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Effect of Plant Density and Soil Fertility on Pearl Millet Under Drought and Good Rainfall Situations

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Abstract Pearl millet (var. BJ 104) was grown in a drought and a good rainfall year with four plant densities (30,45,60 and 75 cm rows providing about 2.17 x 10^5 to 0.91 x 10^5 plants ha^{-1}) under low (20 kg ha^{-1} each of N and P_2O_5) and improved (80 kg ha^{-1} each of N and P_2O_5) soil fertility conditions. Crop performance, water use and nutrient uptake were better due to more favourable soil moisture conditions during the good, as compared to the drought year. However, in both the years increased row spacing progressively increased the height, tiller number, leaf area, dry matter, grain yield and N and P uptake $plant^{-1}$. Water use increased with increased row spacing in a good rainfall year but was unaffected by plant population in the drought year. The improved performance of individual plants could possibly be attributed to larger availabilities of moisture and nutrients under wider row spacing. However, a decrease in plant population below ca. 1.45 x 10^5 plants ha^{-1} or 45 cm row spacing reduced the dry matter production, grain yield, leaf area index, water use efficiency and uptake of N and P per unit of area in both the years. It seems that improved performance of individual plants under wider spacing could not compensate for the losses accrued due to a decrease in plant population per unit area beyond a point. Improved soil fertility imparted significant beneficial effects, per plant or per unit area, in both the years. However, the magnitude of this effect was less in the drought year.

Key words Pearl millet, Soil fertility, Drought, Performance, Nutrient uptake, Water use

Among other constraints of arid and semi-arid regions, frequent droughts of varying intensity and timing (Lahiri 1990) and poor fertility of sandy soils often restrict the growth and yield of the rainfed pearl millet crop, which is grown extensively in many parts of West Africa and also in Rajasthan, India. Under such a situation, a reduction in plant population may reduce competition for soil moisture and nutrients and may thus stabilise the yield. Reduction of maize yield under high population and N deficit (Keating *et al.* 1990), on one hand, and reduction of sorghum yield under high density and limitation of water (Rees 1986), on the other, support this contention. But a number of studies (Gautam 1970, 1975, Umrani *et al.* 1983) undertaken on pearl millet in India suggest that a row spacing of 45 to 50 cm is optimum for this crop. Again, Bationo *et al.* (1990) found in Niger that wide spacing (low plant density) did not significantly increase the yield of pearl millet in the dry year and did not help in fully realising the potential of the land in good rainfall years. They further noted that at high crop density addition of fertilizer N carried little additional negative risk in a drought year and under moderate and excellent rainfall greatly increased the crop yield. It has also been reported (Lahiri 1990) that improved soil fertility can significantly alleviate the adverse effects of intermittent droughts on the growth and yield of pearl millet.

In view of the aforesaid contradictions, the present study was undertaken to ascertain the optimum plant density and soil fertility conditions for the pearl millet crop under poor and good rainfall situations.

Materials and Methods

A hybrid (var. BJ 104) pearl millet (*Pennisetum americanum* (L) Leeke) was grown in field plots (net harvesed area 4.0 x 3.0 m) on loamysand soil of Central Research Farm of CAZRI Jodhpur (annual average rainfall 360 mm) under four plant densities (30,45,60 and 75 cm row spacings with 15

