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Agronomic studies on irrigated soybeans in central Sudan: I. Effect of plant spacing on grain yield and yield components

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ABSTRACT
A field trial was conducted for two consecutive seasons (2008/09 and 2009/10), at the Gezira Research Station, central Sudan, to study the effect of plant spacing on grain yield and yield components of soybean varieties. The experimental design was a split-plot randomized complete block with three replicates. Main plots were four plant spacing (4, 8, 16, and 20 cm). Subplots were four soybean varieties. Data were collected on days to 50% flowering, days to maturity, plant height (cm), height to first pod (cm), grain yield (kg/ha) and fodder yield (kg/ha). The effects of plant spacing and variety were highly significant ($P \leq 0.001$) for grain yield (kg/ha) and fodder yield (kg/ha) in both seasons. The highest grain yield and fodder yield were obtained at 4 cm plant spacing in both seasons. In the first season, average grain yield at 4 cm plant spacing, ranged from 2694 kg/ha for TGx 1905-2E variety to 2011 kg/ha for TGx 1903-1F variety. In the second season, the range of grain yield at 4 cm plant spacing was between 2465 kg/ha for TGx 1905-2E and 1939 kg/ha for TGx 1903-1F variety. Days to 50% flowering, plant height and height to first pod showed significant difference among plant spacing and varieties in both seasons. Decreasing plant spacing has generally resulted in an increase in plant height and height to first pod.

Keywords*: *irrigated soybean, plant spacing, variety, grain yield, yield components

INTRODUCTION
Soybean [*Glycine max* (L.) Merr.] is a legume crop with high protein content (40%) and high-quality oil (20%). The world production of soybean is about 265.8 million ton, accounting for nearly 57.9% of the total global oilseed production (FAO 2011). It provides approximately 60% of vegetable protein and 30% of vegetable oil in the world. The USA, Brazil, Argentina and China are the major soybean-producing countries, accounting for almost 87.8% of world output. The highest soybean average yield is 2890 kg/ha in the USA and the world average yield is 2430 kg/ha. According to Food and Agriculture Organization data, soybean was grown on an average of 1.26 million ha in Africa with an average production of 1.48 million ton in 2007. African countries with the largest area of production were Nigeria, South Africa, Uganda, Malawi, and Zimbabwe. Demand for soybean remains strong and continues to grow because it is used as an ingredient in the formulation of a multitude of food, feed and industrial products. These applications include a wide range of soyfoods, shortening to biodiesel applications for soybean oil, and

feed to vegetable protein substitutes for meat and dairy products for soybean meal/protein. In addition, soybean is a primary source of high-value secondary co-products such as lecithin, vitamins, nutraceuticals and anti-oxidants.

Soybean was first introduced to Sudan in 1910 by the colonial Garden (Shurtleff and Aoyagi 2009). Further introductions in the country were made in 1912. In 1949 soybean was introduced into South-West Sudan to prevent the severe malnutrition that exists among infants, children, pregnant and lactating women. Research on soybean in Sudan started as early as 1930. Soybean varieties were tested at Gezira Research Station, Wad Medani, central Sudan, between 1973 and 1977 (Salih 1977). An intensive research in developing improved soybean varieties suitable for irrigated and rainfed farming began in 1975 by Agricultural Research Corporation (ARC), in collaboration with International Soybean (INTSOY) varietal testing program, USA (Ageeb and Khalifa 1979). International Soybean Variety Evaluation Experiment (ISVEX) trials were conducted at Wad Medani, Abu Naama and Kadugli during 1977-1984. Results of field trials indicated that Sudan has great potential for growing soybeans as irrigated and rainfed crop. Most of the early introduced soybean varieties were sensitive to photo-periods and high temperature resulting in poor vegetative growth, shorter plant height and height to first pod, making mechanical harvesting impossible. Recently, the ongoing soybean research program at the Agricultural Research Corporation (ARC) is currently focusing on developing improved soybeans varieties and suitable agronomic practices (Ibrahim 2011). Soybean varieties introduced from USA and International Institute of Tropical Agriculture (IITA), Nigeria were tested at multi-locations over many years. The results of variety and on-farm trials show that grain yields of over 2.5 ton/ha could be obtained under irrigated conditions.

