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PHYSIOLOGICAL RESPONSE OF AUTUMN PLANTED SUGARCANE TO SOIL MOISTURE DEPLETION AND PLANTING GEOMETRY ON DIFFERENT SOILS UNDER ARID CONDITIONS

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Abstract

A field experiment was conducted on autumn planted sugarcane cv. HSF 240 at two locations, i.e., Research Area at Rakh Bibi Campus Gomal University, Dara Ismail Khan on Silty clay soil and Main Line Lower Land Reclamation Research Station, Chak No 37 TDA (Thal Development Authority) Bhakkar, Pakistan on sandy loam soil during 2003-04 and 2004-05. The experiment was laid out according to a randomized complete block design (RCBD) with a split plot arrangement having four replications. There were four available soil moisture depletion levels (ASMDL) including $ASMDL_1$ -20%, $ASMDL_2$ -40%, $ASMDL_3$ - 60% and $ASMDL_4$ -80%, which were kept in main plots and four planting patterns viz. G_1 -60 cm, G_2 -75 cm spaced single row planting patterns and G_3 -30/90, G_4 -30/120 cm spaced paired row strip planting pattern, assigned to the sub plots having net subplot size of 24 m^2. Analysis of pooled data of both locations showed that Leaf area index (LAI), Leaf area duration (LAD), Crop growth rate (CGR) and Net assimilation rate (NAR) were significantly affected by ASMDL and were maximum at 40% ASMD level followed by 60%, 20% and the minimum at 80% ASMD level during both years. Whereas LAD, CGR and NAR were also significantly affected and were maximum in 30/90cm spaced paired row strip planting pattern followed by 75 cm and 60cm and minimum in 30/120cm spaced paired row strip planting pattern during both years. Treatments interactive effects of ASMD levels and planting patterns on LAD, CGR and NAR were significantly different except LAI and were maximum in 40% ASMDL x 30/90cm spaced paired row strip planting pattern and minimum in 80% ASMDL x 30/120 cm spaced paired row strip planting pattern during both years. Therefore it was concluded that under arid conditions on Silty clay and sandy loam soils sugar cane crop gave best physiological performance by irrigation at 40% ASMD level and sowing in 30/90 cm spaced paired row strip planting pattern.

Introduction

A C_4 plant, Sugarcane (*Saccharum officinarum* L.) is a tropical crop of long duration, producing huge biomass requires abundant water. The increasing urban growth and environmental concerns are limiting the amount of water for agricultural use. In Pakistan, especially in Punjab and NWFP, the larger sugarcane area lies in low rain fall region and its successful growth needs artificial irrigation. Water is not always available in desired quantity during the long growth period of crop and occurrence of drought conditions results in considerable loss in yield.

It has been seen that water stress and row spacing not only reduces leaf area but also drastically reduces cane yield. In Pakistan due to poor soil moisture management and improper planting geometry, the average cane yield is much lower than the genetic potential of our existing sugarcane cultivars. Therefore, resource conservation technology and site-specific strategies are required to make best use of limited water by the sugar cane crop, with the adoption of deficit irrigation practices as suggested by English and Raja (1996). Ramesh (2000), Singh (2002), Inman-Bamber (2004) and Wiedenfeld and Enciso (2008) reported that drought conditions significantly reduce the total dry-matter production (TDMP).

It is necessary to grow plants in the field with such geometry that there is a least intraspecific competition for essential growth factors in order to capture the full benefits of land and environmental resources. Gill (1995) stated that a significant effect was observed on crop growth rate under various planting systems. Afghan (1996), Bashir (1997) and Ali (1999) reported that planting patterns had a significant effect on NAR. El-Geddawy *et al*., (2002) obtained significantly higher cane yield with the row spacing of 100 cm than 120 or 140 cm apart rows in the 1^{st} ratoon crop. Whereas Singh *et al.* (2006) recorded significantly highest cane yield (62.9 tons ha^{-1}) at 45 cm spacing followed by 60 and 75 cm in ratoon crop.