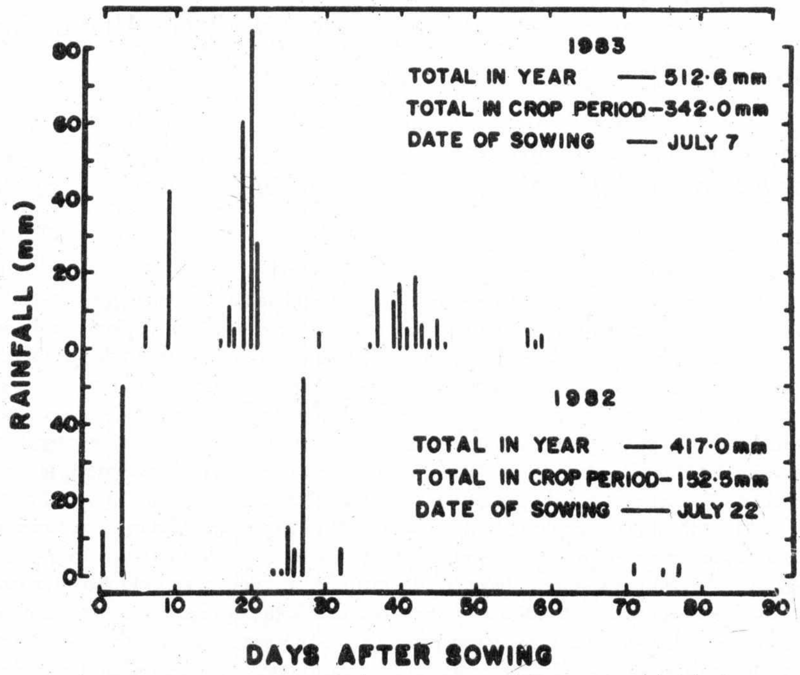

Fig 1 Rainfall pattern during the cropping period of 1982 (drought year) and 1983 (good rainfall year)

cm distance between plants in a row, providing about 2.17 x 10^5, 1.45 x 10^5, 1.09 x 10^5 and 0.91 x 10^5 plants ha^{-1} respectively) and two soil fertility conditions improved soil fertility IF (80 kg ha^{-1} each of N and P_2O_5) and low soil fertility LF (20 kg ha^{-1} each of N and P_2O_5). The experiment was conducted in 1982 (date of sowing July 22) and 1983 (date of sowing July 7) adopting a randomised block design with five replications under each treatment. The former was a drought year and the later had favourable rainfall (details given under results and discussion). Soil analysis (Jackson 1973) showed organic carbon and total N contents of 0.28% and 0.033% respectively. The available N, P and K contents were 80, 12 and 120 kg ha^{-1} respectively. The pH of the soil was 8.1.

Soil moisture upto a meter depth was gravimetrically determined from sowing to harvest at 10 days intervals, and the consumptive use of moisture was determined adopting water balance equation. The soil held 10 and 3% moisture at FC (-0.03 MPa) and PWP (-1.5 MPa) respectively. Observations were recorded on diverse parameters of plant performance (5 observational plants in each replicate), as well as on leaf area (LI-COR model LI-3000), final dry matter and grain yield per plot. Water use efficieny (WUE) was determined in terms of both grain yield and dry matter production per unit of water used. Representative samples of shoot and grain were analysed for ascertaining N and P uptakes (Jackson, *loc. cit.*). Significance of data were assessed through analyses of variance wherever necessary.

Results and Discussion

Rainfall and soil moisture : Although the total rainfall during 1982 was more than the annual average (360 mm) of the region, crops were subjected to acute drought due to meagre precipitation during the cropping period (152.5 mm) and two prolonged dry spells extending from 3 to 23 days after sowing (DAS) and again from 32 DAS to maturity (Fig 1). In contrast, during the following year (1983), rainfall was not only well distributed but was higher (512.3 mm) than the previous year and the rainfall during the cropping period (342.0 mm) was more than twice of that received during the previous year.

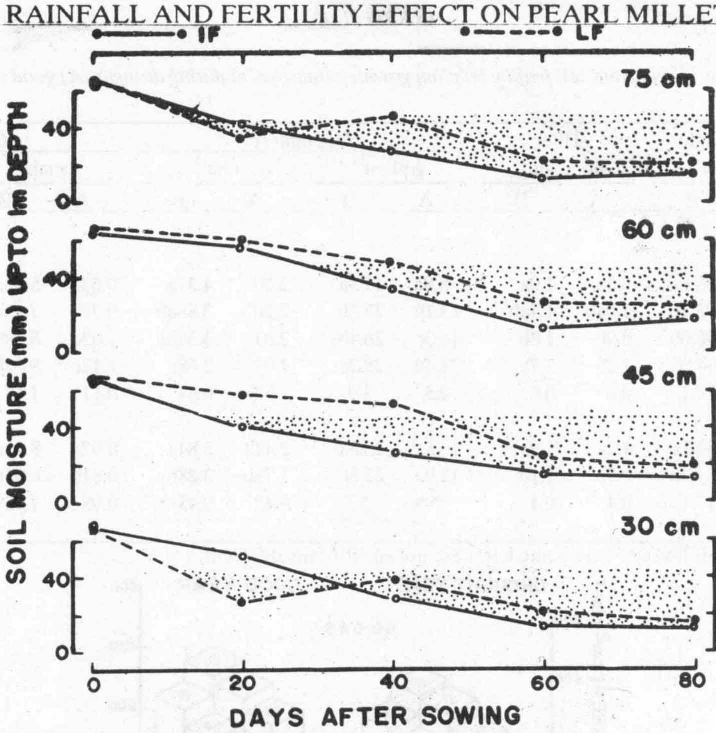

Fig 2 Soil moisture up to 1 m depth beneath a pearl millet crop grown at different row spacings and two soil fertility conditions during the drought year (A), and good rainfall year (B). Dotted area indicates moisture below the availability limit.

