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Effect of irrigation and nitrogen on soil water dynamics, productivity and input-use efficiency of *Bt* cotton (*Gossypium hirsutum*) in a Vertic Ustropept

K K BANDYOPADHYAY[1], A H PRAKASH[2], K SANKARANARAYANAN[3], B DHARAJOTHI[4] and N GOPALAKRISHNAN[5]

Regional Station, Central Institute for Cotton Research, Coimbatore, Tamil Nadu 641 003

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ABSTRACT

A field experiment was conducted during 2006–08 in a mixed red and black calcareous soil at Coimabtore to study the effect of irrigation levels (protective irrigation and irrigation at 0.6 IW/CPE, 0.8 IW/CPE, 1.0 IW/CPE) and N levels (control, 60 kg N/ha, 90 kg N/ha and 120 kg N/ha) on soil water dynamics, productivity and input-use efficiency of 'RCH 2' Bt cotton (*Gossypium hirsutum* L.) under winter irrigated situation. It was observed that the seed cotton (1 980–2 160 kg/ha) and lint yield (700–772 kg/ha) under different irrigation treatments were statistically at par with the protective irrigation but increased significantly due to nitrogen application. However there was no significant difference among 60, 90 and 120 kg N/ha with respect to seed cotton and lint yield. There was significant reduction in water-use efficiency of cotton with the increase in the level of irrigation but there was increase in the water-use efficiency due to N application over no nitrogen control. However, there was no significant difference in the water-use efficiency due to 60, 90 and 120 kg N/ha. The partial factor productivity of nitrogen decreased significantly with the increase in irrigation and N levels. Thus, 'RCH2*Bt*' cotton hybrid may be grown with protective irrigation and 60 kg N/ha to achieve higher water- and nitrogen-use efficiency without significant yield reduction in winter-irrigated situation in the southern zone of the country.

Key words: *Bt* cotton, Irrigation, Nitrogen, Partial factor productivity of nitrogen, Water-use efficiency

Cotton (*Gossypium hirsutum* L.), one of the major cash crops of India, is popularly known as 'white gold' for its role in the national economy in terms of foreign exchange earnings and employment generation. This crop provides livelihood to 60 million people in India by way of support of agriculture, processing and textiles and it contributes to 29% of the national GDP (Khadi *et al.* 2007). India has the credit of the largest area under cotton (95 lakh ha) and ranks second in cotton production (310 lakh bales, 1 bale = 170 kg) during 2007–08 (Gopalakrishnan 2008). However, in India about 50% of the total pesticides are applied in cotton, which accounts for only 5% of the total cropping area in the country (Ghosh 2001). Among the cotton pests, bollworm (*Helicoverpa armigera* Hubner) alone causes intensive damage to cotton in India, Pakistan, China and Australia, of which in India alone 70% of the insecticide in cotton is applied against this single pest (Natarajan *et al.* 2000). Introduction of *Bt* cotton hybrids has resulted in substantial increase in yields (Qaim and Zilberman 2003, Barwale *et al.* 2004, Morse 2005) owing to effective bollworm control (Perlak *et al.* 2001, Bombawale *et al.* 2003) and the consequent economic benefits and drastic reduction in the use of chemical insecticides leading to environmental benefits (Purcell *et al.* 2004). The rapid increase in the *Bt* cotton area from a merely 29 000 ha since its introduction in 2002 to nearly 66 lakh ha in 2007–08 has significant bearing in increasing the cotton productivity in India. However the productivity of cotton in India (555 kg lint/ha) is below the world average (790 kg lint/ha). Water and nitrogen are the key inputs for improving cotton productivity, which must be used in most efficient manner to sustain the cotton productivity at higher level. On the one hand, it has been reported that moisture stress had adverse effect on cotton yield and on the other hand there are reports that excess irrigation decreased the yield and increased the growing season (Wanjura *et al.* 2002 and Karam *et al.* 2006). Similarly, it has been reported that nitrogen deficiency in cotton reduces vegetative and reproductive growth and induces premature senescence, thereby potentially reducing yields (Tewolde and Fernandez 1997), whereas high N availability may shift the balance between the vegetative and reproductive growth

