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Growth and NPK uptake of high-yielding cotton grown at different nitrogen levels in a permanent-plot experiment

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Abstract

Growth and N, P, K uptake of Acala SJ-2 cotton (*Gossypium hirsutum*) were investigated in an irrigated permanent-plot field (Typic chromoxerert) at Bet Dagan, Israel, under semi-arid conditions using different nitrogen levels: 0, 60, 120, 180 and 240 kg N ha^{-1}. The total dry matter accumulation at these levels was 9.0, 10.7, 15.1, 17.1 and 15.6 ton ha^{-1}, respectively. The uptake of N, P and K was 110, 144, 267, 322 and 301 kg N ha^{-1}: 31, 34, 46, 44 and 38 kg P ha^{-1}; and 120, 151, 208, 251 and 230 kg K ha^{-1}, respectively.

Dry matter production, as well as N, P, K uptake by the cotton plants were greatly increased by raising the N application levels to 120 or 180 kg N ha^{-1}, but the pattern of accumulation and relative distribution of dry matter and NPK among plant organs were not considerably affected.

Introduction

Growth and nutrient uptake by the cotton plant have been the subjects of many studies, as reviewed by Hearn (1981). Most of these studies were carried out under soil N levels considered as optimal for the crop. Yields are now much higher due to the use of improved cultivars, higher amounts of fertilizers, especially nitrogen, more precise management and irrigation.

Halevy (1976) studied the dry-matter production and N, P, K uptake of two cotton cultivars, 'Acala 1517-C' and 'Acala 4-42', fertilized with 100 kg ha^{-1} of N. In his study, the lint yield was 1700 kg ha^{-1} (while the average for commercial cotton fields was 1300 kg ha^{-1}), and the total uptake of N, P and K was 230, 45 and 124 kg ha^{-1} respectively. In Israel, most of the cotton is usually continuously cropped and the most common cultivar is 'Acala SJ-2'. The average lint yield in commercial fields is more than 1500 kg ha^{-1} and in some of the best fields, yields of more than 2200 kg ha^{-1} have been attained.

Relatively little information is available on the growth and nutrient uptake of high-yielding cotton grown at different N levels under semi-arid conditions.

The objectives of the present work were to study the growth and the N, P, K uptake of cv. Acala SJ-2 grown at different N levels under favorable conditions conducive to high yields.

The data obtained will enable producers to get better yields of cotton due to N fertilizer application and will be useful for further development of cotton growth and uptake models (Jones *et al.*, 1974).

Materials and methods

The present investigation was conducted in a long-term fertilizer and manure field experiment, the Bet Dagan Permanent Plot Experiment, on a vertisol (Typic chromoxerert) with pH 7.8, 1.2% organic matter, and 10% $CaCO_3$.

Cotton (*Gossypium hirsutum* L., cv. Acala SJ-2) has been continuously grown in this experiment from 1978 till 1985. It was planted each year in April and picked in October.

The cultural methods were those normally practised in the area as described in a former publication (Halevy, 1976).

The plots (27 × 4 m), which were chosen for the present investigation in 1982, received the usual phosphorus and potassium fertilization: $80\,kg\,P\,ha^{-1}$ and $300\,kg\,K\,ha^{-1}$ (as ordinary superphosphate and potassium chloride).

The nitrogen levels tested were 0 (plots that had not received any nitrogen fertilizer since 1960), 60, 120, 180 and $240\,kg\,N\,ha^{-1}$ (as ammonium sulphate), the same nitrogen levels were applied to the cotton each year from 1981 till 1985.

Cotton plants from a 1-m long section of a row were taken in four replicates (randomized blocks design) at the following stages of growth (in days after full emergence = 10 days after planting): 48 days at flowering initiation; 68 days at flowering: 82 days at end of flowering; 95 days at boll formation; 110 days at open bolls; and 138 days at defoliation.