There was, however, a dry spell after 50 DAS. Therefore, 1982 and 1983 have been designated in the subsequent portion of the text as 'drought' year and 'good rainfall' year, respectively.

In both 'drought' and 'good rainfall' years soil moisture in the upper 1 m profile was depleted more under the improved fertility as compared to low fertility condition at all the stages of crop growth irrespective of the row spacing (Fig 2). This was possibly due to larger leaf area of IF plants (Fig 3). In the 'drought' year soil moisture in the profile declined over time from sowing to maturity and fell below the availability limit (-1.5 MPa) between 20 and 40 DAS in different treatments. It seems that the crop survived and completed its life cycle as its roots are known to extract water even beyond the depth of 2.0 m (Gregory & Squire 1979, Azam Ali *et al.* 1984). But the data do not suggest that wider row spacing of 60 or 75 cm led to any soil moisture conservation. However, in the 'good rainfall' year, the available soil moisture did not decline below the availability limit in any of the spacing treatments throughout the growing period of the crop except in the latter portions/grain filling (Fig 2B) towards the end. But there was no clear indication of any influence of row spacing on soil moisture.

Crop performance : In all the performance indices of the crop considered here, both spacing and soil fertility, but not their interactions, had significant effects. Therefore, marginal means only have been presented (Table 1). It indicates that the final growth in height and the total tiller number per plant increased with increased spacing in both drought and good rainfall years but in most cases the differences were not significant beyond 45 cm row spacing. It thus seems that row spacing wider than 45 cm even in the drought year did not significantly improve the height and tiller number of individual plants. An improvement in soil fertility significantly increased both these indices of performance in both years. As expected the growth was generally more in the good rainfall year. The spacing and fertility levels did not, however, had any significant influence on the leaf number of the main shoot.

Total leaf area plant^{-1} at both 40 and 60 DAS progressively increased with increase in row spac-

Table 1 *Influence of row spacing and soil fertility on plant growth parameters at during drought (A) good rainfall years (B)*

Treatments	Plant height (cm)		Tiller no. plant^{-1}		Dry matter g plant^{-1}		Dry matter t ha^{-1}		Grain yield g plant^{-1}		Grain yield t ha^{-1}	
	A	B	A	B	A	B	A	B	A	B	A	B
Row Spacing (cm)												
30	65.1a*	68.6a	0.4a	1.0a	8.8a	17.5a	2.20	4.37a	0.63a	5.63a	0.15a	1.38a
45	83.6b	93.1b	1.0ab	1.4ab	13.1b	23.3b	2.20	3.88ab	0.79b	7.13b	0.14a	1.20ab
60	93.2b	98.0b	0.9b	1.8b	16.3c	26.4bc	2.01	3.30bc	1.02c	8.18b	0.14a	1.05bc
75	95.8b	104.0b	1.2b	1.7b	21.4d	28.2c	1.97	2.68c	1.12c	8.32b	0.10b	0.82c
LSD 5%	16.2	24.1	0.6	0.6	2.5	3.9	NS	0.64	0.11	1.65	0.02	0.26
Fertility												
IF	93.2a	100.5a	1.2a	1.9a	16.8a	25.5a	2.42a	3.84a	0.97a	8.03a	0.14a	1.28a
LF	80.6b	81.4b	0.5b	1.1b	12.9a	22.3b	1.78b	3.28b	0.81b	6.01b	0.12b	0.95b
LSD 5%	11.5	17.1	0.4	0.4	NS	2.7	0.42	0.45	0.08	1.16	0.02	0.17

.*Values within coloumns followed by the same letter are not significantly different.

