In India sugarcane is cultivated in over 4.5 million ha with annual production of 347.0 million tonnes in the year 2016-17 (Anonymous 2017). It is estimated that a crop of 100 tonnes cane yield removes 208, 52, 280, 30, 3.4, 1.2, 0.6 and 0.2 kg N, P, K, S, Fe, Mn, Zn and Cu respectively (Bhaskaran and Palanisami 2016) and therefore soil alone cannot sustain the heavy nutrients requirement of this crop during different crop growth stages. Indiscriminate use of inorganic fertilizers to supplement the crop nutrients need makes the soil more and more deficient in most of the plant nutrients along with declining soil microbial activity resulting in poor soil health (Singh et al. 2007). Organic manures have the potential to supply both macro and micro nutrients on sustainable basis for healthy crop growth and higher productivity. Balanced use of organic, inorganic and bio-fertilizers not only help to keep the soil in good soil physical and chemical conditions but also it serves as a source of energy for useful soil microbes. Integrated use of organic manures and chemical fertilizers is highly beneficial (Bangar and Sharma 1997 and Chaudhary and Sinha 2001), improves soil fertility for sustained crop productivity (Yadav 2000). Significantly higher cane yield was obtained from sugarcane inoculated with Azotobacter along with recommended nitrogen application. The cane yield obtained with recommended nitrogen application was statistically similar to that with 75% of recommended nitrogen along with seed inoculation with Acetobacter (Gosal et al. 2012). Application of 25% of the total nitrogen through press-mud or FYM could be used to prevent soil nutrient depletion and sustain the crop productivity as well (Banerjee et al. 2018).

The present study aimed to develop INM strategies for conjunctive use of organic and inorganic source of nutrients along with bio-fertilizers in such a way to sustain soil health and sugarcane productivity on long term basis under subtropical conditions of Punjab.

**MATERIALS AND METHODS**

**Experimental site and soil characteristics:** Field experiment on sugarcane was conducted (during spring 2016 and 2017) at Research Farms of Punjab Agricultural University, Regional Research Stations, Kapurthala located (31° 22'N latitude, 75° 22' E longitude and at an elevation of 229 m AMSL), Punjab located in Trans-Gangetic alluvial plains of India. The soil (0–15 cm layer) of the experimental field is a sandy loam in texture, with pH 8.05, low in Walkley-Black organic C 3.70 g/kg, electrical conductivity
Crop management: The crop was planted on 13th and 27th of February during 2016 and 2017, respectively and harvested at full maturity in end February during 2017 and 2018. After seed bed preparation, farmyard manure (FYM) was applied as per the treatments 15 days prior to crop sowing and was mixed well in the soil. On an average, per cent content of C, N, P and K in FYM was 20.0, 0.67, 0.82 and 0.88, respectively. It also contained 10100, 523, 462 and 129 mg/kg of Fe, Mn, Zn and Cu, respectively. Bio-fertilizers were applied in band along the rows after covering the setts with soil as per the treatments. The seed setts of variety CoJ 88 were treated with 0.25% solution of Tilt 25 EC (Propiconazole) and then planted at a row spacing of 75 cm using recommended seed rate, i.e. 50 thousand (three budded setts) per ha. The crop was raised following recommended practices as given in the package of practices for crops of Punjab–rabi crops (Bhatti and Kaur 2018). The size of each sub-plot was 27 m² (6.0 m long and 4.5 m wide).

Climate characteristics: Mean monthly maximum temperature during both the years was similar in all months except February, July and November (Fig 1 and 2). In year 2017 February and March months were comparatively warmer by 2.2°C and November was relatively cooler by 4.9°C as compared to 2016. The mean monthly minimum temperature of February 2017 was 3.6°C higher than in February 2016. Total rainfall of 647.5 mm was received in year 2016 (Fig 1) that was comparatively lesser than the total rainfall of 806 mm received during 2017 (Fig 2). Highest rainfall (241 mm) was received in July 2016, whereas during 2017 it was highest (395 mm) in the month of June. There was no rainfall in November and December 2016 (Fig 1). Rainfall of 21.5 mm and 18 mm was received in November and December during 2017, respectively (Fig 2).

