Full Length Research Paper

Relative response of Bt cotton (*Gossypium hirsutum*) to balanced fertilization in irrigated cotton-wheat cropping system

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A field experiment on nutrient omission plot technique (NOPT) on Bt cotton-wheat cropping system was conducted at research farm of the Division of Agronomy Indian Agricultural Research Institute, New Delhi during rainy season of 2010 and 2011. The experiment had 10 treatments, laid out in Randomized Block Design with three replications in fixed plots. Treatments comprised omission of N, P, K, S and Zn, 50% omission of N, P, and K, absolute control (no nutrient applied) and optimum plane of nutrition (150-26.4-50-15-3 kg ha⁻¹ N-P-K-S-Zn). Same nutrient omission treatments were tested on wheat keeping the plots fixed. Yield was estimated in terms of seed cotton, lint, seed and oil yield. The uptake of nutrients in omission plots gave an estimate of the indigenous soil nutrient supply and nutrient use efficiencies. Results showed that N was the most limiting factor nutrient and there was a reduction in the seed cotton yield to the tune of 28, 6.5 and 14.5% due to N, P and K omissions during the year 2010. The corresponding figures for the year 2011 were 26.5, 15.5 and 12.4%, respectively. N continued to be the most limiting nutrient followed by P and K during the year 2011. P omission led to the higher yield reduction during the second year of experimentation which proves that P supplies fast depleted in the cotton-wheat cropping than the K supply. Lint yield followed similar trends. The yield reduction due to S and Zn omission ranged from 2.0 to 5.0% which was statistically at par with the plots under balanced fertilization both the years.

Key words: Seed cotton yield, lint yield, nutrient omissions, nutrient concentration, nutrient uptake, nutrient use efficiency.

INTRODUCTION

Cotton is the most important commercial crop of India, often referred as the 'White Gold' providing employment to about 60 million people, is cultivated on an area of 11.1 m ha and out of which the area under Bt cotton has already crossed 90% (CICR, 2011). Of the cotton pests, the American boll worms alone cause a yield reduction of 40 to 70% under severe infestation. An alternate strategy to circumvent this problem was followed by cloning and transferring the genes encoding the toxic crystal δ-endotoxin protein from the soil bacterium *Bacillus thuringiensis to cotton*. The Bt transgenic cotton (Bollgard of Monsanto) was developed successfully in USA, having the ability to control the bollworms during crop growth effectively. In India, cotton wheat cropping system is followed on 1.40 m ha and on 2.62 m ha in Pakistan. The total area under cotton-wheat cropping system comes to about 4.0 m ha in the north-western plains of India and Pakistan. In North zone (Punjab, Haryana and Rajasthan),

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cotton is cultivated under irrigation in 1.50 m ha and is rotated mostly (90%) with wheat (*Triticum aestivum* L. emend. Fiori and Paol) (Mayee et al., 2008).

Impact of nitrogen (N) and potassium (K) fertilization on yield and yield components are well documented but their combined effects on Bt cotton are poorly understood. N or K application increased lint yield, and a combination of high plant density, N and K application further improved lint yield in the lower fertility field, while only K application increased lint yield in the higher fertility field (Dong et al., 2010). Similarly, Blaise et al. (2005) reported that NP and NPK plots yielded more seed cotton than the PK or NK plots, so little response to K was observed. Cheng-Song et al. (2010) reported that NPK treatment obtained the highest biomass and lint yield among the treatments, and the lint yields were enhanced, compared to the corresponding controls, by 2.53, 28.67 and 30.47% in the low, middle, and high salinity soils, respectively. Significant reduction in seed cotton yields was reported due to P and K omissions. NP and NPK treatments had significantly higher nutrient uptake levels in plants in the 3 types of saline soils, and significantly especially the NPK treatment. The nutrient use efficiencies of cotton were the highest for NPK treatment regardless the salinity level. The response of cotton to major nutrients is highly site specific, governed by the indigenous nutrient supply apart from variety, soil condition and climate.

Cotton, particularly hybrids being exhaustive, draw plenty of soil nutrients and thus under continuous cropping pattern nutrient management assumes importance. Nutrient recommendation varies with crop response, soil condition and the cropping system followed. Cotton and wheat are exhaustive crops as evident from the fact that they remove 43.2-29.3-53.3-24.0 and 25.0-9.0-33.0-4.7 kg of N-P-K-S t⁻¹ of economic product, respectively (Tandon, 2004). An estimated 150 ± 6 (Mullins and Burmester, 1993) and 294.3 g (Mishra et al., 2006) of zinc are also removed by every tonne of cotton lint and wheat grain produced, respectively.

To cater to the uptake needs of these crops, soil reserves alone are not sufficient making it is necessary to supply them through chemical fertilizers. However, the fertilizers applied are either insufficient or imbalanced and not based on soil supply capacity after suitably taking into consideration the fertilizer contribution and crop requirements that is leading to un-sustainability of the production systems. Hence, initiatives are made in recent years through nutrient omission approaches to assess the soil and fertilizer contributions to the crop performance and finally arrive at site specific nutrient management recommendations for targeted and sustainable yield. Such studies are currently being carried out in rice/maize-wheat cropping systems only. Therefore, keeping the above facts in view, a field experiment was conducted to assess the response of cotton to the balanced fertilization through nutrient omission experiment in cotton wheat cropping system.

**MATERIALS AND METHODS**

**Climate and soil**

A field experiments on Bt cotton was conducted during the rainy seasons of years 2010 and 2011 following cotton-wheat cropping system, at the research farm of the Indian Agricultural Research Institute, New Delhi (India). New Delhi is situated at 28°35'N latitude and 77°12'E longitude at an altitude of about 228.61 m above mean sea level. It has a semi-arid and sub-tropical climate with hot dry summers and severe cold winters. The mean maximum temperature in June, which is the hottest month of the year, ranges from 40 to 45°C associated with hot dry winds and sand storms. The mean annual rainfall is about 650 mm, of which nearly 80% is received during the monsoon period extending from July to September and the rest during the period between October and May. The mean daily U. S. Weather Bureau Class ‘A’ open pan evaporation value reaches as high as 10.9 mm in the month of June and as low as 1.5 mm in the month of January. Mean relative humidity attains the maximum value (85 to 90%) during the south-west monsoon and the minimum (30 to 45%) during the summer months.