The economic yield is determined by the capability of plant to produce photosynthates and their partitioning to economic yield. Proper orientation of plants in the field and management of soil moisture for optimum utilization of plant nutrients plays a significant role in the proper development and functioning of vital plant organs. Research conducted in Pakistan on these aspects of sugarcane crop have been confined to spring planted crop as a whole and little attention was paid to autumn planted sugarcane crop. Therefore, there is a dire need to formulate some concrete information on soil moisture management and planting geometry in autumn sugarcane crop on silty clay and sandy loam soils under the edaphic and agro-climatic conditions of two contiguous sugarcane growing areas of Pakistan viz. Dara Ismail Khan, NWFP and Bhakkar, Punjab, Pakistan situated at 031^{o}N and 071^{o}E.

Materials and Methods

The study was conducted at Rakh Bibi Campus, Gomal University Dera Ismail Khan and Main Line Lower Land Reclamation Research Station, Chak No 37 TDA (Thal Development Authority) Bhakkar during 2003-2004 and 2004-2005 on silty clay and sandy loam soils respectively. The agro-climatic conditions of the experimental sites are detailed in Table 1 and Fig. 1. The depletion levels of soil moisture under study were $ASMDL_1$ -20%, $ASMDL_2$ -40%, $ASMDL_3$ -60% and $ASMDL_4$, -80% (Table 2). Planting patterns comprised of G_1 -60, G_2 -75 cm spaced single row planting pattern and G_3 -30/90, G_4 -30/120 cm spaced paired row strip planting pattern. The experiment was laid out in a randomized complete block design (RCBD) with a split plot arrangement keeping the available soil moisture depletion levels in main plots and planting patterns in sub-plots. The net plot size was 24 m^2 with four replications. Each year the crop was planted during the 1st week of September and harvested in first week of November next year. The seed rate used was 70,000 double-budded setts ha^{-1}. Cane cultivar 'HSF 240' was used as a test variety. The fertilizers were applied @ 200-200-100 NPK kg $ha^{-1.}$ All the phosphorus, potassium and 1/4 of total nitrogen was applied at the time of planting while, remaining nitrogen was applied in two equal split doses each at completion of germination and at the start of cane formation. The crop was kept weed free by hand weeding. All other agronomic practices were kept normal and uniform for all the treatments. The irrigation requirements of the crop on the basis of ASMD levels were calculated as under:

Table 1. Physico-chemical characteristics of soil of experimental sites.

Soil texture	Unit	Dera Ismail Khan		Bhakkar	
		2003-04	2004-05	2003-04	2004-05
		Silty clay loam	Silty clay loam	Sandy loam	Sandy loam
N	%	0.03	0.04	0.044	0.049
P	Ppm	8	8.5	3.55	4.75
K	Ppm	80	92.5	55	60
Field capacity	% by volume	23.85	24.24	15.71	17.97
Bulk density	g/cm^{-3}	1.3	1.35	1.4	1.38
Permanent wilting point	% by volume	11.54	11.852	7.14	8.33
pH (1:5)	14-Jan	8	8.1	7.7	8
Ec	dSm^{-1}	4.6	5.2	1	1

Source: Analysis by the soil and water testing laboratory Directorate of Land Reclamation Punjab, Lahore Pakistan