The plants were divided into component parts, dried, weighed, ground and analyzed for N, P and K as described previously (Halevy, 1976). Only in the last stage the reproductive parts were divided into: burrs, lint and seeds. The nitrogen and phosphorus content of the lint at this stage was negligible, hence the uptake of those elements in the lint could not be calculated. Soil samples were taken at a few growth stages. Ammonium and NO_3^--N were determined in KCl extract, available P in $NaHCO_3$, and K in $CaCl_2$ extract, as cited by Feigin *et al.* (1984).

Other growth and yield parameters, as listed in Table 1, were based on observations and samples taken from a 2-m row from the same 4 replicate plots at the end of the growing season.

Results and discussion

Growth, dry-matter accumulation and rate

The effect of nitrogen on different growth and yield parameters of the cotton plant is presented in Table 1.

Plant height was considerably increased by N application (Table 1) but the number of mainstem nodes per plant was affected only slightly. It was 19–20 at the low nitrogen levels, N_0 and N_{60}, and 22–23 at the higher levels. As shown by Oosterhuis *et al.* (1983), the effect of N on plant height was primarily the result of internode elongation rather than an increase in mainstem node number.

Both vegetative and reproductive plant components responded to N fertilization with an increase in the dry weight of the plant. The ratio of the reproductive dry weight to the total dry weight was somewhat greater in low N levels than in higher N levels, due to a greater effect of N on the vegetative growth. The number of open bolls, and the yield of seed cotton and of lint were increased by nitrogen fertilizer.

The pattern of dry matter accumulation curves (Fig. 1) obtained in their different N treatments is typical of the cotton crop (Halevy, 1976). Nitrogen greatly increased dry matter (D.M.) yield. The actual D.M. yields were 8950, 10660, 15070, 17050

Table 1. Effect of N fertilizer on cotton growth and yield at the end of the season

Parameter	Treatment ($kg\,N\,ha^{-1}$)				
	0	60	120	180	240
Plant height (cm)	80.3a[a]	94.0b	111.6c	120.0d	115.2cd
No. of nodes per plant	19.4a	20.2a	22.2b	22.5b	22.0b
Node of the 1st fruiting branch	8.0a	8.4a	8.5a	7.4b	8.3a
Vegetative dry weight ($ton\,ha^{-1}$)	3.47a	5.49b	8.00c	8.15c	7.36d
Reproductive dry weight ($ton\,ha^{-1}$), A	4.45a	6.26b	7.15c	7.91d	8.19d
Total dry weight ($ton\,ha^{-1}$), B	7.92a	11.75b	15.14c	16.06c	15.55c
Ratio A/B (%)	56.2a	53.3a	47.2b	49.2b	52.7b
Open bolls/1-m row (no.)	63.3a	87.2b	87.3b	91.2b	97.1b
Seed cotton yield ($ton\,ha^{-1}$)	4.00a	5.64b	6.12c	6.78d	7.02d
Lint %	41.7a	41.2a	39.9b	38.1d	39.3c
Lint yield ($ton\,ha^{-1}$)	1.67a	2.32b	2.44bc	2.58cd	2.76d
Boll weight (g)	6.32a	6.47a	7.01b	7.43c	7.23b

[a] Values within one row, followed by different letters are significantly different ($p < 0.05$).