The meteorological data for the rainy seasons of 2010 and 2011 recorded at the meteorological observatory of Indian Agricultural Research Institute, New Delhi are depicted graphically in Figure 1. The experimental field was under pigeonpea-wheat, sorghum-wheat and cotton-wheat cropping systems during the preceding three years. Soil samples were collected from ten different places (0 to 30 cm depth) at the experimental site before the start of the experiment. The soil was mixed thoroughly to make composite representative sample, shade dried for two weeks, passed through 2 mm sieve and analyzed for soil physical and chemical properties. The main physical and chemical properties are presented in Table 1.

**Treatment details**

The experiment had 10 treatments laid out in Randomized Block Design with three replications in fixed plots (Table 2). Treatments comprised omission of N, P, K, S and Zn, 50% omission of N, P and K, absolute control (no nutrient applied) and optimum plane of nutrition (150-26.4-50-15-3 kg ha⁻¹ N-P-K-S-Zn). Same treatments were repeated in wheat in fixed plots. The fertilizers used were urea (46% N), triple superphosphate (46% P₂O₅), muriate of potash (60% K₂O), gypsum (15% S) and zinc oxide (81% Zn) so that each fertilizer shall supply only a single nutrient under investigation. The nutrient doses given to cotton are summarized in Table 2.

The cotton variety used was transgenic ‘Rasi 134 BG II’ with stacked genes, *cry1ac* and *cry1ab* for resistance against American bollworm and tobacco caterpillar (*Spodoptera litura* Fabricius). The variety is medium tall with bushy growth habit having a ginning percentage of 37% and staple length of 27 to 28 mm.

**Cultural practices**

The experimental plot was given a pre sowing irrigation during both the years and the fertilizer was incorporated two days before sowing. The optimum fertilizer dose was decided on the basis of the fertilizer recommendations of the Central Institute of Cotton Research for hybrid cottons in Haryana State with the assumption that the crop growth will not be limited at the recommended dose.

Cotton was sown on 28th of May and 1st of June during the year 2010 and 2011, respectively. The plot area was 6.3 m x 3.6 m accommodating 7 rows of Bt cotton, planted at a spacing of 90 cm x 45 cm. Two to three seeds were dibbled and the crop was thinned 15 days after sowing (DAS) to maintain optimum plant population.
Pre emergence spray of pendimethalin at 1.0 kg a.i ha⁻¹ was followed by hand weeding at 45 DAS to control the weeds. The crop was also given two need based insecticide sprays of monocrotophos at 0.04% to control the pests.

**Sampling and measurements**

The harvesting was completed in two pickings and the seed cotton from the central three rows was taken as net plot. Seed cotton from

![](image)

**Figure 1.** Mean weekly meteorological data during rainy seasons of 2010 and 2011.

![](image)

**Table 1.** Physical and chemical properties of the surface profile (0-30 cm) of the experimental site measured in 2010.

<table>
<thead>
<tr>
<th>Particular</th>
<th>Values/ Status</th>
<th>Method followed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mechanical analysis</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand (%)</td>
<td>69.8</td>
<td>Hydrometer method (Bouyoucos, 1962)</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>13.5</td>
<td></td>
</tr>
<tr>
<td>Clay (%)</td>
<td>16.7</td>
<td></td>
</tr>
<tr>
<td>Textural class</td>
<td>Sandy loam</td>
<td></td>
</tr>
<tr>
<td><strong>Chemical properties</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic carbon (g kg⁻¹)</td>
<td>4.3</td>
<td>Walkley and Balck method (Jackson, 1973)</td>
</tr>
<tr>
<td>Available N (mg kg⁻¹)</td>
<td>87.3</td>
<td>Alkaline permanganate method (Subbiah and Asija, 1956)</td>
</tr>
<tr>
<td>Total N (g kg⁻¹)</td>
<td>0.48</td>
<td>Kjedahl method (Jackson, 1973)</td>
</tr>
<tr>
<td>Available P (mg kg⁻¹)</td>
<td>5.6</td>
<td>Olsen’s method (Olsen et al., 1954)</td>
</tr>
<tr>
<td>Total P (g kg⁻¹)</td>
<td>0.53</td>
<td>Olsen and Sommers (1982)</td>
</tr>
<tr>
<td>Water soluble K (mg kg⁻¹)</td>
<td>14.9</td>
<td>Flame photometer method (Jackson, 1973)</td>
</tr>
<tr>
<td>Exchangeable K (g kg⁻¹)</td>
<td>0.13</td>
<td>Flame photometer method (Jackson, 1973)</td>
</tr>
<tr>
<td>Non exchangeable K (g kg⁻¹)</td>
<td>1.51</td>
<td>Flame photometer method (Jackson, 1973)</td>
</tr>
<tr>
<td>Available S (mg kg⁻¹)</td>
<td>15.2</td>
<td>Williams and Steinberg (1959)</td>
</tr>
<tr>
<td>Available Zn (mg kg⁻¹)</td>
<td>0.88</td>
<td>Lindsay and Norvell (1978)</td>
</tr>
<tr>
<td>pH (1:2.5: soil:water ratio)</td>
<td>7.8</td>
<td>Beckman’s pH meter (Piper, 1950)</td>
</tr>
<tr>
<td>ECe (dSm⁻¹)</td>
<td>0.32</td>
<td>Richards (1954)</td>
</tr>
</tbody>
</table>
each net plot was dried and weighed. A sample of 500 g seed cotton was taken randomly from each plot and ginned on roller ginning machine to separate it into seed and cotton. A random sample of 100 cotton seeds was weighed and expressed as seed index (g). The 10 g cotton seed sample was used for oil content determination using Nuclear Magnetic Resonance (NMR) model MQC of the Oxford Instruments.