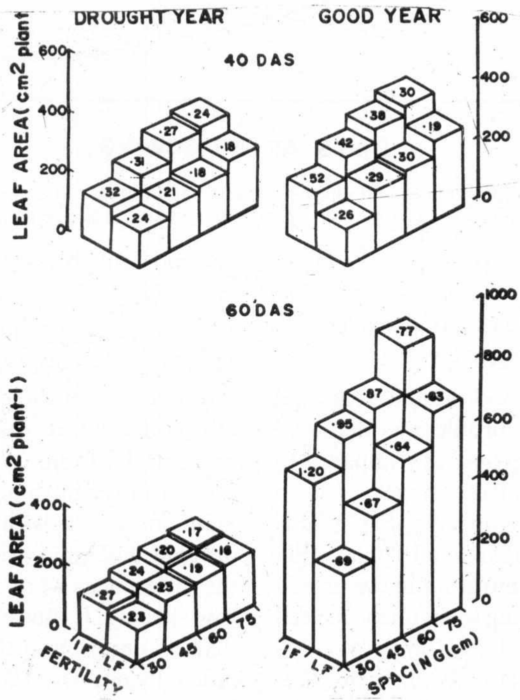

Fig 3 Leaf area per plant and leaf area index (shown on top of bars) under different spacings and soil fertility conditions at 40 and 60 DAS.

ing in both the years, specially during the good rainfall year (Fig 3). It may be further noted that during the good rainfall year leaf area increased with time. This contrasts with the drought year where the leaf area did not show an increase but in some cases declined probably due to leaf death or drying. In both the rainfall situations an improvement of soil fertility markedly increased the leaf area under all spacings at both growth stages. LAI consistently declined in both the years with the increased row spacings. This indicated that despite an increase in the leaf area plant^{-1}, the canopy cover per unit land area declined with wider row spacing. LAI was always higher under the IF as compared to LF condition at all row spacings in both years. Other researches (Alassi & Power 1975, Remison & Lucas 1982, Muller & Preez 1988) have also observed that in maize the LAI increased with an increase in plant density, as has been found here. However, Azam Ali *et al.* (1984) found that the LAI was greater at low plant population at later growth stages when pearl millet was grown on stored soil moisture.

An increase in row spacing or decline in plant population progressively and significantly increased the dry matter production per plant notwithstanding the higher yield in the good year as compared to the drought year (Table 1). The improved fertility condition significantly and consistently increased total dry matter plant^{-1} in both years.

However, dry matter production per unit area (tha^{-1}) during the drought year showed a non significant decline with increased spacing. In the good rainfall year increased row spacing progressvely and markedly reduced the dry matter production per unit area, where the differences between any two consecutive row spacings (i.e. 30 and 45 cm, 45 and 60 cm, and 60 and 75 cm) were not significant. Similarly, grain yield plant^{-1} consistently increased in both drought and good rainfall years with increased spacing although the differences were not significant between 60 and 75 cm in the drought year and between 45, 60 and 75 cm in the good rainfall year. However, the situation was reversed when grain yield unit^{-1} area was considered. The yield per unit area (t ha^{-1}) progressively and consistently declined with increased spacing in both the years where the differences between 30, 45 and 60 cm row spacings were not significant in the drought year. The same was true for 30 and 45 cm, 45 and 60 cm and 60 and 75 cm row spacing in the good rainfall year. However, improved soil fertility significantly increased the dry matter and grain yield plant^{-1} and unit^{-1} area in both the years. An exception was dry matter yield plant^{-1} during the drought year where the fertility induced increase was not large enough to be significant.

The data thus suggest that improvements in the performance of individual plants brought about by increased row spacing beyond 45 cm (or decrease in population below 1.45 x 10^5 plants ha^{-1}) could not fully compensate the yield losses per unit area in both drought and good rainfall years. Gautam (1970) also found that on loamy sand soil at Dehli, a row spacing of 45 cm (1.41 x 10^5 plants ha^{-1}) provided the optimum yield of pearl millet as compared to 60 and 75 cm row spacings. Gautam (1975) subsequently reported that the yield of pearl millet was higher at 50 cm row spacing as compared to 25,75 and 100 cm row spacings under laterite-loam soil of Coimbatore. The present study has furthermore indicated that an improvement of soil fertility augmented the yield under both drought and good rainfall although the magnitude of yield improvement was greater under favourable rainfall. The present study thus supports the findings of Bationo *et al.* (1990) who failed to observe any merit of wide spacing under variable rainfall condition.

