Researchers are finding that India’s sugarcane production systems are suffering from incremental stress as they attempt to raise production to meet growing demands. In recent years, yields have declined due to inappropriate water and nutrient management practices. Large vegetative growth with heavy tonnage removes substantial amounts of nutrients from the soil that need to be replenished. Conventional nutrient management practices lead to N losses through immobilization, denitrification, volatilization, and leaching. Applied P and K is susceptible to soil fixation, which contributes to their imbalance within the rhizosphere. Applying fertilizers in limited splits at inappropriate timings reduces nutrient use efficiency (NUE).

Study Description

The experiment described below compared subsurface drip fertigation (SSDF), surface drip fertigation (SDF), and traditional surface-applied granular fertilizers (GF) combined with in-furrow, surface irrigation (SI). Mixtures of Subsurface drip fertigation, an advanced method for co-application of water and nutrients following the principles of 4R Nutrient Stewardship (right source, rate, time, and place), has the capability to deliver nutrients uniformly within the effective root volume zone where most of the active roots are concentrated. When adopted in the sugarcane fields of Tamil Nadu, this system demonstrated an overall increase in cane yield of 62 t/ha while improving nutrient use efficiency and farm net income.

KEYWORDS: 4R Nutrient Stewardship; fertigation; water soluble fertilizers.

ABBREVIATIONS AND NOTES:
N = nitrogen; P = phosphorus; K = potassium; DAP = diammonium phosphate; MAP = monoammonium phosphate; KCl = potassium chloride; KNO₃ = potassium nitrate; K₂SO₄ = potassium sulfate; US$1 = 64.37 Indian Rupee (Rs.).

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The solubilized fertilizer (WSF) were also compared with GF in different combinations designed around the state recommendation (SR = 300-100-200 kg N-P$_2$O$_5$-K$_2$O/ha) for a yield target of 200 t cane/ha (Table 1).

The SSDF design included 16 mm lateral distribution lines that were laid out belowground at a spacing of 1.65 m. The emitter spacing was 0.4 m. The water discharge rate was 4 l/hr. Nutrient stock solutions were prepared by dissolving fertilizers within a 1:5 mixture of fertilizer to water. During each fertigation schedule, the drip system was flushed with water prior to the application of the fertilizers. This was followed by another flushing of drip system for five to ten minutes every second day. Surface and subsurface drip fertigation were carried out by slightly wetting of the root zone before fertigation, followed by flushing the nutrients with water. The control for this study was the SI treatment, which applied all the P basally as granular DAP and all the N (granular urea) and K (granular KCl) were applied in three equal splits at 30, 60, and 90 days after planting. Irrigation occurred every second day and fertigation events occurred at one week intervals (Table 2). The fertigation schedule was designed to meet the sugarcane nutrient requirement at different stages of crop growth. A total of 27 fertigation applications occurred between 15 and 210 days after planting.

**The Case for Subsurface Drip Fertigation**

The option of SSDF offers an ideal opportunity to place soluble nutrients from fertilizer in the root zone, along with irrigation water. SSDF also ensures that nutrients are sup-

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**Table 1. Outline of treatment details applied to sugarcane, Tamil Nadu, India.**

<table>
<thead>
<tr>
<th>Treatment/Source</th>
<th>% of State rec.</th>
<th>Rate, kg N-P$_2$O$_5$-K$_2$O/ha</th>
<th>No. of applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsurface Drip Fertigation (SSDF)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1: WSF$^1$</td>
<td>75</td>
<td>225-75-150</td>
<td></td>
</tr>
<tr>
<td>T2: WSF$^2$</td>
<td>100</td>
<td>300-100-200</td>
<td></td>
</tr>
<tr>
<td>T3: WSF$^2$</td>
<td>75</td>
<td>225-75-150</td>
<td></td>
</tr>
<tr>
<td>T4: GF$^3$</td>
<td>100</td>
<td>300-100-200</td>
<td></td>
</tr>
<tr>
<td>T5: GF</td>
<td>75</td>
<td>225-75-150</td>
<td></td>
</tr>
<tr>
<td>T6: WSF+GF</td>
<td>25</td>
<td>75-25-50</td>
<td>27</td>
</tr>
<tr>
<td>T7: WSF+GF</td>
<td>50</td>
<td>150-50-100</td>
<td></td>
</tr>
<tr>
<td>T8: WSF+GF</td>
<td>25</td>
<td>75-25-50</td>
<td></td>
</tr>
<tr>
<td>Surface Drip Irrigation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T9: WSF$^2$</td>
<td>100</td>
<td>300-100-200</td>
<td></td>
</tr>
<tr>
<td>T10: GF</td>
<td>100</td>
<td>300-100-200</td>
<td>27</td>
</tr>
<tr>
<td>Surface Irrigation (SI)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T11: GF</td>
<td>100</td>
<td>300-100-200</td>
<td>1</td>
</tr>
</tbody>
</table>