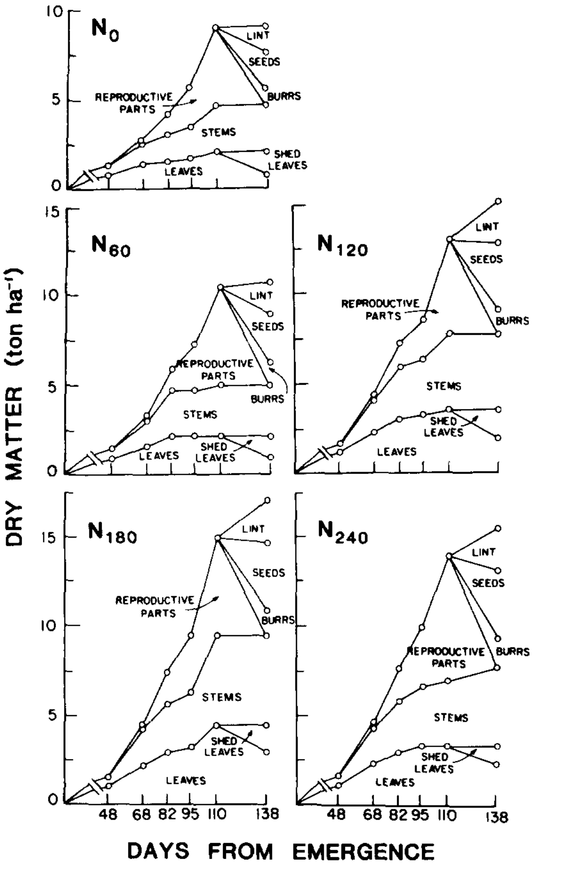

Fig. 1. Accumulation and distribution of dry matter in the aerial parts of the cotton plant at several nitrogen fertilizer levels.

and 15550 kg D.M. ha^{-1} for the 0, 60, 120, 180 and 240 kg N ha^{-1} treatments respectively. The ratio of the reproductive dry weight to the total dry weight was similar in all treatments, ~ 50%, except for the N_{180} which was 44%.

The seed cotton yields were 3340, 4450, 5960, 6090 and 6230 kg ha^{-1} for the 0, 60, 120, 180 and 240-kg N ha^{-1} treatments respectively. The seed cotton increased significantly (0.05) with treatments up to N_{120}. The relatively high yields of cotton in the N_0 plots, which had been cropped since 1960 without addition of N-fertilizer, are probably due to high mineralization rate of organic N in this soil.

Maximum leaf dry weight was measured 110 days from emergence, after which it decreased because of leaf senescence and shedding. Leaf shed was estimated by the difference between the two last samplings. This is probably an under-estimation, since leaves did not stop appearing. In the N_{60} treatment, maximum leaf dry weight was measured 82 days after emergence, but at 138 days the value dropped to below 50% of the original. Observations indicated earlier leaf shed in this treatment, but growth of new leaves compensated for this loss until 110 days, when leaf growth diminished and was exceeded by leaf shed.

In the first stage of growth, 60% and more of the total dry weight consisted of leaves with very small differences between treatments. Thereafter, the percentage of leaves decreased and at the last stage at 138 days, it was 9, 9, 12, 18 and 16% respectively. These data indicate that an inadequate nitrogen level in the soil results in less leaf formation and increased leaf shedding. The dry weight of the stem was 35% of the total dry matter at the first stage with no difference among treatments. The growth of the reproductive parts of the plant was very rapid being 2% of the total weight at the first sampling and 50% at the last. Although the vegetative growth came almost to an end at 110 days except in the N_{240} treatment where the stems continued to grow, the reproductive parts continued to accumulate dry matter in the N_{120}, N_{180} and N_{240} treatments. The N_{60} treatment accumulated very little dry matter, and in N_0 it was even slightly diminished.

The rate of growth was very slow until flower initiation (48 days). Then it increased three- to fourfold during flowering (49–68 days) with further acceleration until the end of flowering (82 days). The highest growth rate in all the treatments was found between 96 and 110 days and it reached 211–389 kg ha^{-1} day^{-1} in the different treatments. After 110 days, the rate of growth was very slow and it nearly stopped in the N_0 and N_{60} treatments.

In the present experiment, 70–72% of the total dry matter was produced during 42 days of growth (between 69 and 110 days) in treatments N_0 and N_{60}, and 60% in the other treatments.

Nutrient content, total uptake and rate

Nitrogen. Nitrogen content in the plant parts was dependent on the amount of nitrogen fertilizer. From the lowest to the highest nitrogen levels, N content in the leaves ranged early in the season from 2.6–3.9% N, and in mature plants from 1.1–2.7%. In the stems, early in the season, it ranged from 1.0–1.4% and in mature plants from 0.5–0.8%. At harvest, the seed contained from 3.4% (in N_0) to 4.4% (in N_{240}).

