Effect of plant density on growth, yield and quality of morphologically varying cotton varieties

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Abstract

Field experiments were conducted at Rahad Research Station for seasons 1987-88, 1988-89, 2000-01and 2001-02, focusing on how the variation in genotypes, plant density, spatial arrangement and their interactions affects cotton yield and quality. Studies on inter and intra-rows (1987-88 and 1988-89) revealed that 100 cm rows being pre-requisite for cotton mechanical pickers had significantly decreased the seed cotton yield by 20% averaged across seasons. Future cotton pickers should therefore be adjusted to 80 cm rows. On the other hand variation due to within row spacings (10-20cm) corresponding to plant density of 63.000–375.000 plants/ha had small and insignificant effect on seed cotton of variety Shambat–B. Therefore, variety based specific plant density is not appropriate, hence, regression analysis for plant density yield targeting response curve exhibited a curvilinear relationship with the highest seed cotton yield achieved at 125000 plants/ha for the three varieties studied and thereafter started to decrease. Differences in the range of 75.000–187.000 plant\ha were not significant. Sticky cotton due to honeydew secretions was thermodetectly measured, with sticky spots for Acala (93)H, Barac(67)B and Sudac-K being in the ranges of 6-40, 4-22 and 0-12, respectively. Yet, for each variety the sticky spots increased concomitantly with the increase in planting density. This was discussed in relation to variability in variety specific traits such as hairiness, glabrousness and plant canopy architecture. Nevertheless, these values were dramatically lower than those recorded internationally for the Sudan Cotton. Days to the last pick were 130,170 and 185 for Sudac-k, Barac(67)B and Acala (93)H, respectively. Accordingly, Sudac-K which is an early maturing, super-okra-leaf (SOL), highly resistant to whiteflies (Bemisia tabaci) but of comparatively low yield emerged as a suitable choice for a short duration low management system where problems of late irrigation and build up of whiteflies are anticipated. Conversely, Nour (93), being hairy, physiologically efficient in compensating yield losses due to late adversities and with stay green character is best fitted into the integrated crop management (ICM) strategy.

Introduction

For more than 70 years of irrigated cotton cultivation in the Sudan, plant population of 75000 plants/ha arranged into 80 cm inter-row × 50 cm intra-row with three plants/hill is officially recommended for both cotton species (*barbadense* and *hirsutum*). Even though, in the early 1950's the current spacing practice (80 × 50 cm with 3 plant/hill) was referred to as being wide and a closer spacing of 80 × 35 cm with 3 plants/hill (107000 plants/ha) was suggested to be better (low, 1953). Experimental evidence, however, failed to support this hypothesis and moreover the previous findings (Kheiralla,1969; Fadda,1962;Burhan and Taha,1974), can best be summarized as being

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conflicting and indefinitve. On the other hand, the recommended plant population in neighboring Egypt is 120.000-150.000 plants/ha with long time average seed cotton yield double that of Sudan (personel communication).

According to Tamboul Pilot Farm Standard Practices, the recommended spacings were 100×10 cm with one plant/hill (100.000 plant/ha), hence cotton pickers can work only in 100 cm rows. However, in 1984-85 the era of demechanization was started and cotton had to be manually planted into 80×30 cm spacings with 3 plants/hill (52.000 plants/fed) i.e. 125.000 plants/ha. In 1987-88 the plant population was reduced to 40.000 plants/fed (94.000 plants/ha) in 80×40 cm spacings with 3 plants/hill. This had resulted in scheme average of 6.16 kantar/fed. Unfortunately in 1988-89 the scheme average yield dropped to only 5.6 kantar/fed. This was misconceptionally attributed to the newly adopted plant density (40.000 plants/fed). Therefore, from 1989-90 onward the scheme management re-adopted the old practice of 80×30 cm with 3 plants/hill (52.000 plants/fed). In 1994-95 the recommended plant population of 31.500 plants/fed spaced into 80×50cm with 3 plants /hill was imposed via the "Productivity Upgrading Committee". Since then, the scheme average yields were not as high as when the 52.000 plants/fed (125.000 plants/ha) had been in place.

In view of the above, re-evaluation of the plant population as related to cotton yield is needed, as new cotton varieties of contrasting morphologies were released. This study has therefore been focused on how the variation in morphologies of some cotton varieties affects plant density, spatial arrangement, growth, yield and quality parameters.

