Bio-Economic Response of Autumn Sugarcane to Soil Variation, NPK Management and planting Geometry under Arid Climate

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Abstract: Autumn sugarcane crop is commonly fertilized at 175-60-60 and 300-175-125 NPK kg ha⁻¹ in sandy loam and silty clay soils, respectively. Whether these fertilizer doses are sufficient or otherwise for the fulfillment of this sugarcane crop demand is yet to be established. A comprehensive study (2005-06 to 2007-08) was conducted to identify the optimum NPK dose in sandy loam and silty clay soils. This study was conducted on autumn sugarcane cv. HSF 240 at two different locations, Land Reclamation Research Station 37/TDA, Bhakkar and Gomal University Dera Ismail Khan, Pakistan. The experiments were laid out according to randomized complete block design with factorial arrangement. The trial was replicated four times with net plot of 24 m². Five NPK doses i.e. F0 (0-0-0), F1 (100-100-100), F2 (150-150-100), F3 (200-200-100) and F4 (250-200-100) kg ha⁻¹ along with four planting arrangements i.e. G1 (60cm), G2 (75cm) single row planting patterns, G3 (30/90cm) and G4 (30/120cm) spaced paired row strip planting patterns were tested. Statistical analysis of three years pooled data showed that NPK doses affected the sugar yield contributing parameters, significantly. Maximum shoot dry weight (1900.8 & 1949.2 g m⁻²) was recorded in F4×G3, while minimum in F0×G4 (624.8 & 629.2 g m⁻²) on sandy loam and silty clay soil, respectively. Maximum sugar yield (14.81 & 15.52 t ha⁻¹) was recorded in F4×G3 and minimum (3.66 & 4.03 t ha⁻¹) in F0×G1 on sandy loam and silty clay soils. Maximum sugar recovery (11.5 and 10.90%) was recorded in the treatment interaction of F0×G4 and minimum (7.67 and 8.64%) in F4×G1 on sandy loam and silty clay soils. Maximum FUE (289.4 & 290.2 kg kg⁻¹) in sandy loam and silty clay soils in arid climate. Sugar recovery percentage was recorded maximum in interaction of control and 30/120cm spaced paired row strip planting. Nutrient application of 200-200-100 NPK kg ha⁻¹ having planting geometry of 30/90 cm paired row strips planting was proved optimum for maximum sugar yield.

Keywords: Autumn Sugarcane, Saccharum officinarum, NPK, Soil texture, planting geometry.

1. Introduction

Sugarcane (Saccharum officinarum L.) is considered a huge tropical, long duration, nutrient loving plant as it consumes 83 kg N, 37 kg P₂O₅ and 168 kg K₂O for production of 125 t ha⁻¹ biomass (Yadava, 1991). Therefore an adequate and balanced supply of all inputs in the effective root zone of crop is essential for obtaining sustainable cane yield. Sugarcane is cultivated in Pakistan on an area of 0.99 m ha with average cane yield of 56.0 t ha⁻¹ (MINFAL 2010-11). Country average yield is much lower as compared with sugarcane production other countries of the world (GOP 2010). Lower cane yield in sugarcane is due to improper nutrient management and planting geometry (Saggu et al. 2010). Afghan (1996) reported that application of bio-compost and NPK gave significantly higher shoot dry weight (SDW). Application of 250-100-100 kg NPK ha⁻¹ gave the highest SDW (Ali, 1999). NPK accumulation and uptake in plants were higher at 225:112:168 NPK kg ha⁻¹ (Soomro et al. 2014). Ali (1999) reported that N application decreased the sucrose contents in cane juice however, Rani et al. (1989) concluded that addition of N in combinations with P and K improved the sucrose consents as against with only N application. On the contrary, Ayub et al. (1999), Ramesh and Varghese (2000) and Shafshak et al. (2001) proposed that sucrose contents were not affected significantly by fertilizer application. The economic yield is determined by the capability of plant to produce photosynthates and their distribution to economically valuable plant parts. In order to harvest the maximum benefits of soil and environmental resources, it is necessary to lay out crop in such a pattern that there must be less inter plants competition for essential growth elements.

Sugarcane planting in widely spaced rows (Kathirisan and Narayanasamy, 1991) had higher sucrose contents in comparison with narrow spaced rows planting. However, Vains et al. (2000) reported that sucrose content in cane juice was not affected significantly by different spatial arrangements and plantation methods. El-Geddawy et al. (2002) obtained significantly higher cane yield at the row spacing of 100cm than 120 or 140cm spaced rows in the 1st. ratoon crop in Egypt, whereas Singh and Prasad (2006) recorded significantly higher cane yield at 45cm spacing followed by 60cm and 75cm in ratoon crop.