Treatments and experimental design: The experiment was conducted in randomized block design (RBD) with nine treatment combinations and was replicated thrice (Table 1).
Table 1 Effect of integrated use of FYM, inorganic sources of plant nutrients and bio-fertilizers on yield attributes, cane and sugar yield, net returns and benefit-cost ratio of spring sugarcane

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cane length (cm)</th>
<th>Cane diameter (cm)</th>
<th>Millable cane wt. (g)</th>
<th>Number of shoots (thousand/ha)</th>
<th>Net returns (thousand/ha)</th>
<th>Benefit-cost ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>No FYM + 50% of RDF</td>
<td>121.4</td>
<td>2.25</td>
<td>103.3</td>
<td>88.4</td>
<td>2.31</td>
<td>1.56</td>
</tr>
<tr>
<td>No FYM + 100% RDF (150 kg N/ha + P as FYM)</td>
<td>121.1</td>
<td>2.28</td>
<td>102.2</td>
<td>89.1</td>
<td>2.31</td>
<td>2.28</td>
</tr>
<tr>
<td>FYM @ 20 t/ha + 50% RDF</td>
<td>124.2</td>
<td>2.25</td>
<td>114.2</td>
<td>91.7</td>
<td>2.28</td>
<td>2.25</td>
</tr>
<tr>
<td>FYM @ 20 t/ha + STB</td>
<td>124.2</td>
<td>2.25</td>
<td>114.2</td>
<td>91.7</td>
<td>2.28</td>
<td>2.25</td>
</tr>
<tr>
<td>FYM @ 20 t/ha + BF + RDF</td>
<td>121.7</td>
<td>2.27</td>
<td>103.3</td>
<td>88.4</td>
<td>2.31</td>
<td>1.56</td>
</tr>
<tr>
<td>FYM @ 20 t/ha + BF + STB</td>
<td>123.5</td>
<td>2.30</td>
<td>105.5</td>
<td>85.4</td>
<td>2.30</td>
<td>1.56</td>
</tr>
<tr>
<td>CPCS-1</td>
<td>135.9</td>
<td>2.31</td>
<td>107.5</td>
<td>92.4</td>
<td>2.31</td>
<td>1.56</td>
</tr>
<tr>
<td>CPCS-2</td>
<td>135.9</td>
<td>2.31</td>
<td>107.5</td>
<td>92.4</td>
<td>2.31</td>
<td>1.56</td>
</tr>
</tbody>
</table>

Cane yield and components: Cane yield was measured by manual harvesting of an area of 15 m² from the centre of each plot to avoid the border effect. Total number of millable canes (NMC) and number of shoots at 150 days after crop planting were manually counted from net plots of each subplot and converted into thousands per ha. Other yield contributing characteristics like cane length, cane diameter and single cane weight was measured from 10 randomly selected canes from each plot and their respective values are presented as mean of 10 canes. The cane diameter was measured from top, middle and basal part of the cane with the help of vernier calliper and mean of three values was considered as cane diameter (cm).

Estimation of sugarcane quality parameters: The cane juice quality parameters were estimated from the three randomly selected canes from each treatment plot. Juice was extracted from the canes of each respective treatment by using sugarcane crusher. Sucrose and purity was estimated by using sucromat (automatic saccharimeter). Total soluble solids/brix was estimated with hydrometry using brix spindle (0-20 and 21-30) as per the method described by Meade and Chen (1977). Commercial cane sugar % was computed using winter crop equation (Shukla 1991) from which sugar productivity was calculated by multiplying CCS% and cane yield.

\[
CCS% = \left\{\text{sucrose } \% - (\text{Brix }\% - \text{Sucrose } \%) \times 0.04\right\} \times 0.74
\]

where, 0.4 = multiplication factor; 0.74 = cruiser factor.

Statistical analysis: The data on various aspects were statistically analysed as prescribed by Cochran and Cox (1967) and adapted by Cheema and Singh (1990) in statistical package CPCS-1. The treatments were compared at 5% level of significance.

RESULTS AND DISCUSSION

The relative effect of different treatments on growth, cane yield and yield contributing attributes are presented in (Table 1). Highest cane yield of 96.6 t/ha was obtained in treatment FYM + STB as compared to the yield obtained from all other treatments but was statistically similar to the cane yield obtained from treatment FYM + RDF or treatment FYM + BF + STB. Cane yield obtained from treatment FYM + STB was statistically similar to cane yield obtained either from treatment FYM + RDF or FYM + BF + STB. On an average, application of FYM @ 20 t/ha along with STB nutrient application (187.5 kg N/ha) produced 35% and 17.9% higher cane yield over treatment FYM + RDF and FYM + RDF respectively (Table 1). Higher cane yield in plots receiving FYM may be attributed to the improved soil conditions and balanced nutrients application encouraging root growth for efficient utilization of soil plants nutrients and water from the soil (Banerjee et al. 2018). Application of FYM along with recommended dose of fertilizer produced significantly higher cane and sugar yield in comparison to nitrogen application through inorganic fertilizers alone (Lakshami et al. 2011). Integrated use of organics sources and in-organics sources...
of plant nutrients markedly improves the soil physico-
chemical status and impart more conducive environment
for plant growth and development and hence enhance the
crop yield (Ranjjan et al. 2020). Statistically similar single
cane weight was observed in treatments FYM_{20} + STB,
FYM_{20} + RDF_{100} and FYM_{10} + BF + STB but these were
significantly higher over all other treatments during the
year 2017 and mean of pooled data over two years (Table 1).
Commercial cane sugar (CCS) yields of treatments FYM_{20} +
RDF_{100}, FYM_{20} + STB and FYM_{10} + BF + STB were
statistically similar but were significantly higher over rest of
the treatments in pooled mean data of two years (Table 1).