Material and methods

Experiment 1

Effect of inter and intra-row spacing (1987-88 and 1988-89)

There were 14 treatments comprising factorial combinations of seven intra-row spacings (10, 20, 30, 40, 50, 60 and 70 cm) and two inter-row spacings (80 and 100 cm) with three plants/hill. The experimental design was a spilt-plot with 4 replicates. The inter-row spacings occupied the main plots and intra-row spacing the subplots. The subplot size was 72 m^2 (10 × 9 m × 0.8 m and 0.8× 9m ×1m). Shambat-B, a high quality cotton (fine count) and resistant to fusarium wilt, was used. The harvested area was 28 m^2. (5 × 7 m × 0.8 and 4 × 7 m × 1 m). Fertilizer in form of urea was broadcasted in one dose (86 kg urea/fed.) at 5 weeks after sowing. Other cultural practice were as recommended by ARTC.

Experiment 2

Effect of plant density and spatial arrangement (2000-01 and 2001-02)

The experimental variables involved 36 treatments, representing factorial combinations of three varieties, three levels of plants/hill and four intra-row spacings, in split-split plot design with three replications. The inter-row spacings kept at 80 cm. The main plots were assigned to the number of plants /hill, the subplots to the varieties and the sub-sub-plots to the intra-row spacings. The sub-sub-plot composed of 4 rows × 9 m× 0.8 m and the harvested area was 2×7×0.8 m (11.2 m^2). Cultural practices other than treatments were performed as recommended by the Agricultural Research and Technology Corporation.(Anon, 1967).

Factors

I. Plants per hill:

Five to seven seeds were hill-dropped at sowing (first week of July) and were thinned to the required number (1, 2 or 3 plants/hill) according to treatments at two to three weeks after the effective sowing date.

II. Varieties:

1. Barac (67)B: The commercial cultivar, glabrous, bushy with moderately closed canopy and medium count (MC) quality.
2. Acala(93)H (Nour 93): It is hairy with closed canopy, high leaf area and of high count (HA) quality and high yield (30-40%) as compared to Barac(67)B.
3. Sudac-K: It has a super-okra- leaf (SOL), glabrous, of open canopy and with medium count quality.

III. Intra-row spacings:

20, 30, 40 and 50 cm.

Observations

1. Plant height: It was measured at harvest on five plants in each plot, from the ground surface to the highest point on the main system.
2. Leaf area Index (LAI): It was calculated by punching and weighting discs of known area from a 10 leaves samples per plant for five plants in each plot to give specific leaf weight (SLW) in mg/cm^2. Then the leaf area was estimated by using SLW data which correlates leaf area to leaf weight. Then, leaf area index (LAI) was calculated as a total leaf area over ground area.
3. Boll size (boll weight(g)): It was calculated as the average weight of 25 unweathered, perfect open bolls randomly picked from the top, middle and bottom fruiting zones of each test plant.
4. Seed index (g/100 cotton seeds): Weight of seeds in a sample of 100 cotton seeds.
5. lint index (g/100 cotton seeds): Weight of lint in a sample of 100 cotton seed.
6. Fibre quality test: This was carried out by the Fibre Testing and Spinning Laboratory of the Cotton Research Program, ARC. Sudan.
7. Insect-pest complex: Weekly observations were made on 100 leaves of each variety to count the adults and nymphs of jassids *(Jacobiasca lybica*) and adults of whiteflies (*Bemisia tabaci*).
8. Seed cotton yield (kg/ha): Seed cotton per harvested area (11.2m^2) was hand picked, weighed and adjusted to kg/ha.
9. Plant populations: The spatial arrangement of per hill treatment (1, 2, 3 plants/hill) and the intra-row spacings (20, 30, 40, and 50 cm) cumulatively resulted into different plant populations (Table 1).

Data analysis

Analysis of variance was computed for all measured attributes to test treatments differences. Regression analysis was also performed for quantifying the relationship between the yield and plant densities to determine the optimum plant density that maximize yield (SAS, 1985).