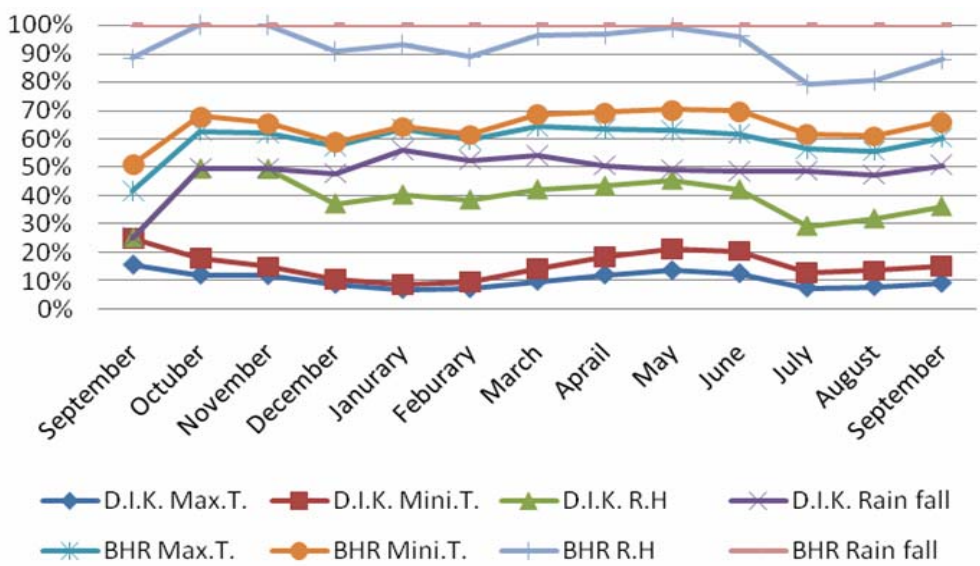

Fig 1. Mean metrological data of 2003-04 and 2004-05 of Dera Ismail Khan and Bhakkar.
D.I.K = Dera Ismail Khan, BKR = Bhakkar, Max. T. = Maximum temperature °C, Mini. T. = Minimum temperature °C, R.H. = Relative humidity %

Table 2. Water received by the crop during 2003–2004 and 2004–2005.

Available soil moisture depletion levels (ASMDL)	Total number of irrigations applied	Depth of irrigation (mm)	Irrigation + rain fall (mm)	Total number of irrigations applied	Depth of irrigation (mm)	Irrigation + rainfall (mm)
	Dera Ismail Khan 2003 - 2004			Bhakkar 2003 - 2004		
ASMDL1=20%	55	36.93	2359.15	93	25.71	2820.76
ASMDL2=40%,	16	73.86	1509.76	28	51.42	1869.49
ASMDL3=60%	15	110.8	1990	22	77.13	2126.59
ASMDL4=80%	12	147.72	2100.64	16	102.84	2075.17
	Total rainfall received = 328.00 mm			Total rainfall received = 373.23mm		
	Dera Ismail Khan 2004-2005			Bhakkar 2004-2005		
ASMDL1=20%	50	37.17	2442.5	87	28.92	2896.28
ASMDL2=40%,	14	74.33	1624.62	25	57.84	1826.24
ASMDL3=60%	13	111.5	2033.5	20	86.76	2115.44
ASMDL4=80%	11	148.65	2219.15	14	115.68	1999.76
	Total Rainfall received = 584.00mm			Total Rainfall received =380.24mm		

Soil Sampling and determination of moisture content: Gravimetric procedure of direct method of soil water measurement was applied to determine the water contents in the soil. Soil sampling for soil moisture measurement was carried out regularly on alternate days keeping in view the weather conditions from first week of May to last week of September, one month before the time of crop harvest each year at both locations. Composite soil samples at the depth intervals of 30 cm up to 150cm were taken from randomly located sites in each plot for moisture determination, as the maximum moisture extraction depth of root zone of sugar cane crop was taken as 150 cm, with the exception of 15 cm surface layer. Available soil moisture contents by volume in the soil at different depletion levels were computed as outlined by Penman, (1970) and French & Legg (1979):

$$ASMDL = \frac{(Fc - Oi)100}{(Fc - Pwp)}$$

where,
ASMDL= Available soil moisture depletion level
Pwp = Permanent wilting point
Oi = Soil moisture content before irrigation in percent by volume

Available soil moisture contents by volume in the soil at $ASMDL_{1,}$ $ASMDL_{2,}$ $ASMDL_3$ and $ASMDL_{4,}$ were 21.38, 18.93, 16.46 and 14%, respectively at Dera Ismail Khan and 13.99, 12.28, 10.57 and 8.85%, respectively at Bhakkar during 2003-04 and 21.76, 19.28, 16.81 and 14.33%, respectively at Dera Ismail Khan and 16.04, 14.11, 12.19 and 10.26%, respectively at Bhakkar during 2004-05. Irrigation was applied to respective plots as soon as the desired available soil moisture depletion level reached in the soil of crop root zone.

Irrigation: Depth of irrigation for each ASMD level was predetermined by adopting the direct measurement or field sampling method of crop water requirement as reported by Rafiq (2001):

$$Dw = \frac{(Drz\ (Fc - Oi)}{100}$$

here,
Dw = Depth of water to be applied in (mm)
Drz = Depth of root zone (mm)
Fc = Field capacity in percent by volume

Discharge of water applied to each treatment was determined with the help of a cut throat flume (3' x 8"). The time required to supply the required depth of irrigation water to each plot was calculated according to Rafiq (1970) with the following equation (Rafiq, 2001):

$$t = \frac{d \times a}{q}$$

where,
t = time in minutes;
d = depth of water in cm
a = area in m^2
q = discharge of irrigation water in liter/sec

The leaf area index (LAI) was determined by using the method of Watson (1974), crop growth rate (CGR), leaf area duration (LAD) and net assimilation rate (NAR) were calculated by the formulae of Hunt (1978). The data were analyzed statistically using Fisher's analysis of variance technique and subsequently significant means were separated by LSD test (Steel & Torrie, 1984).