Sugarcane crop research has been confined mainly to spring planting while autumn sugarcane was left out of research.
arena. Therefore it was considered outstanding obligation to establish sound information on impact of NPK doses, planting geometry and soil texture in autumn sugarcane in two different agro ecological pockets of unexplored areas of Pakistan. The objective of this study was to enhance the capability of plant to produce photosynthates and their mobilization to economically valuable plant parts through proper crop management.

2. Materials and Methods

Three year studies (2005-06 to 2007-08) were conducted on autumn sugarcane cultivar (HSF 240) at two sites in Pakistan. First location was Land Reclamation Research Station, Chak No. 37/ TDA (sandy loam soil) Bhakkar (031°34'-35-4 N and 071°03'-33 E) Punjab and second site was Research Area (silty clay soil) of Gomal University Dera Ismail Khan Kyber Pakhtunkhwa (031°38'-33-1N and 070°15'-56 -49 E). Physico-chemical properties of two different soil types as tested pre-planting and post harvest during each crop season/year are presented in Table 1 and 2.

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Characteristic (unit)</th>
<th>2005-06</th>
<th>2006-07</th>
<th>2007-08</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bhak Kar</td>
<td>Soil Texture</td>
<td>class</td>
<td>Sandy Loam</td>
<td>Sandy Loam</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td></td>
<td>N %</td>
<td>0.03</td>
<td>0.038</td>
<td>0.036</td>
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</tr>
<tr>
<td></td>
<td>P ppm</td>
<td>3.41</td>
<td>4.54</td>
<td>4.05</td>
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</tr>
<tr>
<td></td>
<td>K ppm</td>
<td>54.3</td>
<td>58.89</td>
<td>59.24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Field capacity</td>
<td>% by volume</td>
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<td>17.97</td>
<td>16.8</td>
</tr>
<tr>
<td></td>
<td>Bulk density</td>
<td>gcm⁻³</td>
<td>1.4</td>
<td>1.38</td>
<td>1.4</td>
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<tr>
<td></td>
<td>Perm ant wilting point</td>
<td>% by volume</td>
<td>7.14</td>
<td>8.33</td>
<td>7.74</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>7 to 14</td>
<td>7.7</td>
<td>8</td>
<td>7.8</td>
</tr>
<tr>
<td></td>
<td>Ec</td>
<td>dSm⁻¹</td>
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<td>1.1</td>
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</tbody>
</table>

<table>
<thead>
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<th>Location</th>
<th>Description</th>
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<th>2006-07</th>
<th>2007-08</th>
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<tbody>
<tr>
<td>Dera Ismail Khan</td>
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<td>Silty clay</td>
<td>Silty clay</td>
<td>Silty clay</td>
</tr>
<tr>
<td></td>
<td>N %</td>
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<td>0.04</td>
<td>0.035</td>
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<tr>
<td></td>
<td>P ppm</td>
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<td>8.5</td>
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<tr>
<td></td>
<td>K ppm</td>
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<td>92.5</td>
<td>84</td>
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</tr>
<tr>
<td></td>
<td>Field capacity</td>
<td>% by volume</td>
<td>23.85</td>
<td>24.24</td>
<td>24.05</td>
</tr>
<tr>
<td></td>
<td>Bulk density</td>
<td>gcm⁻³</td>
<td>1.3</td>
<td>1.35</td>
<td>1.31</td>
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<tr>
<td></td>
<td>Perm ant wilting point</td>
<td>% by volume</td>
<td>11.54</td>
<td>11.85</td>
<td>11.68</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>-----</td>
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<td>8.1</td>
<td>8.07</td>
</tr>
<tr>
<td></td>
<td>Ec</td>
<td>dSm⁻¹</td>
<td>4.6</td>
<td>5.2</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Source: Soil and Water Testing Laboratory Directorate of Land Reclamation Punjab, Lahore, Pakistan
April of the following years. The crop was kept free of weeds. All other agronomic requirements applied uniformly. Seventeen irrigations, each of 100 mm was applied to silty clay soil while 27 irrigations were provided to sandy loam soil to keep the field at 40 % available soil moisture depletion level. The observations on shoot dry weight and sugar yield, sugar recovery percentage, water use efficiency, fertilizer use efficiency and benefit cost ratio were recorded following standard procedures.