Results

Experiment 1

Significant differences for seed cotton yields were obtained due to inter-row treatments (80 vs. 100 cm) in both seasons (Table 1 and Table 2). Thus the narrow inter-row (80 cm) out-yielded the 100 cm by 12 and 29 % for seasons 1987-88 and 1988-89, respectively with overall average across the two seasons of about 20%. On the other hand, differences due to the intra-row spacings (10, 20, 30, 40, 50 and 60 cm) were small and insignificant for both 80 and 100 cm rows (Table 1 and 2). However, there was a trend of yield decrease due to 70 cm intra-row but the differences being only significant in season 1987-88 with the 80 cm row. Hence, response of Shambat-B to intra-row spacings in the range of 10-70 cm (375.000-63.000 plants/ha) was small and insignificant

Experiment 2

Data on the seed cotton yield from the separate and the combined analysis of the two seasons exhibited the same trend. Accordingly, only the combined data averaged across the two seasons is presented (Table 3). Significant effects were obtained via the main treatments of plants/hill, intra-row spacing and variety but their interactions were not. Differences due to spatial arrangement were also not significant. Though significant differences were found due to plant population components (plant/hill and intra-row spacings) as separate main effects, their cumulative effect as planting density (Table 3) showed a consistent linear increase in seed cotton yield via increasing the number of plants/ha from 25.000-125.000 plants/ha, and thereafter, started to decrease (Fig.1). However, these differences were not significant in the range of 75.000-187.000 plants/ha. Nevertheless, regression analysis exhibited a curvilinear relationship between plant density and seed cotton yield as indicated by the quadratic functions of figures 1 and 2. Accordingly, 125.000 plants/ha (3x30 or 2 x20) was estimated on average fit data to be the optimum planting density with the corresponding maximum seed cotton yield of 3898 kg/ha. For the three varieties, the number of the first fruiting node, plant height and stickiness ranges were increased by increasing plant density, whereas the SLW and the number of nodes/plant were not affected (Table 4). Growth and yield attributes of the three varieties (Table 5) showed that Sudac-K had the lowest records of LAI, first fruiting node and days to the last pick as compared to the other two varieties, whereas the corresponding values for Acala (93)H were the highest. However, differences between varieties in seed index, lint index, G.O.T and boll weight were not significant. Data on insect load (Table 6) revealed that Acala(93)H had the lowest jassid load but the highest build up of whiteflies and was the most sticky, whereas the opposite values were recorded for Sudac-K. The values for sticky spots and whiteflies build up for variety Barac(67)B were intermediate. The fibre length and strength for Acala (93)H were of better ranges as compared to the other two varieties (Table 7).

Discussion

Adoption of the Rahad Scheme to relatively higher plant population (52.000 plants/fed) as compared to the official recommended density (31.500 plants/fed) for other schemes about 10 seasons was viewed by many agriculturalists at Rahad as a critical factor in the increase of productivity and it has there to stay in place. This, however, was proved not to be wholly true, hence, productivity was not affected by a wide range of plant density (63.000-375.000 plants/ha). Inter-row spacings has emerged in this study as the plant density component that directly affects seed cotton yield. Recent studies (2000 to 2002) on the effect of plant population on seed cotton yield had also indicated that the differences between a wide range of plant population (i.e. 75.000-187.000 plants/ha) were not significant The significant response to plant density below 63.000 plants/ha indicated that monopodial branching of cotton did not compensate for yield losses below 63.000 plants/ha. This was in agreement with the earlier work (Burhan and Taha, 1974; Elmhadi, 1986 and Lazim, 1988). However, the data presented herein were further analyzed via fitting response function using regression analysis as suggested by (Petersen, 1977), hence, the experiment was composed of factorial combinations of three treatments at three or more levels. Accordingly, the optimum plant density was computed from the quadratic functions as shown in Fig. 1 and 2. Therefore, 125000 plants/ha, though not significantly different from 75.000 plant/ha was estimated on average to be the optimum for maximum seed cotton yield of 3890 kg/ha (Fig. 2). The decrease in seed cotton with the highest plant population (187.000 plants/ha) as indicated by the negative sign of the quadratic coefficient of the curvilinear response function (Fig. 2), may be attributed to plant competition at such a high plant density. Thus, the increases in plant growth attributes such as the first fruiting node, LAI, plant height, stickiness and the decrease in SLW values were reflections of rank growth (Table 4). Accordingly, the excessive growth enhanced the shedding of flowers at the lower nodes and increased the internode length via increasing the plant height, since the numbers of nodes were not affected. Also, the LAI which can be used as a measurement of light interception efficiency increased via increasing plant density with concomitant yield decrease due to shading. On the other hand, the decrease in SLW with the increase in plant density, indicated that leaves of the highest density had less weight per leaf area and therefore were very thin. Accordingly, they behaved like shade leaves because of competition for light. Likewise, a trend of increase in the stickiness with increase in plant density was observed for all varieties, though relative differences between varieties were still there (Table 4). This was attributed to the favorable environment being created by the closed canopy of the highest plant density which was more appealing to whiteflies.