The cotton sticks from each net plot were cut at ground level, field dried and weighed. Samples of stalk were ground after oven drying at 70°C to constant weight. Samples of stalk, seed and fiber were digested in sulphuric acid for total N content estimation using Kjeldahl digestion and distillation procedure. Di-acid (HClO4 + HNO3) digestion was used for the estimation of total P, K, S and Zn in plant samples. P concentration was estimated through vanadomolybdate yellow colour method (Jackson, 1973) and K concentration was measured using flame photometry. S content was determined through turbidity method (Tabatabai and Bremner, 1970) and Zn content through atomic absorption spectrometer.

### Table 2. Fertilizer nutrient rates (kg ha⁻¹) for the nutrient omissions treatments applied to Bt cotton during the year 2010 and 2011.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>S</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPKSZn (N-P-K)</td>
<td>150</td>
<td>26.4</td>
<td>50</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>PKSZn (-N)</td>
<td>0</td>
<td>26.4</td>
<td>50</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>NKSZn (-P)</td>
<td>150</td>
<td>0</td>
<td>50</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>NPSZn (-K)</td>
<td>150</td>
<td>26.4</td>
<td>0</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>NPKZn (-S)</td>
<td>150</td>
<td>26.4</td>
<td>50</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>NPKS (-Zn)</td>
<td>150</td>
<td>26.4</td>
<td>50</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Control</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>NPKSZn (-50%)</td>
<td>75</td>
<td>26.4</td>
<td>50</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>NPKS (-50P)</td>
<td>150</td>
<td>13.2</td>
<td>50</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>NPKS (-50K)</td>
<td>150</td>
<td>26.4</td>
<td>25</td>
<td>15</td>
<td>3</td>
</tr>
</tbody>
</table>

Apparent recovery P (ARP %) = (U_{NPKSZn} - U_{NPKS})/PA x 100

Apparent recovery K (ARK %) = (U_{NPKSZn} - U_{NPKS})/KA x 100

Where U_{NPKSZn}, U_{PKSZn}, U_{NKSZn} and U_{NPSZn} are the seed cotton yield in optimum nutrition, N, P and K omission plots, respectively. NA, PA and KA are the amounts of N, P and K kg ha⁻¹ applied in the treatment plots. U_{NPKSZn}, U_{PKSZn}, U_{NKSZn} and U_{NPSZn} are the uptake of respective nutrients in the above ground biomass in optimum nutrition, N, P and K omission treatments.

### Fertilizer computations for targeted yield

Fertilizer N/P/K (kg/ha) = (U_{NP/K} - INS_{NP/K}) / AR(%) , where U_{NP/K} is the plant N/P/K uptake requirement for the yield goal (kg/ha), INS_{NP/K} is the indigenous N/P/K supply measured as plant N/P/K uptake in a 0 N, 0 P and 0 K plots, respectively. AR(%) is the apparent recovery efficiency of respective nutrients (Doberman and Fairhurst, 2000).

### Data analysis

The statistical analysis of the data was performed using Microsoft Excel and MSTAT-C software's. Statistical significance between mean differences among treatments for various parameters such as yield attributes, above ground biomass, seed cotton yield, ginning percentage, cotton yield, oil content, yield N, P, K content and uptake etc. were analyzed using critical differences (CD) at 0.05 probability level. Regressions equations were computed to quantify the relationship between seed cotton yield and yield attributes, seed cotton yield and N, P and K uptake. Pearson correlation coefficients were also computed to assess the strength of relationship between seed cotton yield and yield components using MS-Excel software.

### RESULTS

The mean weekly minimum and maximum temperatures varied between 14.2 to 28.9°C and 23.2 to 41.5°C during the year 2010 and 10.7 to 27.2°C and 26.8 to 39.2°C during the year 2011, respectively (Figure 1). The corresponding figures for the sunshine hours day were 1.51 to 7.1 for the year 2010 and 1.61 to 7.98 for the year 2011, respectively. The corresponding figures for the
The effect of various nutrient omission treatments on yield and yield attributes of cotton.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Sympodials plant$^{-1}$</th>
<th>Bolls plant$^{-1}$</th>
<th>Unopened bolls plant$^{-1}$</th>
<th>Boll weight (g)</th>
<th>Stalk yield (t ha$^{-1}$)</th>
<th>Seed cotton yield (t ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPKSZn</td>
<td>34.4 34.3</td>
<td>46.7 43.9</td>
<td>18.0 15.5</td>
<td>4.5 4.3</td>
<td>7.68 7.21</td>
<td>3.42 3.24</td>
</tr>
<tr>
<td>PKSZn (-N)</td>
<td>23.0 21.7</td>
<td>35.7 31.4</td>
<td>11.6 9.7</td>
<td>3.9 3.3</td>
<td>5.06 4.11</td>
<td>2.45 2.39</td>
</tr>
<tr>
<td>NKSZn (-P)</td>
<td>33.0 31.4</td>
<td>45.4 38.6</td>
<td>16.8 13.3</td>
<td>3.9 3.9</td>
<td>7.55 6.75</td>
<td>3.18 2.73</td>
</tr>
<tr>
<td>NPSZn (-K)</td>
<td>33.4 32.1</td>
<td>41.4 37.8</td>
<td>13.9 14.5</td>
<td>3.8 4.3</td>
<td>6.93 6.36</td>
<td>2.91 2.83</td>
</tr>
<tr>
<td>NPKZn (-S)</td>
<td>34.4 34.3</td>
<td>44.5 35.6</td>
<td>14.6 14.7</td>
<td>4.3 4.1</td>
<td>7.29 6.87</td>
<td>3.21 3.09</td>
</tr>
<tr>
<td>NPKS (-Zn)</td>
<td>35.0 33.3</td>
<td>47.8 37.2</td>
<td>17.2 14.6</td>
<td>4.4 4.2</td>
<td>7.72 6.95</td>
<td>3.34 3.05</td>
</tr>
<tr>
<td>Control</td>
<td>22.4 21.1</td>
<td>28.4 29.1</td>
<td>8.9 9.1</td>
<td>2.7 2.7</td>
<td>4.56 3.80</td>
<td>2.27 2.17</td>
</tr>
<tr>
<td>(-50%N)</td>
<td>30.4 29.8</td>
<td>40.1 33.8</td>
<td>13.2 11.8</td>
<td>3.9 4.1</td>
<td>7.05 5.85</td>
<td>2.98 2.83</td>
</tr>
<tr>
<td>(-50%P)</td>
<td>34.4 33.7</td>
<td>45.4 36.6</td>
<td>11.6 13.1</td>
<td>4.3 4.1</td>
<td>7.44 6.71</td>
<td>3.34 2.97</td>
</tr>
<tr>
<td>(-50%K)</td>
<td>34.6 32.6</td>
<td>47.6 37.6</td>
<td>13.2 13.9</td>
<td>3.9 4.3</td>
<td>7.58 7.00</td>
<td>3.13 3.05</td>
</tr>
<tr>
<td>CD (P = 0.05)</td>
<td>2.57 1.93</td>
<td>5.15 5.96</td>
<td>3.43 2.6</td>
<td>0.34 0.28</td>
<td>0.70 0.96</td>
<td>0.43 0.37</td>
</tr>
</tbody>
</table>