2.1. Soil Sampling and Determination of Moisture Content

Gravimetric procedure of soil moisture measurement (direct method) was applied to determine the water contents in the soil. Soil sampling for soil moisture measurement was carried out regularly on alternate days from sowing to the final irrigation (30 days before harvesting each year at both locations). The irrigations were applied at 40 % available soil moisture depletions in all treatments to bring the field to field capacity. Maximum soil moisture extraction depth of 150 cm (83 % of active root zone) was followed as per procedure proposed by Black, 1957. Five samples were collected and blended. Composite soil samples were taken up to 150 cm at the depth intervals of 30 cm from randomly selected 5 sites in each plot for moisture determination. Available soil moisture contents on volume basis at 40 % depletion level were calculated as proposed by Penman, 1970, French and Legg, 1979) and presented in Table 3.

\[
\text{ASMDL} = \frac{(F_c - O_i)}{(F_c - P_{wp})} \\
\]

Where ASMDL = Available Soil Moisture Depletion Level, \(F_c\) = Permanent wilting point, \(O_i\) = Soil moisture content before irrigation in percent by volume, \(F_c\) = Field capacity in percent by volume.

Table 3: Critical soil water contents in percent on volume basis for different ASMD levels

<table>
<thead>
<tr>
<th>Available soil moisture depletion level (ASMDL)</th>
<th>Sandy loam</th>
<th>Silty clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>40%ASMDL</td>
<td>12.3</td>
<td>14.1</td>
</tr>
<tr>
<td></td>
<td>19.3</td>
<td>13.5</td>
</tr>
<tr>
<td></td>
<td>18.9</td>
<td>19.2</td>
</tr>
</tbody>
</table>

Irrigation was applied to respective plots as soon as the desired available soil moisture depletion level reached in the soil in the crop root zone.

2.2 Irrigation

Irrigation depth for 40 % ASMD level was determined by adopting the direct measurement method of crop water requirement as proposed by Rafiq 2001:

\[
\text{Dw} = \frac{(F_c - O_i)}{100} \\
\]

Discharge of water applied to each treatment was determined with the help of a cut throat flume (8”× 3”).

The time required to bring back the field to field capacity supply was calculated with the help of following equation (Rafiq 2001):

\[
t = \frac{(d x a)}{q} \\
\]

Where \(t\) = time in minutes, \(d\) = depth of water cm, \(a\) = area \(m^2\), \(q\) = discharge of irrigation water in liter/sec. The observations on shoot dry weight and sugar yield were recorded using standard procedures. The sugar recovery percentage was calculated using formula (CIMMYT manual, 1988):

\[
\text{Sugar Recovery} = 100 \times \frac{(J - S)}{(S - J)} \\
\]

Where \(S\) = Sugar 100%, \(J\) = Juice purity, \(M\) = Molasses purity = 35%, \(P_{wp}\) = Pol% juice (sucrose %). Juice extraction = 0.65, Boiling house efficiency = 0.98, Water use efficiency was calculated as provided by Phulare and Upadhyay (1978).

\[
\text{WUE (kg mm}^{-1}\text{ ha}^{-1}) = \frac{\text{Stripped cane yield (kg)}}{\text{Water applied (mm})^{-1}} \\
\]

Benefit cost ratio was calculated by using the following formula

\[
\text{BCR} = \frac{\text{Total income}}{\text{Total expenditure}} \\
\]

Fertilizer use efficiency (FU E) was determined by the formula as proposed by Barber (1976).

\[
\text{(St.C. Yield)}_F\text{(kg)} - (\text{St.C. Yield})_C\text{(kg)} \\
\]

FUE (Kg Kg\(^{-1}\)) = -----

Fertilizer nutrients applied (kg nutrients)

Where (St.C. yield) \(F\) = Stripped cane yield of fertilized crop, (St.C. Yield) \(C\) = Stripped cane yield of controlled crop

Shoot dry weight was calculated by taking five randomly selected cane shoots from each treatment at 30 days interval. These shoots were sun dried and then oven dried at 70 °C for 72 hours, to a constant dry weight. Dry weight per plant was converted to total dry weight \(m^2\) by multiplying it with stalk population. Sugar yield was calculated by multiplying striped cane yield (t ha\(^{-1}\)) with sugar recovery percentage. The data were analyzed statistically using Fisher’s analysis of variance technique and Least Significant Test at 0.05 level was used to compare the differences among the treatment means (Steel et al., 1997).

