm	4.2	4.5	1.9	2.5	4.2	4.8	2.3	2.2	6.5	7.0
30 cm	5.1	5.3	2.3	3.0	4.7	4.9	2.7	2.9	7.4	7.8

Cropping systems										
Soles	3.4	3.9	1.7	2.0	-	-	-	-	-	-
Intercrop	-	-	-	-	2.3	2.5	1.2	1.4	3.5	3.9

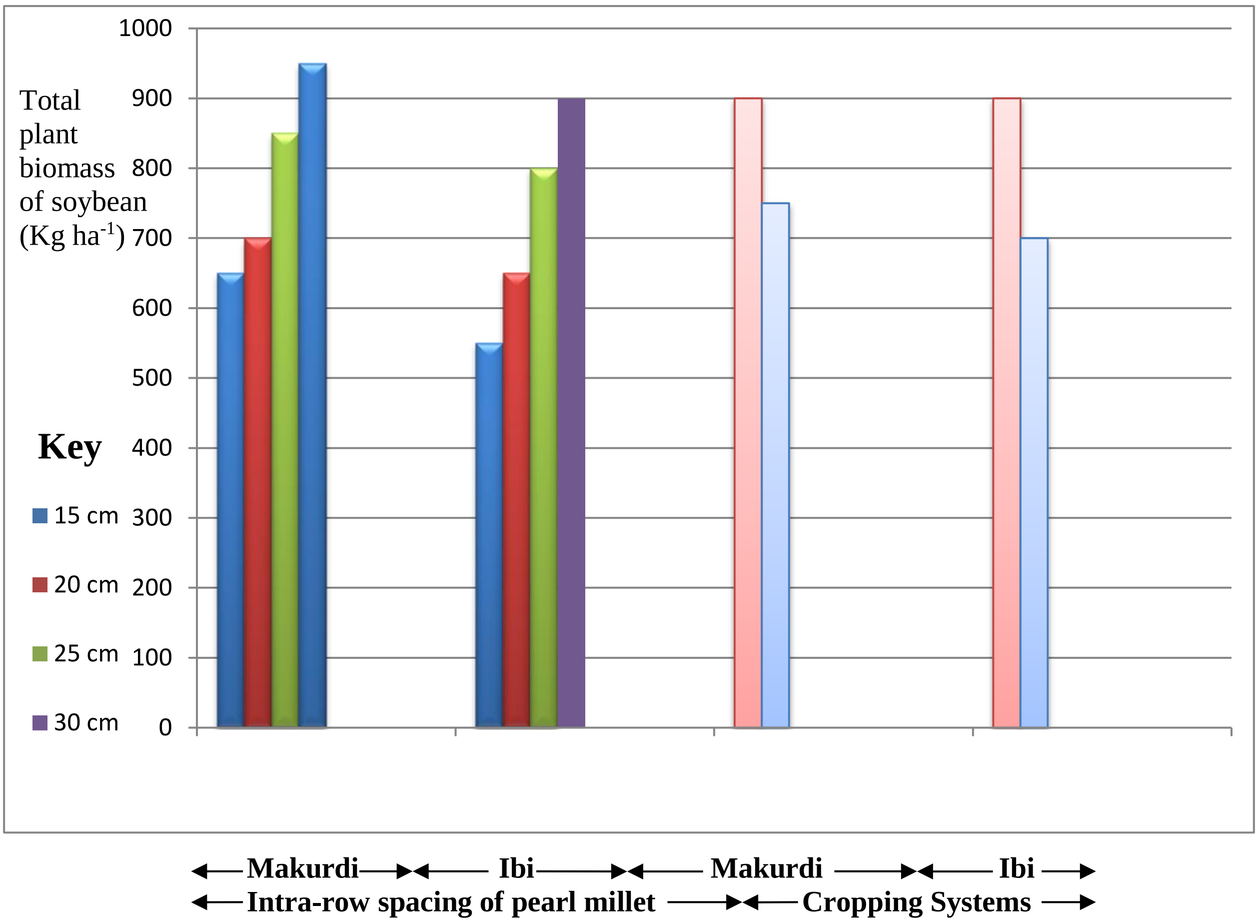

Fig. 2. Main effects of intra-row spacing of pearl millet and cropping systems on total plant biomass (Kg ha^{-1}) of soybean at Makurdi and Ibi locations, in year 2012.