mean minimum and maximum weekly relative humidity ranged from 33.1 to 90.2% and 48.5 to 88.2% during the year 2010 and 2011, respectively. The total rainfall was 926.60 mm from 1st June 2010 to 31st December, 2010 and 574.30 mm for the corresponding period during 2011. Overall above normal monsoonal rainfall associated with favorable temperatures during the year 2010, was optimum for the cotton growth and yield than the year 2011.

**Yield attributes**

Nutrient omissions significantly influenced the yield components of cotton during both the years of experimentation (Table 3). Sympodials plant$^{-1}$, the boll bearing branches, were significantly lower in the N omission and control plots during the first year, however P and K omission also significantly reduced the sympodials plant$^{-1}$ during the second year of experimentation. Although, N omission resulted in severe reduction in opened bolls plant$^{-1}$, P and K omission also had a significant effect on the opened bolls plant$^{-1}$ an important yield attributes. The unopened bolls plant$^{-1}$ was significantly lower in control and N omission treatments. Boll weight was also significantly reduced due to N, P and K omissions. Lowest boll weight was recorded in control and N omission plots followed P and K omission. Lower number of bolls plant$^{-1}$ and boll weight was recorded during second year in the respective omission treatments. The effect of S and Zn omission on yield attributes was not as pronounced as that of major nutrients.

Correlation coefficients were computed between seed cotton yield and important yield attributes to assess their relative contribution towards yield formation (Table 4). Sympodials plant$^{-1}$ ($r = 0.93$) had strongest and significant correlation with the seed cotton yield followed by bolls plant$^{-1}$ ($r = 0.93$) and boll weight ($r = 0.92$). The correlations between the boll weight and seed cotton yield though lower but was also significant. A similar trend was observed in the regression analysis between the yield attributes and seed cotton yield (Figure 3).

**Stalk yield and seed cotton yield (SCY)**

Growth and biomass production were strongly affected by the indigenous nutrient supply and the nutrients supplied through fertilizers. This was reflected in yield components, stalk and seed cotton yield (Table 3 and Figure 2). Stalk yield ranged from 4.5 to 7.5 t ha$^{-1}$ and 4.1 to 7.2 t ha$^{-1}$ during the years 2010 and 2011, respectively. The corresponding figures for the seed cotton yield were 2.2 to 3.4 t ha$^{-1}$ and 2.1 to 3.2 t ha$^{-1}$, respectively. The reduction in stalk and seed cotton yield was strongly related to the N supply, omission of which resulted in 34.1% and 47.3% reduction in stalk yield during the years 2010 and 2011, respectively. The corresponding figures for the seed cotton yield were 28.1 and 26%, respectively. The reduction in stalk yield was 1.7 and 9% for 2010 and 6.5 and 13.46% for 2011 due to P and K omission, respectively. The corresponding figures for the seed cotton yield are 6.7 and 14.6% for 2010 and 15.5 and 12.4% for the year 2011, respectively.

It was observed that N is the most limiting nutrient and P became progressively limiting under sustained omissions in cotton-wheat cropping system. The reduction in seed cotton yield due K omission was higher than P omission plots during 2010, but remained almost the same during the year 2011. The reduction in stalk yield due to S and Zn omission was statistically at par with optimum nutrition treatments. Seed cotton yield reduction due to S and Zn omission ranged 2.0 to 5.0%
Table 4. Correlation coefficients (R) of the association among the seed cotton yield (SCY) and its attributes for all treatments during the year 2010 (N = 10).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sympodials plant(^{-1})</th>
<th>Bolls plant(^{-1})</th>
<th>Boll weight (g)</th>
<th>SCY (t ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sympodials plant(^{-1})</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bolls plant(^{-1})</td>
<td>0.93**</td>
<td>0.82**</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Boll weight (g)</td>
<td>0.74*</td>
<td>0.92**</td>
<td>0.85**</td>
<td>0.81**</td>
</tr>
<tr>
<td>SCY (t ha(^{-1}))</td>
<td>0.94**</td>
<td>0.93**</td>
<td>0.95**</td>
<td>0.81**</td>
</tr>
</tbody>
</table>

(**Significant at P = 0.0).)

Figure 2. Effect of nutrient omissions on stalk yield (a) and seed cotton yield (b).

which was statistically non-significant when compared to the optimum nutrition treatments. The reduction in the stalk was to the tune 41.5 and 43% for the 2010 and 2011, respectively when no nutrient was applied. Similarly, seed cotton yield reduced to the extent 33.4 and 32.8% for the corresponding years in plots where no nutrient was applied.