3. Results and Discussions

3.1 Shoot dry weight (gm\(^{-2}\))

Data regarding shoot dry weight (Table 4) indicated that interactive effects of NPK doses and planting patterns were
significant at both locations. Maximum SDW was recorded 1900.8 g m⁻² in sandy loam and 1949.2 g m⁻² in silty clay soil in F₄×G₃. Minimum SDW values viz. 624.8 and 629.2 g m⁻² were observed in F₀×G₄ in sandy loam and silty clay soil, respectively. It was observed that shoot dry weight was increased by 204.22% and 209.8% in two soil types in F₄×G₃ over F₀×G₄. It was noted that 64, 37, 27, 1% and 64, 37, 25, 0.5% higher SDW was obtained in F₄×G₃ than F₀×G₃, F₁×G₃, F₂×G₃ and F₃×G₃ in sandy loam and silty clay soil, respectively. Shoot dry weight was higher by 10, 6, 17 and 10, 5, 16% in F₄×G₃ over F₄×G₁, F₄×G₂ and F₄×G₄ in sandy loam and silty clay soil, respectively. It was observed that SDW of F₄×G₃ was 66,42,33,11,10 and 66,41,31,13,10 % higher than F₀×G₁, F₁×G₁, F₂×G₁, F₃×G₁ and G₄×G₁ in sandy loam and silty clay soil, respectively. The increase in SDW in F₄×G₃ was attributed to increased nutrient availability and higher radiation use efficiency. Maximum leaf area duration was recorded in F₄×G₃ (Table 5), resultantly enhanced the shoot dry weight.

As far as individual factors are concerned, maximum gain was observed during the grand growth period (April-August) SDW attained constant values during the month of October each year (Fig 1).
3.2 Sugar Yield

Sugar yield is the interactive effect of stripped-cane yield and sugar recovery percentage. The analysis of three years’ pooled data (Table 4) depicted that different NPK doses and planting patterns affected sugar yield at both locations significantly. Maximum sugar yield 15.34 and 15.75 t ha\(^{-1}\) was recorded in F3×G3 followed by F4×G3 (14.8 and 15.52 t ha\(^{-1}\)) and these were at par statistically. Minimum sugar yields 3.66 and 4.03 t ha\(^{-1}\) were recorded in F0×G1 at sandy loam and silty clay soil, respectively. It was observed that increase in nitrogen by 200 kg ha\(^{-1}\) had left no significant effect on sugar yield. Sugar yield was higher by 67.8 and 68.9% in F3×G3 as compared with F0×G1 in sandy loam and silty clay soil respectively. Sugar yield was also 34, 14, 16.3 and 20.9, 9.4, 18.5 % higher in F3×G3 than F3×G1, F3×G2 and F3×G4 on sandy loam and silty clay soil respectively. Similarly it was noted that sugar yield was 76.1, 85.2, 48.3, 25.4, 28.2 and 74.4, 54, 45.3, 20.9, 19 % higher in F3×G3 than F0×G1, F1×G1, F2×G1, F3×G1 and F4×G1 on sandy loam and silty clay soil, respectively. The increase in sugar yield by 319.13% and 290.82% in F3×G3 over F0×G1 was attributed to interplay of optimum NPK availability and planting geometry which improved stripped cane yield. Increase in sugar yield in response to different fertilizer levels was also reported by Ali et al. (2000) and Khan et al. (2005). These results get supports from the findings of Sajjad et al. (2014) who reported that optimizing the row spacing and seeding densities improved the quality and yield of sugarcane.

3.3 Sugar Recovery Percentage

Maximum sugar recovery of 11.30 and 10.90% was recorded in sandy loam and silty clay soils in F0×G4 and minimum as 7.67 and 8.64% in F4×G1 in sandy loam and silty soil, respectively (Table 4). It was observed that 47.33 and 26.15% higher sugar was recovered in F0×G4 as compared with F4×G1. It was concluded that 23.9 and 16.1 % less sugar recovery was recorded in F0×G1 than F0×G4 on sandy loam and silty clay soil respectively. It was observed that 1.2, 8, 10.2, 11.8 and 0 %, 3.5 %, 7.7 % and 14.2 % less sugar recovery was displayed in F1×G4, F2×G4, F3×G4 and F4×G4 than F0×G4 on sandy loam and silty clay soil respectively. However, low sugar recovery % viz. 18.1, 18.4, 19.6, 22.8, 28.3 and 11, 11.7, 12.6, 14.6 and 18.3 was recorded in F0×G2, F1×G2, F2×G2, F3×G2 and F4×G2 than F0×G4 on sandy loam and silty clay soil respectively. It was indicated that by increasing N and P without parallel increase of K had a negative effect on sugar recovery percentage. Similar findings were reported by Sajjad et al. 2014. The decrease in sugar recovery percentage with
increase in N and P level was attributed to the facts that better availability of N resulted in increase of LA, LAI and plant height. It was obvious that the higher water up take and rapid growth, delayed maturity and less sucrose contents were resulting in lower sugar recovery percentage. The increase in recovery percentage with increase in inter strip spacing were due to improved light interception and better air circulation by way of enhanced photosynthetic activity. These results are in line with Singh and Singh (1984) and Kathirisan and Narayanasmy (1991).