$^1$Mixture of fertilizers (WSF grade) solubilized in water: 19-19-19, Urea phosphate (17-44-0), K,SO$_4$ (0-0-50), Urea (46-0-0)
$^2$Mixture fertilizers (WSF grade) solubilized in water: 19-19-19, MAP (12-61-0), KNO$_3$ (13-0-45), Urea
$^3$Mixture of urea, DAP, and KCl (0-0-60)

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**Table 2. Fertigation schedules for sugarcane growing season, Tamil Nadu, India.**

<table>
<thead>
<tr>
<th>Stage (days)</th>
<th>Concentrations of nutrients applied, %</th>
<th>No of applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 30</td>
<td>N 5.0, P$_2$O$_5$ 10.6, K$_2$O 1.8</td>
<td>3</td>
</tr>
<tr>
<td>31 to 60</td>
<td>N 4.6, P$_2$O$_5$ 8.0, K$_2$O 2.2</td>
<td>4</td>
</tr>
<tr>
<td>61 to 90</td>
<td>N 4.6, P$_2$O$_5$ 4.8, K$_2$O 2.2</td>
<td>4</td>
</tr>
<tr>
<td>91 to 20</td>
<td>N 5.0, P$_2$O$_5$ 4.3, K$_2$O 2.7</td>
<td>4</td>
</tr>
<tr>
<td>121 to 180</td>
<td>N 2.7, P$_2$O$_5$ 0, K$_2$O 4.4</td>
<td>8</td>
</tr>
<tr>
<td>181 to 210</td>
<td>N 1.8, P$_2$O$_5$ 0, K$_2$O 7.7</td>
<td>4</td>
</tr>
</tbody>
</table>

$^1$Each application was scheduled at seven-day intervals.
plied precisely in the area of most intensive root activity.

This study found SSDF to be most effective compared to the SDF or SI systems (Table 3). The average cane yield for all SSDF treatments was 158 t/ha, which was 5% higher than SDF, and 65% higher than the SI control. Bresler (1997) attributed higher cane yields under SSDF to minimizing the potential for wide fluctuations in soil water content during the irrigation cycle. This is an important and advantageous feature of drip irrigation. Its implementation leads to better water use, higher nutrient uptake, and better maintenance of soil-water-atmosphere relationship due to a higher oxygen concentration in the root zone (Raina et al., 2011).

Application of WSF at the full SR produced the best yield of 186 t/ha, which was 94% higher than the control (Figure 1). The next highest yield of 176 t/ha was achieved with a combination of WSF (75%) and GF (25%), which

\[
\begin{array}{cccccc}
\text{Treatment} & \text{Yield (t/ha)} & \% \text{increase over control} & \text{NPK applied} & \% \text{increase over control} & \text{Net income (\'000 Rs./ha)} \\
\text{T1} & 160 & 67 & 356 & 122 & 195 & 53 \\
\text{T2} & 186 & 94 & 310 & 93 & 228 & 79 \\
\text{T3} & 165 & 72 & 366 & 129 & 197 & 55 \\
\text{T4} & 143 & 49 & 235 & 47 & 174 & 36 \\
\text{T5} & 127 & 32 & 282 & 76 & 148 & 16 \\
\text{T6} & 176 & 84 & 294 & 84 & 218 & 72 \\
\text{T7} & 156 & 63 & 261 & 63 & 186 & 46 \\
\text{T8} & 150 & 56 & 250 & 56 & 182 & 43 \\
\hline
\text{Average} & 158 & 65 & 294 & 84 & 191 & 50 \\
\hline
\text{Subsurface Drip Fertigation (SSDF)} & \\
\text{T9} & 168 & 75 & 280 & 75 & 194 & 52 \\
\text{T10} & 133 & 39 & 222 & 39 & 162 & 22 \\
\hline
\text{Average} & 151 & 57 & 251 & 57 & 178 & 37 \\
\text{Surface Drifertigation (SDF)} & \\
\text{T11} & 96 & & 160 & & 127 & \\
\text{SED} & 7.4 & & & & & \\
\text{SD (p = 0.05)} & 15.5 & & & & & \\
\hline
\text{Surface Irrigation (SI) + Soil Applied Fertilizers} & \\
\text{T11} & 96 & - & 160 & - & 127 & - \\
\text{SED} & 7.4 & - & - & - & - \\
\text{SD (p = 0.05)} & 15.5 & - & - & - & - \\
\hline
\end{array}
\]