Ginning outturn, lint and oil yield

Ginning outturn (GOT %) was significantly lower at higher levels of N (Table 5). N omission and control treatments (no nutrient) resulted in higher ginning percentage and differences in other treatments were statistically non-significant. The lint yield reflected a similar trend except...
Figure 3. Relationship between seed cotton yield (SCY) and sympodials plant$^{-1}$ (a), bolls plant$^{-1}$ (b) and boll weight (c) for cotton 2010 and 2011.

Table 5. Effect of various nutrient omission treatments on ginning outturn, lint and seed and oil yield.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>GOT (%)</th>
<th>Lint yield (t ha$^{-1}$)</th>
<th>Seed yield (t ha$^{-1}$)</th>
<th>Seed index</th>
<th>Oil content (%)</th>
<th>Oil yield (t ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPKSZn</td>
<td>35.91</td>
<td>35.81</td>
<td>1.22</td>
<td>2.08</td>
<td>8.90</td>
<td>20.31</td>
</tr>
<tr>
<td>PKSZn(-N)</td>
<td>33.71</td>
<td>32.15</td>
<td>0.83</td>
<td>1.62</td>
<td>7.62</td>
<td>20.97</td>
</tr>
<tr>
<td>NKSZn(-P)</td>
<td>35.22</td>
<td>34.13</td>
<td>1.12</td>
<td>2.06</td>
<td>8.51</td>
<td>19.64</td>
</tr>
<tr>
<td>NPSZn(-K)</td>
<td>33.48</td>
<td>33.61</td>
<td>0.98</td>
<td>1.93</td>
<td>8.33</td>
<td>21.25</td>
</tr>
<tr>
<td>NPKZn(-S)</td>
<td>34.87</td>
<td>35.59</td>
<td>1.12</td>
<td>2.09</td>
<td>8.66</td>
<td>17.58</td>
</tr>
<tr>
<td>NPKS(-Zn)</td>
<td>36.14</td>
<td>35.58</td>
<td>1.21</td>
<td>2.13</td>
<td>8.93</td>
<td>20.08</td>
</tr>
<tr>
<td>Control</td>
<td>32.69</td>
<td>31.88</td>
<td>0.74</td>
<td>1.53</td>
<td>7.46</td>
<td>17.85</td>
</tr>
<tr>
<td>(-50%N)</td>
<td>34.61</td>
<td>34.64</td>
<td>1.03</td>
<td>1.95</td>
<td>8.10</td>
<td>21.24</td>
</tr>
<tr>
<td>(-50%P)</td>
<td>35.37</td>
<td>34.13</td>
<td>1.18</td>
<td>2.16</td>
<td>8.60</td>
<td>20.13</td>
</tr>
<tr>
<td>(-50%K)</td>
<td>35.26</td>
<td>34.51</td>
<td>1.11</td>
<td>2.02</td>
<td>8.83</td>
<td>21.26</td>
</tr>
<tr>
<td>CD (P=0.05)</td>
<td>1.57</td>
<td>1.41</td>
<td>0.15</td>
<td>0.29</td>
<td>0.78</td>
<td>2.02</td>
</tr>
</tbody>
</table>

that P omission appeared to be non significant during first year but resulted in significant reduction during the second year of the experiment. N omission significantly reduced the seed yield during both years; however omission of P and K had also marked effect on the seed yield during the second year. Lowest seed cotton yield was recorded in the control plots where no fertilizer was applied. Seed index (100 seed weight) of cotton was significantly lower in N omission and control plots during the year 2010 and under the cumulative omissions it further reduced due to P, K and S omission also during the year 2011. Oil yield, a function of oil content and seed yield, was significantly affected due to imbalanced nutrition. P, K and S omission tended to reduce the oil
content whereas N omission slightly increased the oil content. Lowest oil yield was obtained in control and N omission plots due to reduction in the seed yield. P and S also significantly reduced the oil yield due to the reduction in seed yield and oil content.

**Nutrient concentration and uptake**

The concentration of different nutrients expressed as mass fraction (g kg\(^{-1}\)) was significantly affected due to nutrient omission (Table 6). Lower N, P and K concentrations were recorded in the respective omission treatments and the control over the optimum nutrition treatments. The reduction in N concentration ranged from 33 to 40% in the stalk and 22 to 25% in the seed in N omission plots, over the two cropping seasons. The corresponding figures for P were 23 to 28% in the stalk and 20 to 25% in the seed, respectively. The reduction in K concentrations ranged from 8 to 17% in the stalk and 16 to 25% in the seed in the K omission plots. N omission also reduced the P concentration in both stalk and cotton seed. N uptake in stalk, seed, fibre and total N uptake were significantly affected by N omission treatments (Table 7). Total N uptake ranged from 47.6 kg ha\(^{-1}\) in the control plots, 59.7 kg ha\(^{-1}\) in the N omission plots and highest (125.1 kg ha\(^{-1}\)) in the optimum nutrition plots during the year 2010. The corresponding figures for the year 2011 were 45.5, 49.9 and 110.0 kg ha\(^{-1}\), respectively. Lowest N uptake was recorded either in the control plots, N omission plots followed by the treatments were N dose was reduced to half. N uptake was lower during the year 2011 than 2010. P uptake in stalk, seed and fibre was significantly reduced due to P omission; it was more so in the N omission plots followed by the control plots where no fertilizer was applied (Table 8). The N, P and K uptake decreased progressively in the respective omission plots with advancement of each crop in the cotton-wheat cropping system (Table 9).

A significant and linear relationship between seed cotton (dependent variable) and uptake of N, P and K in above ground biomass (independent variables) was observed during both the years. A 93.9 and 84.7% variation in mean seed cotton yield can be adequately explained by computed positive and significant relationship existed between the seed cotton yield N (R\(^2\) = 0.93), P (R\(^2\) = 0.84), and K (R\(^2\) = 0.97) for the year 2010. The relation was also positive and significant for N (R\(^2\) = 0.84), P (R\(^2\) = 0.89), and K (R\(^2\) = 0.83) for the year 2011.