Results and Discussion

Crop growth rate (CGR): The pooled data of Dera Ismail Khan and Bhakkar, under two differential conditions (Fig. 1) regarding crop growth rate (CGR) as presented in Table 3 revealed that CGR was significantly different under different ASMD levels during both years. The highest CGR of 8.75 g m^{-2} day^{-1} was recorded at 40% ASMD level followed by 60, 20 and lowest 6.95 g m^{-2} day^{-1} at 80% ASMD level during 2003-04. The increase in CGR was 20.23, 14.88, 10.51% at 40, 60 and 20% ASMD level, respectively during 2003-04. All the ASMD levels also d same trend during 2004-05. Ramesh (2000), Singh (2002), Inman-Bamber (2004) and Wiedenfeld *et al.*, (2008) found that crop growth rate of various cane varieties was reduced at moisture stress. The CGR was significantly affected by different planting patterns during both years. The CGR was highest 8.58 g m^{-2} day^{-1} in 30/90 cm spaced paired row strip planting pattern followed by 75 and 60 cm spaced single row planting pattern, while lowest (6.99 g m^{-2} day^{-1}) CGR during 2003-04 was evidenced in 30/120 cm spaced paired row strip planting pattern. The increase of 18.53, 13.81, 11.74% in CGR was recorded in 30/90, 75 and 60 cm spaced planting pattern, respectively as compared to 30/120 cm spaced paired row strip planting pattern (Table 3). The similar trend of CGR was also recorded in all planting patterns during 2004–05. The interactive effects of ASMD levels and planting patterns on CGR were significantly different during both years. The highest CGR (9.38g m^{-2} day^{-}1) was recorded in 40% ASMDL x 30/90 cm spaced paired row strip planting pattern followed by 60% ASMDL x 30/90 cm spaced paired row strip planting pattern, while the lowest CGR (6.21 g m^{-2} day^{-1}) was recorded in 80% ASMDL x 30/120cm planting pattern during 2003-04. The increase of 33.80 % in CGR was noted during 2003-04 in 40% ASMDL x 30/90 cm planting pattern as compared to 80% ASMDL x 30/120 cm planting pattern.

Leaf area index (LAI): The data of both locations regarding leaf area index (LAI) (Table 3) depicted that LAI was significantly different under different ASMD levels during both years. The LAI was the maximum (6.21) at 40% ASMD level followed by 60 and 20%, whereas it was minimum (5.57) at 80% ASMD level during 2003-04. It was noticed that an increase of 35.78, 26.43 and 17.04% was recorded in 40, 60, and 20% ASMD level, respectively than 80% ASMD level. Naik *et al.*, (1993) also reported reduction of 23.8 to 47.2% in leaf area at moderate and severe water stresses, respectively in different cane varieties. The LAI was not significantly affected by different planting patterns. Alonso & Scandaliaris (1988) reported that LAI was not influenced by spacing in none of the crops in their studies. Interactive effects of ASMD levels and planting patterns on LAI were also statistically similar.

Table 3. Physiological response of autumn planted sugarcane to available moisture depletion levels (ASMDL) and planting geometry on different soils under arid conditions of Pakistan.