The accumulation of N in the various plant parts is presented in Fig. 2. The decrease in the amount of N in the leaves which was shown by Halevy (1976) was found also in the present experiment from 95 days in the N_{120} treatment and from 110 days in the N_{180} treatment. The demand for N by the ripening bolls is high at those stages of growth. Since the quantity of N absorbed by the roots does not satisfy plant needs, some N is translocated from the older leaves to the bolls. This phenomenon was not observed in the N_0 and N_{60} treatments since N deficiency resulting from a low available N level in the soil completely stopped boll development eliminating this N sink and consequently N translocation.

The total uptake of N was 110, 144, 267, 322 and 301 kg N ha^{-1} for the N_0, N_{60}, N_{180} and N_{240} treatments, respectively (Fig. 2). The uptake for the N_0 treatment, in which no N fertilizer had been applied since 1960, was 110 kg.ha^{-1}, which corresponds well with the amount mineralized from the soil organic N in that soil (personal communication, Aviva Hadas).

The rate of N uptake by the plants was slow until flower initiation, but then, except in the N_0 and N_{60}treatments it increased three- to fourfold, and from 48–82 days and reached a level of 2.4–3.7 kg.ha^{-1} in the different treatments.

The highest rate of uptake in all N levels, except N_0, was measured between 96 and 110 days after emergence. This is the stage of filling of the bolls and seed development. This is in accordance with earlier results (Halevy, 1976) for the variety Acala 4-42. Uptake rates for the N_{180} and N_{240} treatments were especially high. The uptake at the beginning and end of the season was much higher in the present experiment than in an earlier one (Halevy, 1976). It seems that this is due to the more productive cultivar and better cultural methods in the present experiment, such as better stand, water distribution, *etc.*

Removal of N by lint and seed was 66, 88, 149, 166 and 166 kg.ha^{-1} for the five treatments, respectively (60–61% of the total in N_0 and N_{60} treatments, and 52–56% of the total in the other treatments). These values are higher than those reported in other works (Halevy, 1976; Oosterhuis *et al.*, 1983).

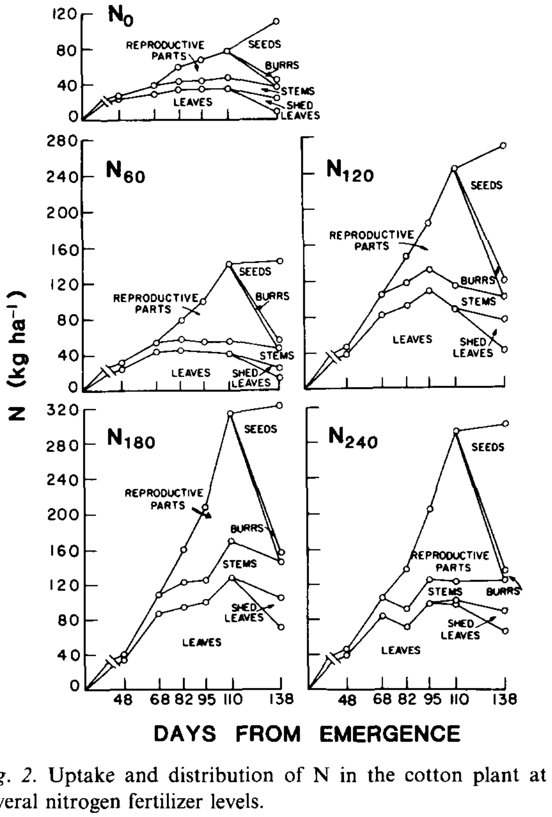

Fig. 2. Uptake and distribution of N in the cotton plant at several nitrogen fertilizer levels.