**Nutrient use efficiencies**

The nutrient use efficiency viz. agronomic use efficiencies (AE) and apparent recovery (AR%) were affected under the nutrient omission due to their effect on nutrient concentrations, stalk and

---

**Table 6.** Effect of nutrient omissions on N, P and K concentration (g kg\(^{-1}\)) in seed, stalk and fibre of cotton.

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Cotton</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>NPKZn</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
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<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PKZn (-N)</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
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<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPKS (-S)</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
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<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK (-K)</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
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<td>0.024</td>
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<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD (P = 0.05)</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
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<td>0.024</td>
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<td>0.024</td>
<td>0.024</td>
<td>0.024</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 7. Effect of nutrient omissions on N uptake (kg ha$^{-1}$) of cotton.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Stalk</th>
<th>Seed</th>
<th>Fibre</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2011</td>
<td>2010</td>
<td>2011</td>
</tr>
<tr>
<td>Cotton</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPKSZn</td>
<td>49.8</td>
<td>43.3</td>
<td>73.73</td>
<td>65.2</td>
</tr>
<tr>
<td>PKSZn (-N)</td>
<td>19.4</td>
<td>14.8</td>
<td>39.50</td>
<td>34.3</td>
</tr>
<tr>
<td>NKSZn (-P)</td>
<td>50.2</td>
<td>45.4</td>
<td>62.95</td>
<td>55.2</td>
</tr>
<tr>
<td>NPSZn (-K)</td>
<td>45.2</td>
<td>41.6</td>
<td>62.43</td>
<td>57.9</td>
</tr>
<tr>
<td>NPKZn (-S)</td>
<td>45.7</td>
<td>43.4</td>
<td>69.02</td>
<td>62.6</td>
</tr>
<tr>
<td>NPKS (-Zn)</td>
<td>50.8</td>
<td>42.3</td>
<td>70.16</td>
<td>60.0</td>
</tr>
<tr>
<td>Control</td>
<td>17.7</td>
<td>16.3</td>
<td>29.21</td>
<td>28.6</td>
</tr>
<tr>
<td>(-50%N)</td>
<td>42.1</td>
<td>34.1</td>
<td>49.17</td>
<td>46.9</td>
</tr>
<tr>
<td>(-50%P)</td>
<td>45.5</td>
<td>41.1</td>
<td>67.03</td>
<td>54.8</td>
</tr>
<tr>
<td>(-50%K)</td>
<td>45.9</td>
<td>42.5</td>
<td>66.46</td>
<td>60.3</td>
</tr>
<tr>
<td>CD (P = 0.05)</td>
<td>5.12</td>
<td>8.41</td>
<td>13.52</td>
<td>10.94</td>
</tr>
</tbody>
</table>

Table 8. Effect of nutrient omissions on P uptake (kg ha$^{-1}$) of cotton.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Stalk</th>
<th>Seed</th>
<th>Fibre</th>
<th>Total</th>
</tr>
</thead>
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<tr>
<td></td>
<td>2010</td>
<td>2011</td>
<td>2010</td>
<td>2011</td>
</tr>
<tr>
<td>Cotton</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPKSZn</td>
<td>8.8</td>
<td>7.7</td>
<td>13.19</td>
<td>11.8</td>
</tr>
<tr>
<td>PKSZn (-N)</td>
<td>5.6</td>
<td>3.5</td>
<td>8.21</td>
<td>6.9</td>
</tr>
<tr>
<td>NKSZn (-P)</td>
<td>6.3</td>
<td>5.5</td>
<td>9.85</td>
<td>7.3</td>
</tr>
<tr>
<td>NPSZn (-K)</td>
<td>7.7</td>
<td>6.7</td>
<td>11.04</td>
<td>9.7</td>
</tr>
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<td>NPKZn (-S)</td>
<td>8.3</td>
<td>6.7</td>
<td>12.14</td>
<td>10.9</td>
</tr>
<tr>
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<td>9.6</td>
<td>7.0</td>
<td>13.47</td>
<td>10.4</td>
</tr>
<tr>
<td>Control</td>
<td>4.9</td>
<td>3.4</td>
<td>6.10</td>
<td>6.4</td>
</tr>
<tr>
<td>(-50%N)</td>
<td>6.6</td>
<td>5.4</td>
<td>10.91</td>
<td>8.7</td>
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<tr>
<td>(-50%P)</td>
<td>6.7</td>
<td>6.7</td>
<td>11.18</td>
<td>9.4</td>
</tr>
<tr>
<td>(-50%K)</td>
<td>7.9</td>
<td>6.4</td>
<td>12.32</td>
<td>9.7</td>
</tr>
<tr>
<td>CD (P = 0.05)</td>
<td>1.26</td>
<td>1.33</td>
<td>3.07</td>
<td>2.46</td>
</tr>
</tbody>
</table>