1Data used to calculate net income: Price of sugarcane = Rs. 2,100/t, Prices of fertilizers (Rs./kg): urea = 5.36, DAP = 24.0, KCl = 16.8, MAP = 78, Urea phosphate = 40, KNO₃ = 80, K₂SO₄ = 70, Total annualized drip cost for SSDF = 29,805/ha, Total annualized drip cost for SDF = Rs. 27,660/ha

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**Table 3. Interaction effect of 4R nutrient management on sugarcane (variety Co.86032) yield, NUE, and net income, Tamil Nadu.**

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**Figure 1. Comparison of cane yields resulting from the best treatment using subsurface drip fertigation (SSDF) of water soluble fertilizer at the state recommendation (SR) and the Control treatment of surface irrigation of surface applied granular fertilizers applied at the SR, Tamil Nadu.**

**Figure 2. Comparison of cane yields resulting from either the full or reduced (75%) state recommendation (SR) using either water soluble fertilizers (WSF) or granular fertilizers (GF) using subsurface drip fertigation, Tamil Nadu.**
also fulfilled the SR. Application of either WSF or GF at the full SR was superior (+13%) to the reduced rate tested (Figure 2), which confirms fit of the current SR in meeting a 200 t/ha yield goal.

Mixes of WSF were superior to GF in both SSDF and SDF (Figure 3). Yield was 30% higher with WSF+SSDF and 26% higher with WSF+SDF (Figure 3). Amongst the options tested, the WSF mix of 19-19-19; MAP, KNO₃, and urea proved to be more effective than the mix of 19-19-19; urea phosphate, K₂SO₄, and urea.

This study measured differences in NUE amongst treatments through the performance indicator called partial factor productivity (PFP), which answers the question ... How did the crop respond to the nutrient input?

\[ PFP = \frac{\text{kg cane yield/ha}}{\text{kg applied NPK/ha}} \]

The highest-yielding SSDF treatment using the full SR had a PFP of 309 kg/kg NPK applied, which was 11 and 94% higher than the corresponding treatment under SDF and SI, respectively (Figure 4).

The SSDF treatments using the reduced rate (75% SR) did record even higher PFP values (Table 3), but lower fertilizer inputs can commonly intersect on a steeper part of the yield response curve, and as in this case, one should consider the value of the yield gap caused by a reduction in fertilizer input. Economic data found SSDF of WSF at the SR to be most favorable—mainly due to higher cane yield. In spite of an additional investment of Rs.40,040/ha for WSF over GF (data not shown), WSF returned an additional Rs.55,290/ha.

**Conclusion**

Subsurface drip fertigation facilitates the practice of efficient nutrient management through 4R principles of Nutrient Stewardship, which resulted in higher cane yield, improved NUE, and better net income. Results of the above experiment showed that for achieving a yield target of about 200 t/ha, sugarcane required an application of the right rate of nutrients (300-100-200 kg N-P₂O₅-K₂O/ha) applied through a mixture of water soluble fertilizers (urea, 19-19-19; MAP, and KNO₃). This was most probably due to the right timing of nutrients through 27 split applications at an interval of seven days, applied through the subsurface drip fertigation system. Large-scale adoption of 4R nutrient management through subsurface drip fertigation provides an opportunity to bridge nutrient-related yield gaps in sugarcane and increase the net income for sugarcane growers in an environmentally sustainable manner.

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**References**