Treatments	Crop growth rate (g m^{-2} day^{-1})		Leaf area index		Leaf area duration (days)		Net assimilation rate (g m^{-2} day^{-1})	
	2003-2004	2004-2005	2003-2004	2004-2005	2003-2004	2004-2005	2003-2004	2004-2005
(A)- Available soil moisture depletion levels (ASMDL)								
ASMDL $_1$ = 20%	7.80 c	8.61 c	5.70 c	5.98 c	690.38 c	782.27 c	1.50 c	1.64 c
ASMDL $_2$ = 40%	8.75 a	10.08a	6.21 a	6.52 a	789.17 a	900.64 a	1.79 a	1.93 a
ASMDL $_3$ = 60%	8.20 b	9.46 b	6.00 b	6.16 b	762.13 b	830.45 b	1.57 b	1.75 b
ASMDL $_4$ = 80%	6.95 d	7.44 d	5.57 d	5.80 d	658.87 d	736.01 d	1.46 d	1.55 d
LSD	0.51	0.51	0.51	0.51	15.17	15.17	0.16	0.16
(B)-Planting patterns (G)								
G_1 = 60 cm	7.92 c	8.84 c	5.85 a	6.06 a	701.40 c	778.48 c	1.42 c	1.65 c
G_2 = 75 cm	8.11 b	9.15 b	6.00 a	6.32 a	740.92 b	845.22 b	1.69 b	1.77 b
G_3 = 30/90cm	8.58 a	9.74 a	6.15 a	6.43 a	776.74 a	876.45 a	1.83 a	1.94 a
G_4= 30/120cm	6.99 d	7.66 d	5.77 a	5.95 a	681.49 d	749.23 d	1.29 d	1.51 d
LSD	0.51	0.51	0.51	0.51	15.17	15.17	0.16	0.16
(C)-F x G								
$ASMDL_1$ x G_1	7.80cdef	8.65cde	5.69 a	5.95a	663.74gh	749.55 ij	1.45 efgh	1.51de
$ASMDL_1$ x G_2	8.02bcde	8.90 cd	5.89 a	6.22a	718.38de	819.42efg	1.81 abcd	1.82abcd
$ASMDL_1$ x G_3	8.56 abc	9.58 bc	6.01 a	6.29a	738.98cd	836.75 de	1.84 abcd	1.95 abc
$ASMDL_1$ x G_4	6.82 fg	7.30 fg	5.59 a	5.85a	640.43hi	723.35 jk	1.31 gh	1.51 de
ASMDL $_2$ x G_1	8.91 ab	10.12ab	6.10 a	6.37a	761.16 c	859.02 d	1.72 abcde	1.92 abc
ASMDL $_2$ x G_2	9.08 a	10.51ab	6.26 a	6.66a	803.68 b	938.55 b	1.91 ab	1.99 a
ASMDL $_2$ x G_3	9.38 a	11.09 a	6.43 a	6.81a	847.41 a	980.92 a	1.93 a	2.02 a
ASMDL $_2$ x G_4	7.61cdef	8.60cde	6.03 a	6.24a	744.43cd	824.08 ef	1.58 cdefg	1.80abcd
$ASMDL_3$ x G_1	8.39abcd	9.58 bc	6.01 a	6.24a	740.28cd	800.16 fg	1.56 defgh	1.80abcd
$ASMDL_3$ x G_2	8.62 abc	9.92 b	6.12 a	6.15a	767.45 c	857.87 d	1.84 abcd	1.95 abc
$ASMDL_3$ x G_3	7.32 ef	10.16ab	6.33 a	6.37a	821.06ab	896.16 c	1.89 abc	1.98 ab
$ASMDL_3$ x G_4	7.32 ef	8.19def	5.93 a	6.02a	719.74de	767.61 hi	1.40 fgh	1.66 cde
ASMDL $_4$ x G_1	6.96 fg	7.41 fg	5.93 a	5.87a	640.43hi	705.17 kl	1.34 fgh	1.59 de
ASMDL $_4$ x G_2	7.11 efg	7.67 ef	5.74 a	6.01a	674.19fg	765.05 hi	1.60bcdefg	1.73abcde
ASMDL $_4$ x G_3	7.50 def	8.12def	5.84 a	6.12a	699.50ef	791.97gh	1.65abcdef	1.81 abcd
ASMDL $_4$ x G_4	6.21 g	6.56 g	5.51 a	5.78a	621.34 i	681.87 l	1.25 h	1.48 e
LSD	1.01	1.01	1.01	1.01	30.34	30.34	0.31	0.31

Means followed the same letter in a column do not differ significantly at 5 % level of probability