On an average FYM application @ 10 t/ha and 20 t/
ha along with chemical fertilizers enhanced the commercial
cane sugar by 5.88% and 14.2% over the treatments without
addition of FYM (FYM_{0} + RDF_{50}, FYM_{0} + RDF_{100}
and FYM_{0} + STB). These results are corroborated with the
findings of (Soomro et al. 2013) who also reported
significantly higher commercial cane sugar yield of sugarcane with the application FYM @ 10 or 20 t/ha in
combination with chemical fertilizer.

**Soil properties at the harvest of crop:** It was observed
that the pH values ranged from 8.01 to 8.04 in treatments
receiving FYM and was marginally lower from the
treatments without FYM (Table 2). It might be due to the
application of FYM resulting in the production of organic
acids upon microbial decomposition of organic manures
(Gawai 2003). The average organic carbon content increased
by 34% and 21% with the application of FYM @ 20 and
10 t/ha, respectively in comparison to treatments without
FYM application (Table 2). The per cent increase in KMnO_{4}
oxidizable N content in the treatments receiving 10 and 20 t/ha of FYM over the treatments with no manure was found
to be 8.53 and 15.2%, respectively. The per cent increase
in Olsen P content in the treatments receiving 10 and 20 t/
ha of FYM over the treatments with no manure was found
to be 26.0 and 36.7 %, respectively. Similar trend was
observed in the ammonium acetate extractable K content
and the respective values of per cent increase were found to
be 20.2 and 39.6 (Table 2). Significant improvement in soil
organic carbon, available N, P and K with the application of
FYM and bio-fertilizers was also reported by Kumar (2012).

Application of 10 and 20 t/ha of FYM enhanced the
DTPA extractable Zn by 30.8 and 62%, Fe by 27.6 and
61.4%, Mn by 24 and 51.6% and Cu by 6.4 and 9.2% over
no application of manure. However, the content of DTPA
extractable Fe, Mn, Zn and Cu were at par with application
of either 20 or 10 t/ha of FYM. But the per cent increase of
the respective micronutrients with the application of 20 t/ha
of FYM over 10 t/ha FYM was found to be 26.5, 22.2 and
23%, respectively (Table 2). The significant increase in
the availability of Fe with application of FYM might be due to
very high concentration of Fe in the FYM. The chelation
of Mn by organic matter is the major cause of its higher
availability of Mn in the treatments with organic manures.
The Zn complex with Fulvic acid (Zn-FA) increased the
available Zn than that of ZnSO_{4} (Kumar and Prasad 1989).

**Economics analysis:** Maximum net return was observed
in the treatment FYM_{20} + STB followed by treatment FYM_{10}
+ BF + STB and FYM_{20} + RDF_{100}. However, the net returns
as well as benefit cost ratio were statistically similar in these
three treatments, i.e. (FYM_{20} + STB, FYM_{10} + BF + STB
and FYM_{20} + RDF_{100} (Table 2). Application of FYM or
biofertilizers or both resulted in 12.8 to 17.9% higher cane
yield in these three treatments (FYM_{20} + STB, FYM_{10} +
BF + STB and FYM_{20} + RDF_{100}) over the treatment FYM_{0} +
RDF_{100} thereby enhanced additional net returns to the
tune of ₹ 20592–45230/ha as compared with the cultivation
of sugarcane with recommended dose of fertilizers. It is
suggested that even in the absence of FYM, soil test based
application of nutrients can help to increase the net returns
significantly over the application of recommended doses of
fertilizers (Table 1).