Water use and water use efficiency: Table 2 indicates that in the drought year consumptive use of moisture was less as compared to the good rainfall year at all spacings due to low availability of soil moisture. However, during the drought year, the major part (88.8 to 91.6% under IF and 80.1 to 85.7% under LF) of the total water used by the crop was utilised during the first 40 days of sowing. This could be the reason for the larger dry matter production and very low grain yield. Again during the drought year, the water use was comparable under all row spacings (or populations) under both IF and LF conditions. It would thus appear that under wider spacing or low population, individual plants utilised relatively more water as compared to narrowly spaced plants. This explains the cause of the observed improvement in the performance of individual plants under wider spacing. This, however, did not help to augment the yield per unit of area as it has already been explained. Although the IF treatment in the drought year induced a relatively larger water use as comapred to LF condition during the first 40 days of growth at all spacings, such differences were not obvious during the subsequent period due to dw, dling supply of soil water. Thus the influences of fertility on the total water use of the crop were not discernible.

In the good rainfall year, water use showed an increase with improved soil fertility, as well as,

Table 2 *Influencess of row spacing and soil fertility on water use (mm) during vegetative (0-40 DAS) and reproductive (41 DAS to maturity) phases during drought and good rainfall years.*

DAS	Improved fertility: Consumptive use of moisture at indicated spacings (cm)				Low fertility: Consumptive use of moisture at indicated spacings (cm)			
	30	45	60	75	30	45	60	75
Drought year								
0–40 DAS	183.7	184.8	178.0	184.3	173.5	159.5	164.1	165.3
41–80 DAS	19.9	17.0	22.4	18.2	28.9	39.6	29.9	33.7
Total 0–80 DAS	203.6	201.8	200.4	202.5	202.4	199.1	194.0	199.0
Good rainfall year								
0–40DAS	149.1	151.1	164.7	154.3	121.4	134.7	149.0	132.9
41–90 DAS	115.0	117.3	124.6	124.6	110.4	109.6	117.1	126.7
Total 0–90 DAS	264.1	268.4	289.3	278.9	231.8	244.3	266.1	259.6

increased spacing during 0 to 40 days and 41 days to maturity. The aforesaid trend was also reflected on the total water use. The increase in water use due to increase in row spacing seems to have contributed to some extent towards the improvement of the performance of individual plants (Table 1). But the possibility of a substantial loss through evaporation from the bare soil under wider spacings can not be ruled out.

However, it seems that fertility induced increase in water use through larger leaf area and greater radiation interception was intimately linked with performance improvement of plants.

The contention that the improvement of the performance of individual plants under wider spacing could not compensate the yield losses per unit of area during the drought or good rainfall years was further reinforced from the observation that the WUE with respect to grain yield in both the years progressively declined with increase in the row spacing beyond 30 cm (Table 3). However, the values were very low during the drought year due to meagre grain yields. But, during the favourable rainfall year the order of this efficiency was higher. Similarly the WUE with respect to dry matter production showed a consistent decline with increased spacing, under both IF and LF conditions in the good rainfall year. But in the drought year the trend was not obvious as the spacing did not significantly influence the dry matter production (Table 1). However, in both the years, WUE on the basis of both grain yield and dry matter production, showed consistent increases under IF condition at all spacings.

Welch *et al.* (1966) observed in rainfed sorghum, as it has been found in this study, that increased plant population as well as improved soil fertility contributed to better water use efficiency even when the water use was not significantly influenced due to limitation of water supply. Fussell et al. (1987) also reported that improved fertility may or may not increase the water use but it does

Table 3 *Influence of row spacing and soil fertility on water use efficiency (WUE) on the basis of grain yield and dry matter production during drought and good rainfall years.*

Row spacing (cm)	WUE (kg Grains mm^{-1} ha^{-1}): Drought year IF	Drought year LF	Good year IF	Good year LF	WUE (kg Dry matter mm^{-1} ha^{-1}): Drought year IF	Drought year LF	Good year IF	Good year LF
30	0.78	0.72	6.21	5.08	11.87	9.78	18.50	16.63
45	0.75	0.66	5.20	4.14	13.00	8.92	15.95	14.21
60	0.74	0.64	4.14	3.43	10.91	9.48	11.57	12.19
75	0.54	0.44	3.19	2.90	11.99	7.61	10.18	9.83