### 3.5 Water Use Efficiency

Water use efficiency was maximum 61.3 and 97.6 kg mm\(^{-1}\) in F3×G3 (Table 5). However, it was statistically at par with F4×G3 and was minimum 15.2 and 24.4 kg mm\(^{-1}\) in sandy loam and silty clay soils, respectively (Table 4). It was also observed that FUE was decreased with parallel increase in fertilizer dose from 200:200:100 to 250:200:100 NPK kg ha\(^{-1}\). FUE was also decreased with subsequent decrease of fertilizer dose from 150:150:100 and 100:100:100 NPK kg ha\(^{-1}\). This increase in fertilizer use efficiency was attributed to a substantial increase in stripped cane yield shown in Table 5. It was also observed that FUE was decreased with parallel increase in fertilizer dose from 200:200:100 to 250:200:100 NPK kg ha\(^{-1}\). FUE was also decreased with subsequent decrease of fertilizer dose from 150:150:100 and 100:100:100 NPK kg ha\(^{-1}\). This increase in fertilizer use efficiency was attributed to a substantial increase in stripped cane yield shown in Table 5.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Leaf area duration (LAD)</th>
<th>Stripped cane yield (t ha(^{-1}))</th>
<th>Water use efficiency (kg mm(^{-1}))</th>
<th>Benefit cost ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy loam</td>
<td>Silty clay</td>
<td>Sandy loam</td>
<td>Silty clay</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>F0 × G1</td>
<td>1201.0f</td>
<td>1729.2f</td>
<td>14.55cd</td>
<td>13.19ab</td>
</tr>
<tr>
<td>F0 × G2</td>
<td>1400.8f</td>
<td>1900.8a</td>
<td>14.81a</td>
<td>15.34a</td>
</tr>
<tr>
<td>F0 × G3</td>
<td>1940.4b</td>
<td>2621.6c</td>
<td>14.15a</td>
<td>15.52a</td>
</tr>
<tr>
<td>F0 × G4</td>
<td>1577.4g</td>
<td>2154.9h</td>
<td>14.15a</td>
<td>15.52a</td>
</tr>
</tbody>
</table>

### 3.6 Benefit Cost Ratio

Benefit cost ratio (BCR) calculations revealed that effect of NPK doses and planting patterns on BCR was significantly different (Table 5). The maximum BCR was 1.64 and 1.59 in F3×G3 and minimum 0.01 and 0.02 in F0×G4 in sandy loam and silty clay soils respectively. Increase in BCR in F3×G3 was due to improved water and fertilizer use efficiency (Table 5). Increase in nitrogen level beyond 200 kg ha\(^{-1}\) had left no significant effect on BCR. It was noted that 30/120 cm paired row strip planting proved better sowing method for inter cropping to harvest maximum sugar yield.

### Table 5: Stripped cane yield, water and fertilizer use efficiency as affected by NPK doses, planting geometry and soil texture

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Leaf area duration (LAD)</th>
<th>Stripped cane yield (t ha(^{-1}))</th>
<th>Water use efficiency (kg mm(^{-1}))</th>
<th>Benefit cost ratio</th>
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<tr>
<td>Sandy loam</td>
<td>Silty clay</td>
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<tr>
<td>F0 × G1</td>
<td>666.68m</td>
<td>472.69m</td>
<td>42.50r</td>
<td>44.00n</td>
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<tr>
<td>F0 × G2</td>
<td>481.13l</td>
<td>482.53l</td>
<td>44.75q</td>
<td>47.00m</td>
</tr>
</tbody>
</table>

Means followed the same letter in a column do not differ significantly at 5% level of probability.
4. Conclusion and Recommendations

It was concluded that maximum sugar yield, fertilizer use efficiency, optimum shoot dry weight and benefit cost ratio could be obtained from nutrient dose of 200–200–100 NPK kg ha⁻¹ along with 30/90 cm spaced paired row strip planting pattern in sandy loam and silty clay soils of arid agro-climate. Sugar recovery percentage decreased by increasing row spacing up to 30/120 cm. Therefore, nutrient dose of 200-200-100 NPK of potassium and it was improved by increasing row spacing up to 30/120 cm. Therefore, nutrient dose of 200-200-100 NPK kg ha⁻¹ along with 30/90 cm paired row strip planting was recommended for maximum sugar yield.

5. Acknowledgements

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References