In our study, cane weight highly affected the cane
yield followed by cane length and NMC. The application
of 20 t of FYM along with 100% RDF or by reducing the
application of FYM by one half along with biofertilizers and
100% RDF produced similar grain yield as in conventional

---

**Table 2** Effect of INM and biofertilizers on chemical properties of the soil at harvest of sugarcane after 2 years

<table>
<thead>
<tr>
<th>Treatment</th>
<th>pH</th>
<th>EC (dS/m)</th>
<th>OC (%)</th>
<th>KMNO\textsubscript{4}-available N</th>
<th>P</th>
<th>K</th>
<th>Zn</th>
<th>Fe</th>
<th>Mn</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FYM\textsubscript{0} + RDF\textsubscript{50}</td>
<td>8.10</td>
<td>0.233</td>
<td>0.38</td>
<td>62.6</td>
<td>6.20</td>
<td>61.5</td>
<td>2.35</td>
<td>8.44</td>
<td>3.90</td>
<td>0.35</td>
</tr>
<tr>
<td>FYM\textsubscript{0} + RDF\textsubscript{100}</td>
<td>8.10</td>
<td>0.233</td>
<td>0.40</td>
<td>66.8</td>
<td>6.30</td>
<td>63.0</td>
<td>2.40</td>
<td>8.48</td>
<td>3.92</td>
<td>0.36</td>
</tr>
<tr>
<td>FYM\textsubscript{0} + STB</td>
<td>8.10</td>
<td>0.235</td>
<td>0.41</td>
<td>67.3</td>
<td>6.30</td>
<td>64.0</td>
<td>2.45</td>
<td>8.48</td>
<td>3.92</td>
<td>0.36</td>
</tr>
<tr>
<td>FYM\textsubscript{20} + RDF\textsubscript{50}</td>
<td>8.01</td>
<td>0.238</td>
<td>0.52</td>
<td>73.5</td>
<td>9.80</td>
<td>85.1</td>
<td>3.85</td>
<td>13.70</td>
<td>5.91</td>
<td>0.39</td>
</tr>
<tr>
<td>FYM\textsubscript{20} + RDF\textsubscript{100}</td>
<td>8.01</td>
<td>0.245</td>
<td>0.54</td>
<td>76.3</td>
<td>9.90</td>
<td>88.1</td>
<td>3.90</td>
<td>13.60</td>
<td>5.95</td>
<td>0.39</td>
</tr>
<tr>
<td>FYM\textsubscript{20} + STB</td>
<td>8.01</td>
<td>0.245</td>
<td>0.54</td>
<td>77.0</td>
<td>10.0</td>
<td>90.1</td>
<td>3.92</td>
<td>13.70</td>
<td>5.93</td>
<td>0.39</td>
</tr>
<tr>
<td>FYM\textsubscript{10} + BF + RDF\textsubscript{50}</td>
<td>8.04</td>
<td>0.242</td>
<td>0.48</td>
<td>70.2</td>
<td>8.40</td>
<td>79.9</td>
<td>3.12</td>
<td>10.80</td>
<td>4.86</td>
<td>0.38</td>
</tr>
<tr>
<td>FYM\textsubscript{10} + BF + RDF\textsubscript{100}</td>
<td>8.04</td>
<td>0.242</td>
<td>0.48</td>
<td>71.3</td>
<td>8.51</td>
<td>79.8</td>
<td>3.15</td>
<td>10.80</td>
<td>4.85</td>
<td>0.38</td>
</tr>
<tr>
<td>FYM\textsubscript{10} + BF + STB</td>
<td>8.04</td>
<td>0.242</td>
<td>0.48</td>
<td>72.0</td>
<td>8.51</td>
<td>79.5</td>
<td>3.15</td>
<td>10.80</td>
<td>4.85</td>
<td>0.38</td>
</tr>
<tr>
<td>Initial value</td>
<td>8.05</td>
<td>0.231</td>
<td>0.37</td>
<td>65.3</td>
<td>6.15</td>
<td>60.3</td>
<td>2.32</td>
<td>8.40</td>
<td>3.87</td>
<td>0.35</td>
</tr>
<tr>
<td>CD (P=0.05)</td>
<td>NS</td>
<td>NS</td>
<td>0.06</td>
<td>4.32</td>
<td>2.08</td>
<td>17.9</td>
<td>0.66</td>
<td>2.31</td>
<td>0.91</td>
<td>0.21</td>
</tr>
</tbody>
</table>
practices and provided greater economic returns where there is a scarcity of FYM. Thus the application of 10 t FYM+ biofertilizers along with 100% RDF provided maximum net returns and resulted in gradual improvement in soil fertility with minimum ill effects of chemical fertilizer on soil and environment.

REFERENCES