[1]Senior Scientist (E-mail: kk.bandyopadhyay@gmail.com), [2]Senior Scientist (E-mail: prak_ah@rediffmail.com), [3]Senior Scientist (E-mail: sankaragro@rediffmail.com), [4]Senior Scientist (E-mail: dhara56@yahoo.co.in), [5]Project Coordinator (AICCIP) and Head (E-mail: gopalcotton@gmail.com)

towards excessive vegetative development, thus delaying maturity and reducing yield, harvesting and ginning percentage and promote boll shedding, disease and pest damage. Since both irrigation and nitrogen are costly inputs, efficient utilization of these resources through optimum synergistic combination is essential for higher productivity and input-use efficiency of *Bt* cotton. In this backdrop, a field experiment was undertaken to study the effect of irrigation and nitrogen management on soil water dynamics, productivity and input-use efficiency of *Bt* cotton under winter-irrigated situation in the southern zone of the country.

MATERIALS AND METHODS

The field experiment was carried out during 2006–07 and 2007–08 in a mixed red and black calcareous soil (Vertic Ustropept) of Periyanaiken Palayam series at the Central Institute for Cotton Research, Regional Station, Coimbatore (11°N latitude and 77°E longitude and 426.7 m above mean sea level), Tamil Nadu. The soil of the experimental site was sandy clay loam in texture (31% Clay) having bulk density of 1.35 Mg/m^3 and soil water content on volume basis at 0.33 bar and 15 bar suction was 35.5% and 24.1% respectively. The *p*H of the soil was 8.27 with 0.69% soil organic carbon and 0.186 dS/m electrical conductivity. The soil was low in available N (295 kg N/ha) and available P (6.0 kg P/ha) but high in available K (625 kg K/ha). Coimbatore falls under semi-arid zone with the normal weather condition (25 yeas mean) include a mean annual rainfall of 674.2 mm received in 49 rainy days. The mean maximum and minimum temperatures are 31.5°C and 21°C respectively. The mean relative humidity ranges from 58 to 63% and mean bright sunshine hours is 7.3 with mean solar radiation of 429.2 cal/cm^2/day.

'RCH2 *Bt*' cotton was grown with a spacing of 90 cm×60 cm under ridge and furrow system with 4 levels of irrigation, viz. I_1: protective irrigation and I_2: irrigation at 0.6 IW/CPE, I_3:0.8 IW/CPE, I_4; 1.0 IW/CPE and 4 N levels, viz, N_1: Control, N_2:60 kg N/ha, N_3:90 kg N/ha and N_4:120 kg N/ha in a split-plot design. Protective irrigation refers to one irrigation at sowing, one life saving irrigation within one week after sowing and one irrigation after earthing-up operation at 45–50 days after sowing in the absence of rainfall. Nitrogen was applied as urea in 2 equal splits of 50% as basal and 50% as top-dressing during the earthing-up operation. Phosphorus and potassium were applied at the recommended dose of 45 kg P_2O_5/ha and 45 kg K_2O/ha as single superphosphate and muriate of potash, respectively to all the plots.

Soil moisture content of the effective root zone (0–60 cm) was determined thermo-gravimetrically at 15 days interval during the crop growth period to study the distribution and redistribution of soil water in the profile.

Evapo-transpiration (ET) was computed by water balance method using the following equation:

$$ET = P + I + Cp - Dp - Rf - \Delta S$$
$$= P_{eff} + I - (S_f - S_i)$$

Where P is precipitation, I is depth of irrigation, Cp is contribution through capillary rise from the water table, Dp is deep percolation loss, Rf is runoff, ΔS is charge in soil moisture storage in the profile, S_f is final moisture storage in the profile at harvest, S_i is initial moisture storage in the profile at sowing, Peff is effective precipitation. Effective precipitation was computed from daily rainfall data by FAO method (Brouwer and Heibloem 1986).

Water-use efficiency (WUE) was computed by dividing the seed cotton yield with the seasonal evapotranspiration. Water productivity was computed as the price of the produce per unit quantity of the consumptive use of water.

After the harvest of the crop, representative plant samples were collected and analyzed for total N by kjeldhal method (AOAC 1970). Then using the biomass data, the N uptake by the crop was determined.

Nitrogen-utilization efficiency was computed as the kg of seed cotton produced/kg of N uptake and partial factor productivity of N was computed as the kg of seed cotton produced/kg of N applied.

The fibre quality parameters were determined by the high volume instrument (HVI). The chlorophyll content of the fourth fully opened cotton leaf from top was determined at the peak flowering stage following standard procedures.