3. 4. 6. Sole crop yields, intercrop yields and total intercrop yields as affected by the main effects of intra-row spacing of pearl millet and cropping systems in a soybean-pearl millet intercrop

Irrespective of the main effects of intra-row spacing of pearl millet and cropping systems employed, the total intercrop yields at both locations were higher than the intercrop and sole crop yields (Table 15). Intercropping pearl millet with soybean reduced the intercrop yields of pearl millet and soybean, as compared to their sole crop yields (Table 15). The reduction in the intercropped yields of the component crops as compared to sole crop yields could be linked to the inter-specific competition and greater demands for growth resources occurring under intercropping compared to sole cropping. This view agreed with those of Olufajo (1992) and Muoneke *et al*. (2007) who reported higher yields in sole cropping over intercropping.

3. 4. 7. Evaluation of yield advantages of intercropping pearl millet and soybean as affected by the interaction of intra-row spacing of pearl millet x cropping systems

Sowing pearl millet into soybean at the intra-row spacing of 30 cm gave the highest land equivalent (LER) values of 2.97 and 2.71 respectively, at Makurdi and Ibi locations. The highest land equivalent ratio (LER) values recorded when pearl millet was sown into soybean at the intra-row spacing of 30 cm, signify that it was most advantageous having both crops in intercrop at the interaction level. This could be due to greater efficiency of resource utilization in intercropping. This view agreed with Hiebsch and McCollum (1987) who reported that LER greater than 1.00, could be due to greater efficiency of resource utilization in intercropping.

This level of treatment also recorded highest percentage (%) land saved, highest land equivalent coefficient (LEC) values, lowest competitive ratio (CR) values and lowest aggressivity (A) values of -0.21 and -0.19 respectively, at Makurdi and Ibi locations (Table 16). At this level of interaction, both crops could be termed to have dominated each other.

Table 16. Evaluation of yield advantages of soybean-pearl millet intercrop as influenced by the interaction of intra –row spacing ×cropping systems at Makurdi and lbi locations, in year 2012.

Cropp - ing systems	Intra-row spacing	Lp		Ls		LER		CR		% Land saved		Aggressivity		LEC	
		Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi	Makurdi	Ibi
Soybean - Pearl millet	15 cm	0.94	0.85	0.82	0.65	1.76	1.50	1.15	1.31	43.2	33.3	0.12	0.20	0.77	0.55
	20 cm	1.12	1.03	1.18	0.90	2.30	1.93	0.95	1.14	56.5	48.2	-0.06	0.13	1.32	0.93
	25 cm	1.24	1.23	1.35	1.10	2.59	2.33	0.92	1.12	61.4	57.1	-0.11	0.13	1.67	1.35
	30 cm	1.38	1.26	1.59	1.45	2.97	2.71	0.87	0.87	66.3	63.1	-0.21	-0.19	2.19	1.83

LER: Land equivalent ratio
Aggressivity (A) where:
A = 0 (component crops are equally competitive)
A = - value (Dominated crop)
A = + value (Dominant crop)
Lp: Partial LER for pearl millet
Ls: Partial LER for soybean
CR: Competitive ratio
LEC: Land equivalent coefficient

4. CONCLUSION

From the results obtained, it can be concluded that the highest intercropped yields of pearl millet and soybean, highest LER, highest percentage (%) land saved, highest LEC, lowest CR and lowest aggressivity were recorded sowing pearl millet into soybean at the intra-row spacing of 30 cm.

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