Phosphorus. Phosphorus content in all plant parts was higher in the low nitrogen treatments (N_0 and N_{60}) than in the higher ones (Table 2). This phenomenon was reported also by other authors, but was not given a satisfactory explanation (Basset and MacKenzie, 1978; Eaton, 1955). Maybe it is partly caused by P dilution with increased growth due to higher N levels.

The uptake and distribution of P in the plant is presented in Fig. 3.

The total uptake of P was 31, 34, 46, 44 and 38 kg ha^{-1} for the five treatments, respectively, similar to that found in earlier work (Halevy, 1976). In the present experiment, the amount removed by

Table 2. Concentration of P in plant parts at different N-levels (%, first stage — last stage)

N-level (kg N ha^{-1})	Plant part		
	Leaf blades	Leaf petioles	Seed (last stage only)
0	0.46–0.35	0.29–0.30	0.82
60	0.42–0.36	0.24–0.16	0.83
120	0.39–0.33	0.22–0.16	0.80
180	0.31–0.22	0.18–0.11	0.76
240	0.35–0.25	0.20–0.14	0.66

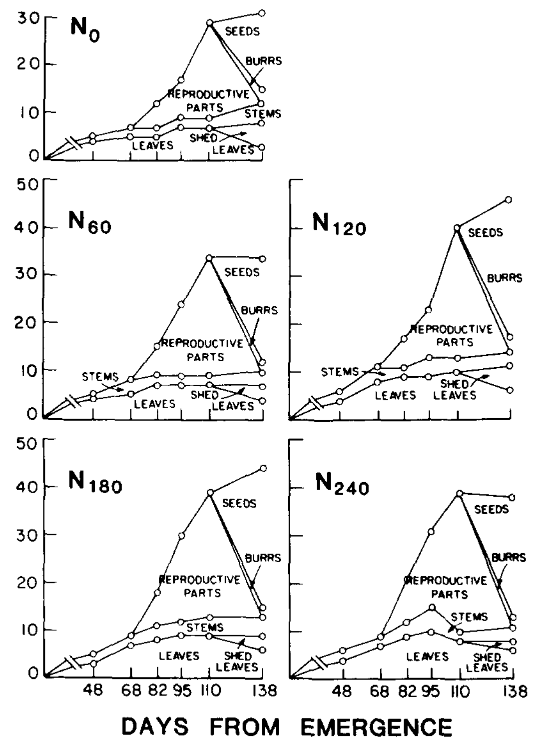

Fig. 3. Uptake and distribution of P in the cotton plant at several nitrogen fertilizer levels.

the seeds was much higher at the higher N levels. It is known that the response of cotton to phosphorus is particularly dependent upon adequate supplies of N (Williams, 1966). The amount of P removed by the seeds for the five N_0 to N_{240} treatments, respectively, was 16, 22, 29, 29 and 25 kg.ha^{-1}. The percentage of the uptake by the seeds out of the total uptake (52, 65, 63, 66 and 66%, respectively) was much greater than in cv. Acala 4-42 or cv. Acala 1517C (Halevy, 1976), as a result of the higher seed yields and P percent in Acala SJ-2, in the present experiment. The uptake of P increased from boll formation to boll opening (95–110 days) due to increased demand by the growing seed (Fig. 3).

Potassium. Some investigators found (Grunes and Krantz, 1958; White, 1965) that at high soil K level an increase in N fertilizer level resulted in a higher percentage of K in the vegetative plant parts. Similar, although not consistent, results were observed in the present experiment. The content of K in the leaves ranged from 2.1–2.6% at the first sampling date to 1.1–2.0% at the end of the growing season. The K content in the burrs was less than 2% in N_0 and more than 4% in the N_{180} treatment, but the content in the seed was 1.4% in N_0 and 1.2 in N_{180}.