Table 9. Effect of nutrient omissions on K uptake (kg ha$^{-1}$) of cotton.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Stalk</th>
<th>Seed</th>
<th>Fibre</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2011</td>
<td>2010</td>
<td>2011</td>
</tr>
<tr>
<td>Cotton</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPKSZn</td>
<td>105.9</td>
<td>86.1</td>
<td>26.0</td>
<td>26.7</td>
</tr>
<tr>
<td>PKSZn (-N)</td>
<td>54.9</td>
<td>43.1</td>
<td>17.5</td>
<td>17.2</td>
</tr>
<tr>
<td>NKSZn (-P)</td>
<td>97.7</td>
<td>78.5</td>
<td>22.4</td>
<td>20.1</td>
</tr>
<tr>
<td>NPSZn (-K)</td>
<td>62.4</td>
<td>57.8</td>
<td>18.3</td>
<td>17.4</td>
</tr>
<tr>
<td>NPKZn (-S)</td>
<td>79.3</td>
<td>69.9</td>
<td>25.6</td>
<td>24.0</td>
</tr>
<tr>
<td>NPKS (-Zn)</td>
<td>107.9</td>
<td>83.8</td>
<td>28.0</td>
<td>25.6</td>
</tr>
<tr>
<td>Control</td>
<td>50.4</td>
<td>44.4</td>
<td>14.2</td>
<td>13.3</td>
</tr>
<tr>
<td>(-50%N)</td>
<td>87.9</td>
<td>68.9</td>
<td>23.2</td>
<td>22.0</td>
</tr>
<tr>
<td>(-50%P)</td>
<td>96.9</td>
<td>78.1</td>
<td>26.3</td>
<td>23.7</td>
</tr>
<tr>
<td>(-50%K)</td>
<td>92.6</td>
<td>71.4</td>
<td>24.4</td>
<td>21.8</td>
</tr>
<tr>
<td>CD (P = 0.05)</td>
<td>12.7</td>
<td>11.8</td>
<td>6.42</td>
<td>4.02</td>
</tr>
</tbody>
</table>

Like higher P use efficiency of N ranged from 2.3 to 7.1 kg increased seed cotton kg$^{-1}$ N applied. Higher use efficiency was achieved in the optimum nutrition plots and (-50%) N plots. Agronomic efficiency of P varied from 1.1 to 19.1 kg increased seed cotton kg$^{-1}$ P applied. Like higher P use
efficiency was recorded in balanced plots and lower values were recorded where N was not applied. Higher P use efficiency values were observed during the second year because of progressive depletion of soil P and therefore better response to the applied P. K use efficiency varied from 1.5 to 10.1 kg seed cotton kg\(^{-1}\) K applied. N omissions reduced K use efficiency but, higher K use efficiency was recorded in optimum nutrition plots. Higher N, P and K recovery efficiency in optimum nutrition plots and 50\% N, P and K plots was observed.

### Table 10. Agronomic use efficiency (AE) kg seed cotton kg\(^{-1}\) nutrient applied of nutrient uptake and apparent recovery (AR%).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>AE (kg seed cotton kg(^{-1}) nutrient)</th>
<th>AR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPKSZn</td>
<td>6.4 5.6</td>
<td>9.0 19.2</td>
</tr>
<tr>
<td>PKSZn (-N)</td>
<td>0.0 0.0</td>
<td>-27.7 -12.9</td>
</tr>
<tr>
<td>NKSZn (-P)</td>
<td>4.9 2.3</td>
<td>- 5.4 -2.1</td>
</tr>
<tr>
<td>NPSZn (-K)</td>
<td>3.1 3.0</td>
<td>-10.2 3.9</td>
</tr>
<tr>
<td>NPKZn (-S)</td>
<td>5.1 4.7</td>
<td>1.1 13.6</td>
</tr>
<tr>
<td>NPZK (-Zn)</td>
<td>5.9 4.4</td>
<td>6.1 12.1</td>
</tr>
<tr>
<td>Control</td>
<td>0.0 0.0</td>
<td>0.0 0.0</td>
</tr>
<tr>
<td>(-50%N)</td>
<td>7.1 5.8</td>
<td>-7.4 3.7</td>
</tr>
<tr>
<td>(-50%P)</td>
<td>5.9 3.8</td>
<td>12.1 17.9</td>
</tr>
<tr>
<td>(-50%K)</td>
<td>4.5 4.4</td>
<td>-1.9 12.1</td>
</tr>
</tbody>
</table>
during both years of experiment.

**Fertilizer requirement for targeted seed cotton yield**

The apparent nutrient recovery (AR%), N, P and K uptake ($U_{\text{ARK}}$) in the optimum nutrition and respective omission plots were averaged over two years (Table 11). The values so computed were used for fertilizer doses calculations for targeted seed cotton yield were calculated. The N:P:O$_2$:K$_2$O dose needed to attain a yield target of 3.0, 3.5 and 4.0 t ha$^{-1}$ seed cotton worked out at 130:42:32, 175:74:74 and 220:106:112 kg ha$^{-1}$ respectively (Table 12).

**DISCUSSION**

Optimum plane of nutrition wherein N, P, K, S and Zn was applied at recommended rates maintained superiority in respect yield of components, stalk and seed cotton yield. The higher above ground biomass yield during the 2010 was due to the excessive rainfall (926 mm) received during 2010 which was 61% higher than 2011 (574 mm). If the cotton receives excessive rain or is irrigated too frequently before fruit set, plant height and vegetative growth will be excessive (Kerby et al., 1996).

N omission resulted in drastic reduction in the growth, yield components and yield, highlighting the importance of N in cotton production in N deficient soils. These findings corroborate the results of Biradar et al. (2011); Zhang et al. (2008) and Sawan et al. (2006). P omission resulted in a yield reduction of 6.7% and 15.5% in the first and the second crop highlighting the fast depletion of soil P resources in cotton-wheat cropping system. Hibberd et al. (1990) from their nutrient omission experiments on cotton in P deficient soils reported a significant reduction in cotton growth under P omission treatments. Charles et al. (2005) from Cullars long term experiment reported that yield losses when P was not applied during the preceding 10 years amounted to 57% compared to standard fertilization (N,P,K,S, with micronutrients).

The reduction in the yield due to K omission ranged from 12 to 14% signifying the importance of K nutrition in cotton production. Pettigrew (2003) also reported the production of more bolls per unit area for one year out of a three-year study due to K application. It appears that K soil supplies remained more or less constant during the cropping seasons. It might also be due to the fact that cotton being a deep rooted plant, absorbed more K from the deeper soil layers (Gulick et al., 1989). Yield losses to the tune of 20% due K omission have been reported by Biradar et al. (2011). Pettigrew and Meredith (1997) concluded that K fertilization had resulted in gain of stem (21%), bur (13%), seed (19%), and lint weight (20%). The reduction in the yield due to S and Zn omission was on marginal and statistically non significant. Several workers have reported a non significant response of cotton to S (Prasad, 2000) and Zn (Yin et al., 2011) application. The reduction in the seed cotton yield was mainly attributed to the lesser number of bolls plant$^{-1}$ and reduced boll weight.