Based on the data of (Tables 5 and 6), Sudak-K being of an open canopy, glabrous, early maturing, with super-okra-leaf shape and therefore, had the lowest range of stickiness. This was in agreement with (Bindra, 1985) who reported that switching to cultivars less favorable to the pests and more suited for efficient pesticide application would ease the cotton protection problems, hence, factors which make a cotton variety more porne to whiteflies infestation are bushiness, hairiness and large leaf area. Nevertheless, commercial acceptance of the okra-leaf varieties has so far been only reported in Australia and was attributed to the high yield of the Australian-bred normal-okra-leaf (NOL) varieties (Thomson, 1994). Acala (93)H had the highest stickiness because of hairiness and the large leaf area that provided shelter for the bulildup of whiteflies. On the other hand, the lowest jassid infestation observed in the Acala(93)H, was due to hairiness. Such a hairy variety may be useful when tested in the well managed integrated crop management (ICM) system. The hair density will reduce the infestation by jassids early in the season offering an opportunity for the buildup of the natural enemies to control the whiteflies which is a late season pest. This may be supported by the fact that whitflies became major pest in late 1950's in the wake of DDT spraying against the cotton jassids. Moreover, the superiorty of Acala(93)H in fibre length and strength will widen the quality range of the Sudanese cotton, hence, both Barac(67)B and Sudac-K are of medium count, but data on quality of Acala(93)H represent high Acala (HA) count (Table 7). The low seed cotton yield of sudac-k as compared to other varieties was also reported by (Hamada and Knapp,1998). This was further documented via large scale piloting of 5.000 feddans of Sudac-K planted into 80×30 cm with 3 plants/hill (52.000 plants/fed) in season 1984-85. This had resulted in seed cotton yield of 3.5 kantars/fed for Sudac-K as compared to 5.0 kantars/fed for Barac(67)B. Despite, the low seed cotton yield of Sudac-K, it can best be suited into short duration management where late season problems of water shortage and insect pests are anticipated. Such a reduced season approach will maximize the economic yield, because additional costs of late irrigation, pest control, labour and management will be avoided. In practice, however, Sudac-K was not commercially adopted due to its low yield, despite its non-sticky lint. Therefore future research should be embarked upon breeding for normal-okra-leaf (NOL) with medium hair (low jassid infestation) and of comparatively high yield than the prevailing Sudac-K of super-okra- leaf (SOL) type. On the other hand, the potentially high yielding Acala (93)H, can best be fitted into long season cropping system due to its stay green character, high leaf area, better boll retention, adaptation to ICM and, hence, tolerance to late season adversities.

Recommendations

Based on the findings reported in this paper, the plant density can be increased in the range of 75.000-125.000 plants/ha (31.500-52.000 plants/fed) provided that:

- Plant protection has to be perfectly emphasized.
- Mechanical planting has to be attended.
- Grantee of proper thinning operation.

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Table 1. Effect of inter and intra-row spacing on seed cotton yield (kg/ha) of variety Shambat(B) at Rahad (1987-88)

Intra-row (cm)	**Inter-row (cm)**		**Inter-row (cm)**		**Mean**
	80	**100**	**80**	**100**	
	(000 plants/ha)		**seed cotton (kg/ha)**		
			(±160)		**(±113)**
10	375	300	2709	2575	2642
20	188	150	2642	2341	2492
30	125	100	2776	2374	2575
40	094	075	2709	2541	2625
50	075	060	2809	2541	2675
60	063	050	2876	2240	2558
70	054	043	2307	2240	2274
Mean			2690	2407	
			(±60)		

Table 2. Effect of inter and intra-row spacing on seed cotton yield (kg/ha) of variety Shambat–B at Rahad (1988-89)