In 1982 Sudanese-Egyptian Integration Agricultural Scheme initiated a 2-year commercial soybean production project in Blue Nile State, Damazin. The area planted to soybeans is 2100 ha. Although Sudan has great potential for growing soybeans, unavailability of improved varieties, processing and utilization technology, guaranteed markets and lack of technical knowhow were the main constraints hindering commercialization and expansion of soybean production during this period. Domestic demand for soybean oil and meal is currently growing rapidly due to shortage in edible oils and increase and expansion in the poultry industry in Sudan. In addition, soybean is considered one of the most promising crops which could be introduced into rainfed and irrigated areas to increase human nutrition and improve soil fertility. A key factor for successful introduction and promotion of commercial soybean production in irrigated and rainfed farming is implementation of broad-based research to develop improved variety and suitable agronomic practices. Plant spacing is an important factor in determining growth, development and grain yield of soybean. In this study field trial was conducted for two consecutive seasons (2008/09 and 2009/10), at the Gezira Research Station, central Sudan, to study the effect of plant spacing on grain yield and yield components of soybean varieties.

MATERIAL AND METHODS

A field trial was conducted for two consecutive seasons (2008/09 and 2009/10), at the Gezira Research Station, central Sudan (14° 22 to 14° 25 N, 33° 29 to 33° 30 E), to study the effect of plant spacing on grain yield and some agronomic traits of soybean varieties. The experimental design

was a split-plot randomized complete block with three replicates. Main plots were four plant spacing (4, 8, 16, and 20 cm). Subplots were four soybean varieties. The four varieties were selected from the highest yielding entries in 2-yr performance trials conducted before 2008 at the Gezira Research Station. These varieties were TGx 1905-2E; TGx 1448-2E; TGx 1903-1F; and Giza 111. Five-row plots, 6 m in length and 80 cm apart, were used. Sowing date was 8 July 2008 in the first season and 29 June 2009 in the second season. All the cultural practices were carried out manually. Data were collected on days to 50% flowering, days to maturity, plant height (cm), height to first pod (cm) and grain yield (kg/ha) and fodder yield (kg/ha). Grain yield and fodder yield were recorded from the net harvested plot in the 4-m length of the central three ridges excluding one meter at both ends of each ridges.

RESULTS AND DISCUSSION

Grain yield and fodder yield

Optimum plant spacing to obtain appropriate plant population is an important factor for maximizing grain yield potential of soybean. In this study, the effects of plant spacing and variety were highly significant ($P \leq 0.001$) for grain yield (kg/ha) and fodder yield (kg/ha) in both seasons. Plant spacing × variety interaction revealed a non-significant difference for grain yield in both seasons (Table 1 and 2). In contrast to grain yield, plant spacing × variety interaction revealed significant difference ($P \leq 0.05$) for fodder yield in both seasons. The non-significance of plant spacing × variety interaction for grain yield seems to indicate less complication in the response of the varieties to the different plant spacing. In both seasons, the highest grain yield and fodder yield for every variety and average of varieties were obtained at 4 cm plant spacing, followed by 8 cm, 16 cm and 20 cm plant spacing (Table 3, 4 and 5). Among the four varieties, TGx 1905-2E variety showed the highest grain yield (kg/ha) and TGx 1903-1F variety had the lowest grain yield (kg/ha) at 4 cm plant spacing in both season. In the first season, average grain yield at 4 cm plant spacing, ranged from 2694 kg/ha for TGx 1905-2E variety to 2011 kg/ha for TGx 1903-1F variety. In the second season, the range of grain yield at 4 cm plant spacing was between 2465 kg/ha for TGx 1905-2E and 1939 kg/ha for TGx 1903-1F variety. In this study, the grain yield (kg/ha) for all varieties were higher in closer plant spacing than wider plant spacing and this might be due to increase number of plants/unit area. Similar result was also reported by many workers (Ball et al. 2000; El-Douby et al. 2002; Singh et al. 2003; Babalal et al. 2005; Khan 2007). They observed that grain yield increased with increasing plant density up to certain levels.