Leaf area duration (LAD): The data on leaf area duration (LAD) revealed that it was significantly different under different ASMD levels during both years (Table 3). Leaf area duration was the longest (789.17 days) at 40% ASMD level followed by 60 and 20%, while it was the shortest (658.87days) at 80% ASMD level during 2003-04. The increase in LAD was 16.51, 13.55, and 4.56 in 40, 60, and 20% ASMD levels, respectively than 80% ASMD level during 2003-04. Similar results were exhibited during 2004-05. The LAD was significantly affected by different planting patterns during both years. It was the longest (776.74 days) in 30/90 cm spaced paired row strip planting pattern followed by 75 and 60 cm spaced single row planting pattern. The shortest (658.87 days) LAD was evaluated in 30/120 cm spaced paired row strip planting pattern during 2003-04 (Table 3). An increase of 12.26, 8.02 and 2.84% in LAD was recorded in 30/90, 75 and 60 cm spaced planting patterns, respectively than 30/120 cm spaced planting pattern during 2003-04. Similar trend was deciphered during 2004-05. For the interaction, significant effects of ASMD levels and planting patterns on LAD were depicted during both years. The LAD was the longest (847.41days) in 40% ASMDL x 30/90 cm spaced paired row strip planting pattern followed by 40% ASMDL x 75cm spaced single row strip planting pattern, while the shortest (621.34 days) in 80% ASMDL x 30/120 cm spaced paired row strip planting pattern during 2003-04. The increase in LAD was 26.68% in 40% ASMDL x 30/90cm spaced paired row strip planting pattern as against 80% ASMDL x 30/120 cm spaced paired row strip planting pattern. The similar trend was manifested during 2004– 05.

Net assimilation rate (NAR): The pooled data regarding net assimilation rate of sugarcane at Dera Ismail Khan and Bhakkar as shown in Table 3 revealed that NAR was significantly different under different ASMD levels and planting patterns during both years. The highest (1.79 g m^{-2} day^{-1}) NAR was recorded at 40% ASMD level followed by 60% and 20%, respectively. Whereas, the lowest (1.46 g m^{-2} day^{-1}) NAR was observed at 80% ASMD level. The increase in NAR was 21.79, 10.83 and 6.67% at 40, 60 and 20% ASMD level, respectively than 80% ASMD level. Similar pattern of NAR was recorded during 2004-05. The NAR was significantly affected by different planting patterns during both years. It was highest (1.83 g m^{-2} day^{-1}) in 30/90 cm spaced paired row strip planting pattern followed by 75 and 60 cm spaced single row planting pattern, respectively and lowest (1.29 g m^{-2} day^{-1}) in 30/120 cm spaced paired row strip planting pattern during 2003-04. The increase in NAR to the extent of 29.51, 23.67, 9.15% was recorded in 30/90, 75 and 60 cm planting pattern, respectively than 30/120 cm spaced planting pattern. These results are in line with those of Gill (1995), Afghan (1996), Bashir (1997) and Ali (1999), who reported that planting patterns had a significant impact on NAR. Interactive effects of ASMD levels and planting patterns on NAR were also significantly different during both years. The maximum NAR (1.93 g m^{-2} day^{-1}) was recorded in 40% ASMDL x 30/90 cm planting pattern followed by 40% ASMDL x 75 cm planting pattern. While, the minimum (1.25 g m^{-2} day^{-1}) NAR was computed in 80% ASMDL x 30/120 cm planting pattern during 2003-04. A 35.23% increase in 40% ASMDL x 30/90 cm planting pattern was recorded as compared to 80% ASMDL x 30/120 cm row strip planting pattern during 2003-04. Similar trend in data were recorded during the subsequent year of studies i.e., 2004-05. The increase in NAR to the tune of 40% in ASMDL x 30/90 cm planting pattern may be due to complementary effect of increased nutrient availability and more available space for air circulation and light interception which increased photosynthetic efficiency and improved CGR, LAI, LAD and ultimately NAR, during either year of studies.

Conclusions

It is concluded that under arid conditions on Silty clay and sandy loam soils maximum CGR, LAI, LAD and NAR is obtained from irrigation at 40% ASMD level and 30/90 cm spaced paired row strip planting pattern. It was also noted that either excess or deficiency of irrigation water was equally harmful for sugarcane crop. It was also noted that sowing of sugarcane in 30/120 cm spaced paired row strip planting pattern, suitable for intercropping, it was not suitable for sole crop. The planting pattern of 30/90 cm spaced paired row strip planting had advantages over other planting patterns as it facilitates interculture without damaging the roots and effects 50% reduction in the number of inter-strip ditches/furrows, thus conserving irrigation water and saving almost 50% in labor and time required for earthing up.

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