Intra-row (cm)	**Inter-row(cm)**		**Inter-row (cm)**		**Mean**
	80	**100**	**80**	**100**	
	(000 plants/ha)		**seed cotton (kg/ha)**		
			(±152)		**(±111)**
10	375	300	2541	2107	2324
20	188	150	2742	2040	2391
30	125	100	2675	2140	2408
40	094	075	2608	2107	2358
50	075	060	2675	2140	2408
60	063	050	2675	1940	2307
70	054	043	2408	1772	2090
Mean			2618	2035	
			(±58)		

Table 3. Effect of plant density with varying spatial arrangement on seed cotton yield (kg/ha) of three varieties over two seasons

Plant density (000 plants/ha)	Spatial arrang Plants/intra-row (cm)	Sudac-K	Barac(67)B	Acala(93)H
			±146	
25	1 × 50	1607	2768	3392
32	1 × 40	1964	2946	3660
42	1 × 30	2275	3034	3482
50	2 × 50	2463	3154	3839
63	2 × 40	2500	3302	3927
63	1 × 20	2670	3316	4284
75	3 × 50	2678	3482	4284
83	2 × 30	2820	3525	4339
94	3 × 40	2882	3703	4417
125	3 × 30	3112	3882	4637
125	2 × 20	3048	3662	4507
187	3 × 20	2989	3482	4374
	Mean	2584	3355 (± 42)	4095

Table 4. Effect of selected plant densities on growth and yield of the three cotton varieties over two seasons.

Variety	PD (000/ha)	Seed cotton (kg/ha)	FFB node	Plant height (cm)	LAI	SLW (g/cm^2)	Nodes (No./plant)	Sticky spots no
Sudac-K	25	1607	5	64	2.0	2.8	17	0-2
	75	2678	5	70	2.5	3.0	17	3-6
	125	3080	6	76	3.0	3.2	17	4-8
	187	2989	8	84	3.6	3.0	17	7-12
Barac(67)B	25	2768	6	62	2.6	3.2	19	4-9
	75	3482	6	67	3.0	3.5	19	6-11
	125	3772	7	74	3.6	3.9	19	9-13
	187	3482	8	80	4.2	3.5	19	12-22
Acala (93)H	25	3392	7	87	3.5	4.0	22	6-9
	75	4284	7	92	3.8	4.4	22	7-13
	125	4574	8	103	4.2	4.7	22	11-21
	187	4374	8	118	5.0	4.3	22	22-40
S.E(±)	-	146	0.3	5	0.18	0.12	0.6	-

PD = Plant density, FFB = First fruiting branch, LAI = Leaf area index, SLW = Specific leaf weight

Table 5. Growth and seed cotton yield parameters of the three cotton varieties over two seasons

Variety	LAI	FFB Node	DLP	Plant height (cm)	Seed index (g)	Lint index (g)	GOT (%)	Boll wt. (g)
Sudac-K	2.4	5	130	70	12	7.5	38	5.6
Barac (67) B	3.0	6	170	67	11.8	7.6	39	5.8
Acala (93) H	3.8	7	185	92	11.9	7.1	37	5.3
S.E(±)	0.18	0.3	4.7	5	0.3	0.26	1.2	0.3

LAI = Leaf area index, FFB = first fruiting branch, DLP = Days to last pick, GOT = Ginning outturn

Table 6. Means number of Jassids and whiteflies per100 leaves and sticky spots counts over two seasons

Variety	Jassids	Whiteflies	Sticky spots counts	
	Average	Average	Range	Average
Sudac-K	16.4	3.8	0-12	4
Barac(67)B	15.6	8.2	4-22	12
Acala(93)H	4.0	12.8	6-40	28

Table 7. Fibre characteristics of three varieties tested at ARC Fibre Testing Laboratory.