Yield components

The effects of plant spacing had a significant effect ($P \leq 0.05$) on days to 50% flowering, plant height, and height to first pod in both seasons (Table 1 and 2). Varieties were found to have a highly significant difference ($P \leq 0.001$) for days to 50% flowering, days to maturity, plant height, and height to first pod in both seasons (Table 1 and 2). Non-significant plant spacing × variety interaction was observed in days to 50% flowering, days to maturity, and height in both seasons. Plant spacing × variety interaction for plant height revealed non-significant difference in the first season, whereas in the second season significant difference ($P \leq 0.01$) was observed. In both seasons, the highest plant height and height to first pod for the four varieties were obtained at 4 cm plant spacing, followed by 8 cm, 16 cm and 20 cm plant spacing (Table 3, 4 and 5). Decreasing plant spacing has

generally resulted in an increase in plant height and height to first pod. Increase in plant height might have resulted due to competition for sunlight than those of plants grown in lower population density. These results are in agreement with that of Khan (2007) who reported that plant height increased with increasing plant density in soybean. Soybean varieties are known to vary in days to flowering and maturity (Muhammad et al. 2003; Shegro et al. 2010). In the present study, the slight difference in the days to 50% flowering and maturity for all varieties at the four plant spacing from one season to another could be due to delayed sowing (8 July 2008 and 29 June 2009) and variation in photo period, temperature and rainfall during the two years of field trials.

Table 1: Mean squares of plant spacing, variety and plant spacing × variety interaction for grain yield and yield components of soybean varieties, Gezira Research Station, 2008/09 season

Traits	Plant spacing (df=3)	Variety (df= 3)	Plant spacing × Variety (df= 9)	Error (a) (df = 6)	Error (b) (df = 24)
Days to 50% flowering	4.48^{*}	39.14^{***}	2.97^{ns}	0.35	1.31
Days to maturity	2.47^{ns}	97.47^{***}	3.86^{ns}	0.99	2.06
Plant height (cm)	1371.69^{***}	133.04^{***}	7.86^{ns}	15.12	5.23
Height to first pod (cm)	222.42^{***}	14.19^{***}	1.27^{ns}	1.76	0.67
Grain yield (kg/ha)	2320636.35^{***}	527336.58^{***}	13083.69^{ns}	20514.73	7743.29
Fodder yield (kg/ha)	3901666.63^{***}	728672.19^{***}	32563.84^{*}	10110.01	11221.74

*; *** and ^{ns} denote the level of significance at 0.05 and 0.001 and non-significant, respectively

Table 2: Mean squares of plant spacing, variety and plant spacing × variety interaction for grain yield and yield components of soybean varieties, Gezira Research Station, 2009/10 season

Traits	Plant spacing (df=3)	Variety (df= 3)	Plant spacing × Variety (df= 9)	Error (a) (df = 6)	Error (b) (df = 24)
Days to 50% flowering	5.53^{**}	47.19^{***}	0.74^{ns}	1.02	0.96
Days to maturity	6.78^{**}	53.00^{***}	2.67^{ns}	1.80	1.21
Plant height (cm)	520.50^{***}	36.43^{***}	20.53^{**}	5.00	5.51
Height to first pod (cm)	145.38^{***}	3.61^{***}	0.44^{ns}	0.19	0.49
Grain yield (kg/ha)	2011095.41^{***}	235969.19^{***}	19828.13^{ns}	13861.62	8271.46
Fodder yield (kg/ha)	4656469.30^{***}	381010.30^{***}	96408.58^{**}	32647.92	19807.88

; * and ^{ns} denote the level of significance at 0.01 and 0.001 and non-significant, respectively

Table 3: Effect of four plant spacing on grain yield and yield components of four soybean varieties, Gezira Research Station, 2008/09 season