The earliness index (EI) was estimated using the following formula:

$$EI = (1/N)\{(Y_1/T) + (Y_1+Y_2)/T.......\}$$

Where Y_1 is seed cotton yield at first picking, Y_2 is the seed cotton yield at second picking, T is the total seed cotton yield and N is the number of total pickings.

Fibre quality index (FQI) was calculated using the following formula:

$$FQI = \frac{L \times S}{\sqrt{M}}$$

Where L is 2.5% span length in mm, S is Bundle strength in g/tex and M is Micronaire value in μg/inch.

The statistical analysis of the data was carried out following the analysis of variance as outlined by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect of irrigation management

Soil water dynamics: The peaks in the soil water storage (Figs 1, 2) during 2006–07 and 2007–08 indicate profile recharge either due to irrigation or rainfall events. In both the years during the later part of the crop growth, the crop suffered from moisture stress under protective irrigation treatment (I_1) due to withdrawal of monsoon.

Nitrogen uptake and chlorophyll content: Nitrogen uptake by the seed cotton, cotton stalk and the total nitrogen uptake increased significantly with the increase in the level of irrigation. This is mainly attributed to higher biomass

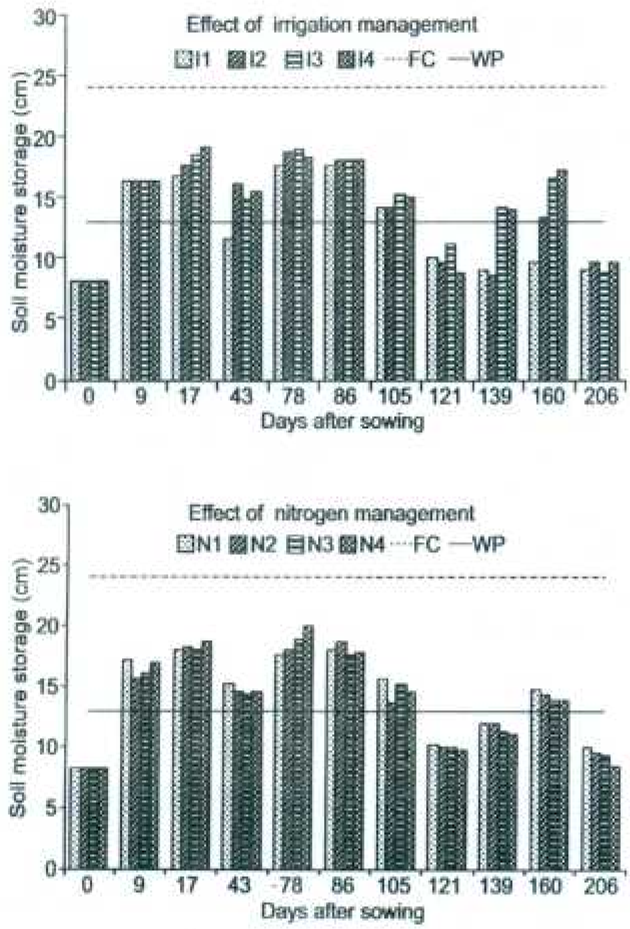

Fig 1 Temporal variation in the soil moisture storage in the root zone (0–60 cm) as influenced by (a) irrigation management and (b) nitrogen management during the year 2006–07; FC is field capacity and WP is wilting point