Although, seed cotton yield decreased in N omission but there was a significant increase in ginning turnout (GOT %) in N omission and control plots. Optimum supply of, P and K in combination with 0 kg N ha$^{-1}$, supplemented with foliar spray of K resulted in significant increase in ginning percentage (Kumari et al., 2008). Regarding the oil content N omission had a positive effect on oil content whereas P and S omission had negative effect on oil content. Nitrogen reduced the oil content (Sawan et al., 2006) whereas P increased the oil content in cotton seed (Sawan et al., 2007). These results are in agreement with Maller (1989), Malhi and Leach (2000) and Subhani et al. (2003) who reported that oil content of canola increased with increase in S.

N, P and K concentrations in stalk, seed and fibre were lowest in the respective omission treatments pointing towards restricted soil nutrient supplies. These concentrations were also significantly lower in the control plots. N omission also reduced the concentrations of P and K in the above ground plant parts highlighting the role of N in the root growth and synergistic effect on the P and K absorption. The nutrient concentrations were further reduced during the second year of cotton because of constant mining and depletion by the previous two crops, that is, cotton and wheat in the sequence. Nitrogen deficiency reduces the uptake of P and K, S and many other nutrients in crop plants (Das and Sen, 1981; Adams, 1980; Terman et al., 1977). N omissions reduced the uptake of N, P and K in aerobic rice and wheat in rice-wheat cropping system (Dai et al., 2010). The drop in S and Zn concentrations in the stalk and seed in S and Zn omission plots was not so severe indicating more or less constant soil supply of these nutrients over three

**Table 11. Total of N, P and K uptake (kg ha$^{-1}$) of cotton in the optimum nutrition and respective nutrient omission plots during the year 2010 and 2011.**

<table>
<thead>
<tr>
<th>Particular</th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2011</td>
<td>Average</td>
</tr>
<tr>
<td>Uptake in OPT plots</td>
<td>125.1</td>
<td>109.9</td>
<td>117.5</td>
</tr>
<tr>
<td>Uptake in Omission plots = INS</td>
<td>59.7</td>
<td>49.8</td>
<td>54.8</td>
</tr>
</tbody>
</table>
seasons. The significant reduction in biomass production and consequent N uptake in N omission, 50% N omission and control plots demonstrated that N was the most important limiting factor keeping other factors at the optimum level similar results have been reported by Reddy et al. (2012); Fritschi et al. (2004) and Mullins and Burmester (1990). Similarly K uptake was more depressed by N omission rather than K omission, due reduction in growth and biomass production in the N omission plots.

Higher agronomic use efficiency of N, P and K was achieved either under balanced fertilization schedule or by reducing the nutrient dose to half. The latter option is not a viable because of the yield penalties associated with it. Higher agronomic N use efficiency and % N recovery under optimum nutrient treatments has been reported from a five year experiment on cotton in China (Zhang et al., 2008). Negative values of -27.7 and -12.9 kg increased seed cotton kg⁻¹ P applied were recorded in N omission plots because the extent reduction in seed cotton yield was higher due N omission than P omission. Similar reasons hold negative value for AE P under K omission. Negative values of AR (%) of P and K in the N omission plots was due to severe reduction in the biomass and consequent depression in the P and K uptake than the P and K omission plots. Using the data of nutrient uptake in optimum fertilization and omission plots along with the recovery efficiency values, the fertilizer doses for targeted seed cotton yield can be safely estimate.

**Table 12.** Fertilizer calculations for targeted yield on the basis of uptake in OPT plots and INS i.e uptake in the respective nutrient omission plots.

<table>
<thead>
<tr>
<th>Particular seed cotton yield SCY (t ha⁻¹)</th>
<th>3.0</th>
<th>3.5</th>
<th>4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated plant nutrient requirement (kg ha⁻¹)</td>
<td>105.9</td>
<td>19.56</td>
<td>115.1</td>
</tr>
<tr>
<td>INS (kg ha⁻¹)</td>
<td>54.8</td>
<td>15.2</td>
<td>96.6</td>
</tr>
<tr>
<td>Net plant nutrient requirement</td>
<td>51.12</td>
<td>4.3</td>
<td>18.5</td>
</tr>
<tr>
<td>AR (%)</td>
<td>39.2</td>
<td>23.5</td>
<td>61.1</td>
</tr>
<tr>
<td>Actual nutrient requirement (kg ha⁻¹)</td>
<td>130.3</td>
<td>18.3</td>
<td>30.3</td>
</tr>
<tr>
<td>P and K (Oxide form) kg ha⁻¹</td>
<td>P₂O₅</td>
<td>K₂O</td>
<td>P₂O₅</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>-----</td>
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<td>-----</td>
</tr>
</tbody>
</table>

Conclusions

Sustained omission of nutrients in the Bt cotton-wheat cropping systems vis-à-vis the optimum plane of nutrition revealed that N is the most limiting nutrient in cotton production. It considerably reduced the yield attributes which was reflected in lower stalk, seed cotton, lint and oil yield. K followed by P also significantly reduced the seed cotton yield during the first year. P proved to be more limiting than K during the second cotton crop highlighting the fact that P supplies depleted faster due to high P demand from both cotton and wheat. Nutrient uptake was reduced in the respective nutrient omission plots. The effect of N omission on N, P and K uptake was more drastic because of its strong influence on the biomass production. The nutrient omission plot technique can be reliable tool for estimating the nutrient doses of cotton in different recommendation domains. S and Zn omissions resulted in non significant reduction in the yield. This establishes the fact that balanced nutrient management is indispensable for sustainable cotton production and nutrient demands of both cotton and wheat need to be taken into consideration.

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