Variety	Plant spacing	Days to 50% flowering	Days to maturity	Plant height (cm)	Height to first pod (cm)	Grain yield (kg/ha)	Fodder yield (kg/ha)
TGx 1905-2E	4 cm	44	115	74.4	17.5	2694	3195
	8 cm	42	116	65.9	11.4	2010	2506
	16 cm	44	113	55.4	8.6	1508	1963
	20 cm	45	113	46.3	6.7	1495	1859
TGx 1448-2E	4 cm	45	116	76.7	18.6	2304	3126
	8 cm	43	114	66.5	11.3	1814	2621
	16 cm	46	116	58.4	9.2	1541	2339
	20 cm	44	115	53.1	8.6	1331	1853
Giza 111	4 cm	42	115	69.6	15.2	2192	2978
	8 cm	42	116	56.6	8.9	1778	2418
	16 cm	41	115	50.9	7.7	1508	1963
	20 cm	40	116	45.2	7.1	1245	1418
TGx 1903-1F	4 cm	41	111	71.8	17.9	2011	2567
	8 cm	40	110	63.9	12.5	1510	2099
	16 cm	41	108	54.2	9.3	1267	1635
	20 cm	41	109	49.3	8.2	1057	1430
C.V.%		2.8	1.3	3.8	7.3	5.1	4.7
S.E.±		0.66	0.83	1.3	0.47	50.8	61.2

***Table 4*:** Effect of four plant spacing on grain yield and yield components of four soybean varieties, Gezira Research Station, 2009/10 season

Variety	Plant spacing	Days to 50% flowering	Days to maturity	Plant height (cm)	Height to first pod (cm)	Grain yield (kg/ha)	Fodder yield (kg/ha)
TGx 1905-2E	4 cm	49	120	64.7	16.3	2465	3185
	8 cm	47	120	59.7	11.5	1750	2603
	16 cm	48	121	54.1	9.6	1480	2093
	20 cm	47	118	47.6	7.9	1377	2221
TGx 1448-2E	4 cm	48	120	65.7	17.3	2232	3249
	8 cm	47	117	57.9	11.5	1527	2346
	16 cm	47	118	57.6	10.3	1345	2133
	20 cm	46	118	55.5	9.7	1244	1793
Giza 111	4 cm	49	119	67.3	15.8	1954	3081
	8 cm	47	118	57.5	10.4	1472	2271
	16 cm	46	118	49.8	9.9	1279	1719
	20 cm	46	117	46.9	8.1	1189	1551
TGx 1903-1F	4 cm	44	115	62.4	17.2	1939	2989
	8 cm	43	113	58.6	11.4	1525	2594
	16 cm	44	115	52.7	10.3	1258	1589
	20 cm	43	116	48.7	9.3	1117	1501
C.V.%		2.1	0.93	4.1	6.1	5.9	6.1
S.E.±		0.57	0.64	1.4	0.41	52.5	81.3

***Table 5*:** Effect of plant spacing on grain yield and yield components of soybeans*, Gezira Research Station, 2008/09 and 2009/10 seasons

Plant spacing	Days to 50% flowering	Days to maturity	Plant height (cm)	Height to first pod (cm)	Grain yield (kg/ha)	Fodder yield (kg/ha)
2008/09 season						
4 cm	43	114	73.1	17.3	2300	2967
8 cm	42	114	63.2	11.0	1778	2411
16 cm	43	113	54.8	8.7	1500	1998
20 cm	43	113	48.5	7.7	1282	1640
2009/10 season						
4 cm	47	118	65.0	16.7	2148	3126
8 cm	46	117	58.4	11.2	1569	2454
16 cm	46	118	53.6	10.0	1341	1883
20 cm	45	117	49.7	8.8	1232	1767

*Average of four varieties (TGx 1905-2E; TGx 1448-2E; TGx 1903-1F; and Giza 111)

CONCLUSION

Research findings suggest that plant spacing of 4 cm with 80 cm ridge result in increased irrigated soybean yields. In addition to increased grain yield, narrow plant spacing help assure adequate plant height, height to first pod, early canopy closure, reduce weed problems at maturity and generally result in increased profits.

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