Table 4 *Influence of row spacing and soil fertility on nitrogen and phosphorus uptake (kg ha^{-1}) during drought (A) and good rainfall (B) years.*

Teatments	N uptake		P uptake	
	A	B	A	B
Row spacing (cm)				
30	16.62a*	40.87a	1.61a	6.57a
40	17.11a	32.94b	1.35b	5.69ab
60	15.59a	27.42bc	1.22bc	5.10bc
75	15.25a	22.04c	1.03c	4.16c
LSD %	NS	5.94	0.21	0.97
Fertility				
IF	22.27a	34.70a	1.55a	6.03a
LF	10.02b	26.93b	1.07b	4.73b
LSD 5%	2.08	4.20	0.15	0.69

*Values within columns followed by the same letter are not significantly different.

improve the water use efficiency. They found that under two contrasting rainfall situations at the ICRISAT Sahelian Centre, millet crop with and without fertilizer used comparable quantities of water but the water use efficiency was much higher under improved soil fertility. It seems that the principal effect of improved fertility is to allow more rapid expansion of the canopy when the crops are young leading to a larger canopy that shades the soil surface more completely and reduces the proportion of the water that is evaporated (Cooper *et al.* 1987, Shepherd *et al.* 1987).

Nitrogen and phosphrous uptake : Total uptake of N and P plant^{-1} (above ground shoot plus grains), in both the years, progressively increased with increased row spacing (or decline in population) and also improved soil fertility (Fig 4). However, table 4 indicates that the N and P uptake per unit of area declined with increased spacing in both the years but the effects were not significant for N uptake during the drought year. It thus seems that increased uptake of N and P plant^{-1} (Fig 4) due to increased row spacing (or lower population) could not fully compensate for the losses occurred through lowering of population under wider spacing. It is noteworthy that N and P uptake per unit of area significantly increased in both the years

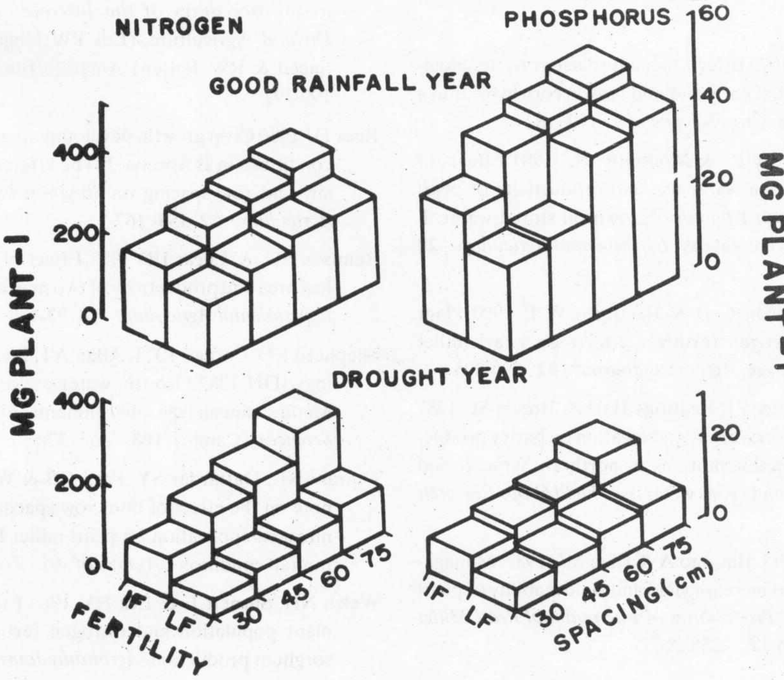

Fig 4 Nitrogen and phosphorus uptake per plant under different spacings and soil fertility conditions during the drought and good rainfall years.

under improved soil fertility notwithstanding the fact that the uptake were more during the good rainfall year.

Conclusion

The results of the present investigation thus indicate that in both drought and good rainfall conditions improved performance of individual plants under wider spacings could not completely compensate the losses which arose due to the decrease in population per unit of area beyond a specific limit (ca. 1.45 x 10^5 plants ha^{-1} or a row spacing of 45 cm). Furthermore, it is evident that improved soil fertility is crucial for improvment of production where the benefits may be large during favourable rainfall conditions.

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