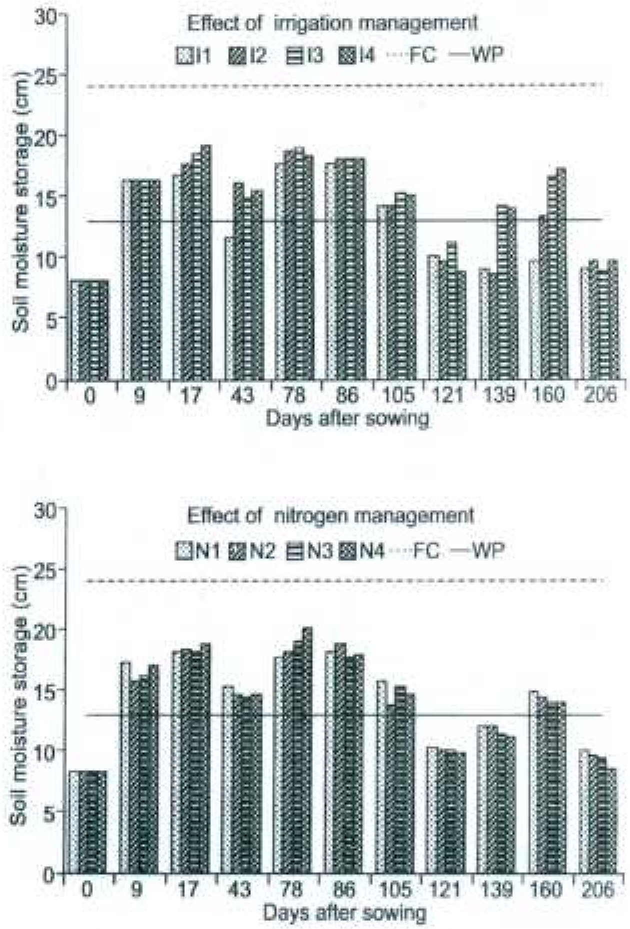

Fig 2 Temporal variation in the soil moisture storage in the root zone (0–60 cm) as influenced by (a) irrigation management and (b) nitrogen management during the year 2007–08; FC is field capacity and WP is wilting point

Table 1 Nitrogen uptake as influenced by irrigation and nitrogen management (pooled over 2006–07 and 2007–08)

Treatment	N uptake by seed cotton (kg/ha)	N uptake by stalks(kg/ha)	Total N uptake (kg/ha)
Irrigation			
Protective irrigation@	29.0	35.2	64.2
0.6 IW/CPE	25.7	58.4	84.1
0.8 IW/CPE	49.1	34.0	83.1
1.0 IW/CPE	41.5	57.1	98.6
Nitrogen			
Control	26.8	42.3	69.1
60 kg N/ha	32.3	48.1	80.4
90 kg N/ha	46.9	47.2	94.1
120 kg N/ha	39.3	47.1	86.4
CV (%)	12.0	20.1	12.0
LSD (I)	3.7**	7.5**	9.1**
LSD (N)	2.9**	NS	6.5**

@ Protective irrigation at sowing and 7 and 45 days after sowing in the absence of rainfall

** significant at $P<0.01$; NS is not significant

Table 2 Chlorophyll content in cotton leaf (RCH2Bt) at flowering stage

Treatment	Chlorophyll-a (mg/g)	Chlorophyll-b (mg/g)	Total Chlorophyll (mg/g)
Irrigation			
Protective irrigation@	1.029	0.320	1.348
0.6 IW/CPE	1.066	0.321	1.387
0.8 IW/CPE	1.195	0.380	1.574
1.0 IW/CPE	1.027	0.311	1.338
Nitrogen			
Control	0.789	0.243	1.032
60 kg N/ha	1.131	0.360	1.491
90 kg N/ha	1.147	0.345	1.493
120 kg N/ha	1.249	0.383	1.632
CV (%)	0.25	2.40	0.56
LSD (I)	0.002**	0.008**	0.008**
LSD (N)	0.002**	0.007**	0.007**

@ Protective irrigation at sowing and 7 and 45 days after sowing in the absence of rainfall

** significant at $P<0.01$

Table 3 Seed cotton yield, lint yield and earliness index as influenced by irrigation and nitrogen management (pooled over 2006–07 and 2007–08)

Treatment	Seed cotton yield (kg/ha)	Lint yield (kg/ha)	Earliness index
Irrigation			
Protective irrigation@	2160	772	0.87
0.6 IW/CPE	2056	731	0.86
0.8 IW/CPE	1980	700	0.87
1.0 IW/CPE	2103	745	0.83
Nitrogen			
Control	1820	652	0.88
60 kg N/ha	2087	749	0.87
90 kg N/ha	2203	774	0.85
120 kg N/ha	2189	774	0.85
CV (%)	12.4	12.2	3.2
LSD (I)	NS	NS	0.027**
LSD (N)	170.5**	59.3**	0.018**

@ Protective irrigation at sowing and 7 and 45 days after sowing in the absence of rainfall

** $P<0.01$; NS, not significant

Table 4 Fibre quality parameters of RCH2 Bt cotton as influenced by irrigation and nitrogen management (pooled over 2006–07 and 2007–08)