Variety	2.5% SL (mm)	Uniformity ratio	Micronaire Value	Stelometer (g/tex)
Sudac-K	26.3-28.7	47-50	4.2-4.4	20-23
Barac (67)B	26.3-28.6	47-50	4.2-4.4	20-24
Acala (93)H	29.1-30.2	47-50	4.2-4.6	21-25

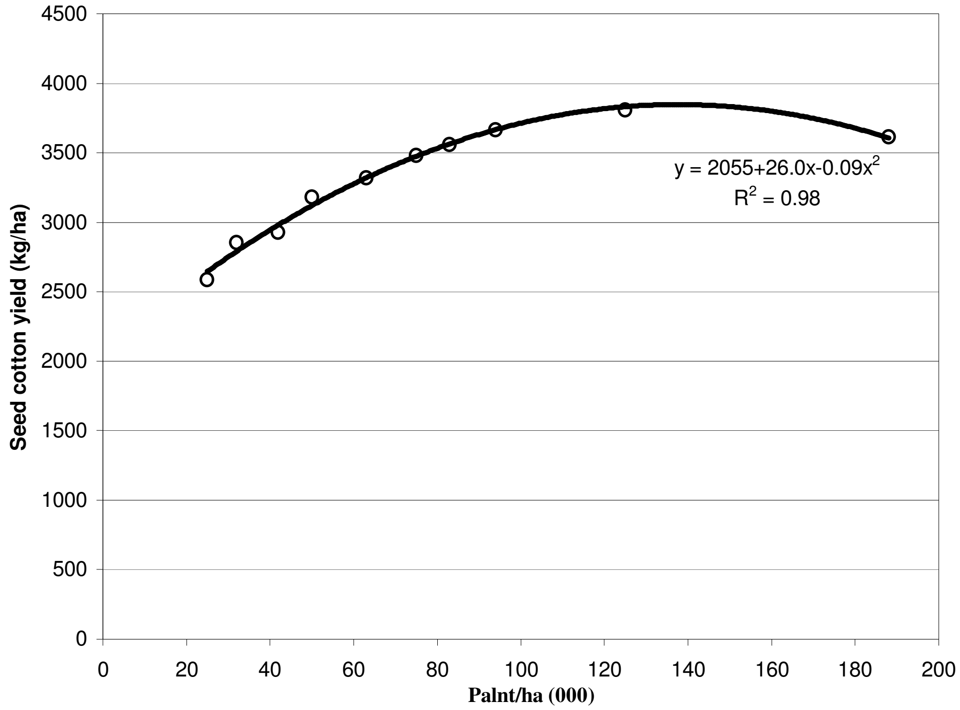

Fig 2. Plant density as related to seed cotton yield averaged across varieties

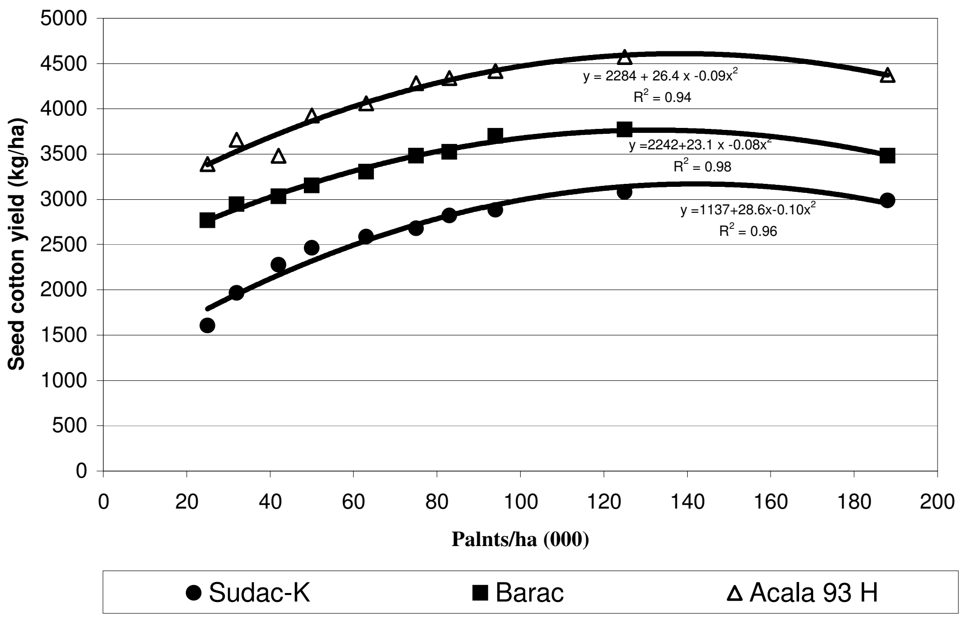

Fig 1 . Plant density as related to seed cotton yield