The pattern of the K uptake curve (Fig. 4) differs from the dry matter, N and P accumulation curves mainly by the decrease in K after 110 days from emergence. Such a decrease is probably typical of the cotton plant (Eaton and Ergle, 1957). The greatest decrease was detected in N_{120}. The main decrease was in the leaves which began at 95 days presumably due to translocation of K to the reproductive parts. The decrease in K in the plant after 110 days may have been due to movement of K back to the soil (Lawton and Cook, 1954). The total uptake of K for the five (N_0 to N_{240}) treatments was 120, 151, 208, 251 and 230 kg.ha^{-1}, respectively. The corresponding removal of K by the seeds and lint was 35, 42, 58, 58 and 65 kg.ha^{-1} (29, 28, 28, 23 and 28% of total K uptake).

In the present experiment the highest rate of uptake for N_0, N_{60} and N_{120} was between 95 and 110 days, and for N_{180} and N_{240} it was between 82 and 95 days.

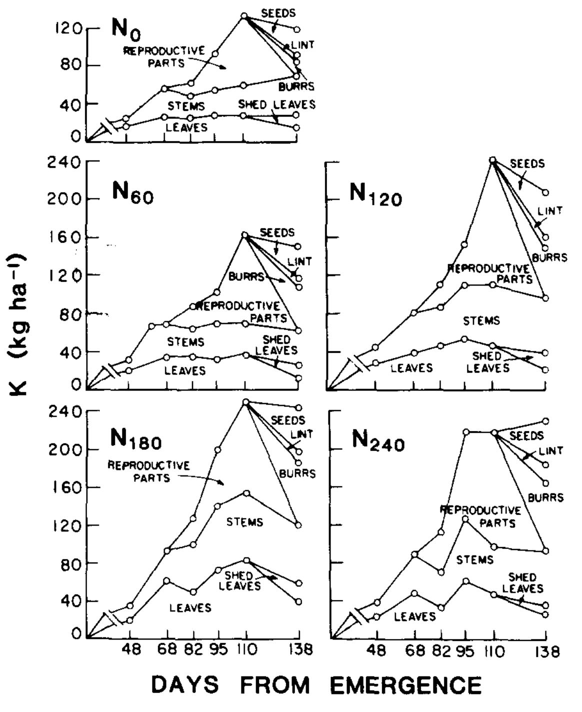

Fig. 4. Uptake and distribution of K in the cotton plant at several nitrogen fertilizer levels.

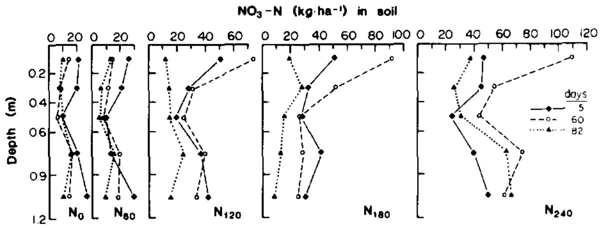

Fig. 5. Distribution of NO_3-N in the soil profiles at several N fertilizer levels on three sampling dates.

Soil analyses. The level of NO_3-N in the soil profile was affected considerably by the N fertilizer treatment (Fig. 5). On the other hand, NH_4-N content was much less affected since conditions during the growth period were favorable for nitrification. Similar results were reported by Feigin *et al.* (1984).

The level of NO_3-N in the N_0 and N_{60} treatments declined from the beginning until 60 days after emergence while it increased in the other treatments, but it declined during the period of 60 to 82 days in all treatments, probably as a result of a high rate of N-uptake during this period (Figs. 2 and 5). Nitrates moved at the higher levels of N from the upper layer to lower layers but they were probably absorbed afterwards by the plants. This corresponds to the results of many cotton fields which did not respond to N fertilizer when high levels of nitrates were found in the soil profile to a depth of 1.20–1.50 m (Halevy, 1979).

The level of P extracted by bicarbonate in the top 20-cm soil layer was between 15 and 25 ppm P, which was found adequate for cotton (Halevy, 1979).

The level of K in a 1:7 $CaCl_2$ solution was 10–12 ppm; this has been reported elsewhere to be adequate for cotton (Halevy, 1977).

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