Treatment	2.5% Span length (mm)	Strength (g/tex)	Micronaire (µg/inch)	Fibre quality index
Irrigation				
Protective irrigation@	28.9	20.9	4.49	284.5
0.6 IW/CPE	29.1	20.6	4.52	281.5
0.8 IW/CPE	28.8	20.9	4.53	283.7
1.0 IW/CPE	29.0	20.9	4.58	283.9
Nitrogen				
Control	28.5	20.9	4.39	284.2
60 kg N/ha	29.0	20.4	4.58	276.5
90 kg N/ha	29.2	21.2	4.55	289.5
120 kg N/ha	29.2	20.8	4.60	283.5
CV (%)	1.9	4.7	3.2	5.7
LSD (I)	NS	NS	NS	NS
LSD (N)	NS	NS	NS	NS

@ Protective irrigation at sowing and 7 and 45 days after sowing in the absence of rainfall

NS, not significant

production at higher irrigation levels (Table 1). The nitrogen harvest index, the proportion of nitrogen uptatke in seed cotton, was maximum when irrigation was applied at 0.8 IW/CPE.

The Chlorophyll a, Chlorophyll b and the total Chlorophyll content of the cotton leaf at peak flowering stage increased significantly in different irrigation treatments compared to the protective irrigation up to irrigation applied at 0.8 IW/CPE (Table 2).

Seed cotton yield, lint yield, earliness index and fibre quality indices: The seed cotton yield and lint yield under different irrigation treatments were statistically at par with the protective irrigation (Table 3). Cotton is a semi-xerophytic and stress-loving crop. Even if there was slight moisture stress under the protective irrigation in the later part of the crop growth, the crop could cope up with that stress. With the increase in the irrigation level, the vegetative growth phase was prolonged and the maturity got delayed, which ultimately resulted in lower earliness index (Table 3). Singh *et al.* (2001) reported that in a light texured soil of Haryana, irrigation frequencies did not significantly affect the yield of cotton due to even rainfall distribution through out the year. Different fibre quality parameters like 2.5% span length, fibre strength, micronair and the fibre quality index were not significantly influenced by the irrigation treatments (Table 4).

Water-use efficiency: Water-use efficiency by 'RCH2' *Bt* cotton decreased significantly with the increase in the levels of irrigation (Table 5). This is mainly attributed to the loss of water through evaporation and deep percolation at higher irrigation levels. Water productivity by cotton also followed similar trend as the water-use efficiency and it decreased from Rs 12.5/m^3 under protective irrigation to Rs 7.64/m^3 under irrigation at 1.0 IW/CPE. Therefore, the consumptive use of water to produce one kg of seed cotton yield increased from 2.04 m^3 under protective irrigation to 3.42 m^3 under irrigation at 1.0 IW/CPE.

Nitrogen-use efficiency: The partial factor productivity

Table 5 Water-use efficiency, water productivity and water use by RCH2 Bt cotton under different water and nitrogen management practices (pooled over 2006–07 and 2007–08)

Treatment	Water-use efficiency (kg SCY/ha-cm)	Water productivity (Rs/m^3)	Water use (m^3/kg SCY)
Irrigation			
Protective irrigation@	52.1	12.50	2.04
0.6 IW/CPE	38.7	9.27	2.71
0.8 IW/CPE	31.6	7.50	3.23
1.0 IW/CPE	31.6	7.64	3.42
Nitrogen			
Control	33.5	7.99	3.18
60 kg N/ha	38.9	9.32	2.80
90 kg N/ha	40.9	9.78	2.65
120 kg N/ha	40.8	9.78	2.78
CV (%)	12.2	11.9	12.2
LSD (I)	3.6**	0.87**	0.28**
LSD (N)	3.1**	0.72**	0.23**

@ Protective irrigation at sowing and 7 and 45 days after sowing in the absence of rainfall

** significant at $P<0.01$; SCY is seed cotton yield

Table 6 Nitrogen-use efficiency parameters of RCH2 Bt cotton under different water and nitrogen management practices (pooled over 2006–07 and 2007–08)

Treatment	Partial factor productivity of N (kg SCY/kg N applied)	N Utilization efficiency (kg SCY/ kg N uptake)	N requirement (kg N uptake/ tonne SCY)
Irrigation			
Protective irrigation@	27.3	37.7	33.5
0.6 IW/CPE	25.0	25.6	44.5
0.8 IW/CPE	23.9	24.5	48.6
1.0 IW/CPE	25.8	22.4	53.6
Nitrogen			
Control		28.7	44.6
60 kg N/ha	34.8	28.1	44.7
90 kg N/ha	23.5	23.7	46.1
120 kg N/ha	18.2	29.7	45.0
CV (%)	10.4	14.5	12.8
LSD (I)	1.96*	2.7**	3.6**
LSD (N)	1.78**	2.6**	NS

@ Protective irrigation at sowing and 7 and 45 days after sowing in the absence of rainfall

**P<0.01;* significant at P<0.05;NS, not significant; SCY, seed cotton yield

of nitrogen and the nitrogen-utilization efficiency under higher irrigation levels decreased significantly than the protective irrigation (Table 6). This may be attributed to the losses of N at higher level of irrigation. Therefore, to produce one tonne of seed cotton, the requirement of N uptake by the crop increased from 33.5 kg under protective irrigation to 53.6 kg under irrigation at 1.0 IW/CPE.

Effect of nitrogen management

Soil water dynamics: In both the years, during the period of water stress after the withdrawal of monsoon, relatively higher soil moisture storage was recorded under no nitrogen control (Figs 1, 2). This may be attributed to lower biomass production and hence lower evapo-transpiration demand under this treatment.

Nitrogen uptake and chlorophyll content: It was observed that N application significantly improved the nitrogen uptake by seed cotton and the total nitrogen uptake by the seed cotton and stalk compared to the no nitrogen control (Table 1). However, with the increase in the N level, the N uptake increased significantly up to 90 kg N/ha and there was no significant difference between the N uptake at 90 and 120 kg N/ha. The nitrogen harvest index, the proportion of nitrogen uptake in seed cotton, increased significantly with the increase in N level up to 90 kg N/ha.

The chlorophyll-a, chlorophyll-b and the total chlorophyll content of cotton leaf at peak flowering stage increased significantly with the increase in the N level (Table 2). The total nitrogen uptake by seed cotton and the stalk was significantly positively correlated with the chlorophyll-a (r = 0.68**), chlorophyll-b (r = 0.64**) and the total chlorophyll content (r = 0.67**) of cotton leaf at peak flowering stage.

Seed cotton yield, lint yield, earliness index and fibre quality indices: Seed cotton yield and lint yield of 'RCH2' *Bt* cotton improved significantly due to nitrogen application (Table 3). However there was no significant difference among 60, 90 and 120 kg N/ha with respect to seed cotton and lint yield. High N availability might have shifted the balance between the vegetative and reproductive growth towards excessive vegetative development, thus delaying maturity and reducing yield, harvesting and ginning percentage and promoted boll shedding, disease and pest damage. Singh *et al.* (1993) reported that in loamy sand soil at Ludhiana, N level beyond 60 kg N/ha led to increase in vegetative growth at the cost of economic yield. Therefore, there was significant decrease in the earliness index at higher level of N application (Table 3). The lower value of earliness index indicates delayed maturity and higher seed cotton yield at later picking than earlier picking. It has been observed that the percentage of bad kapas increases and the fibre quality declines at later picking. Fibre quality parameters like 2.5% span length, fibre strength, micronaire and fibre quality index were not significantly influenced by the levels of N application (Table 4).

Wate-use efficiency: Water-use efficiency of 'RCH2' *Bt* cotton increased significantly due to N application (Table 5). However, there was no significant difference between 60, 90 and 120 kg N/ha with respect to water-use efficiency. Water productivity followed the similar trend as that of water use efficiency. The consumptive use of water to produce one kg of seed cotton yield was maximum for no nitrogen control and it decreased with the increase in the N level.

Nitrogen-use efficiency: The partial factor productivity of nitrogen decreased with the increase in the N level (Table 6). This may be attributed to the fact that with the increase in the N level, there was not proportionate increase in the seed cotton yield and there was increase in the losses of N through leaching, volatilization and deep percolation. However, the nitrogen requirement was not significantly influenced by the N levels. Whereas the nitrogen utilization efficiency at 90 kg N/ha was significantly lower than other N levels. This may be attributed to the fact that the seed cotton yield did not commensurate with the N uptake at 90 kg N/ha.

Thus it may be concluded that 'RCH2' *Bt* cotton hybrid may be grown with protective irrigation and 60 kg N/ha to achieve higher water and nitrogen-use efficiency without significant yield reduction in winter-irrigated situation in the southern zone of the country.

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