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CROP GEOMETRY OPTIMIZATION FOR SUGARCANE-BASED INTERCROPPING IN A NEW PLANTING TECHNIQUE OF THE SUSTAINABLE SUGARCANE INITIATIVE IN INDIA

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ABSTRACT

Field experiments were carried out at the Sirugamani, Sugarcane Research Station of Tamil Nadu Agricultural University India in 2016-17 and 2017-18. The studies were designed to optimize crop geometry and identify a suitable intercrop for a novel planting technique of the sustainable sugarcane initiative. Sixteen treatment combinations (intercrops and crop geometries) were replicated three times in a strip plot design. Four crop geometries such as 150 x 60 cm single row planting, 150 x 60 cm double row planting, 180 x 60 cm single row planting, and 180 x 60 cm double row planting were assigned to the main plot. The subplot, on the other hand was earmarked for sugarcane-based intercropping, which included sole sugarcane, sugarcane + greengram, sugarcane +blackgram and sugarcane +sunnhemp. The intercrops were grown in an additive series, with three rows of sugarcane planted at 150 cm and four rows planted at 180 cm row spacing. The crop received an average of 730.3 mm of rain over the trial period. The soil at the research site was a well-drained clay loam with low, moderate, and high nitrogen, phosphorus, and potassium availability, respectively. A surface drip fertigation system was used to schedule the fertilizers and irrigation to the crops. By observing cane yield and yield-attributing characteristics at harvest, the impact of crop geometry and sugarcane intercropping in the sustainable sugarcane initiative method was investigated. In comparison to the majority of sugarcane-based intercropping, sugarcane+sunnhemp intercropping produced significantly more tillers at 120 days after planting i.e.150.60 $\times 10^3$ and 88.88 $\times 10^3$ tillers ha^{-1}, respectively, in 2016-17 and 2017-18. Furthermore, growing sugarcane+sunnhemp intercropping yielded more millable canes (89.90$\times 10^3$ and 1.43$\times 10^3$) and cane equivalent yield (138.92 and 139.04 t ha^{-1}) in 2016-17 and 2017-18. The 150×60 cm double row planting of sugarcane was found to be the best among the four crop geometries, yielding the highest cane equivalent yields of 132.85 and 152.56 tha^{-1} during plant I and plant II crops.

Keywords: Sustainable Sugarcane Initiative (SSI), Growth, Yield parameters, yield.

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INTRODUCTION

Sugarcane has a unique opportunity for intercropping. To achieve maximum productivity in an intercropping system, the peak growth phases of the two crops must not coincide, so that one quick-maturing crop completes its life cycle before the primary growth period of the other crop begins. Despite the fact that the economic efficiency of the sugarcane (*Saccharum offcinarum)* intercropping system has received a lot of attention around the world, the interaction between different crop geometries and sugarcane intercropping in sustainable sugarcane initiative (SSI) has not been explored yet. With a soil restoration crop like sunnhemp under a unique sustainable sugarcane initiative planting technique is crucial to improve the total system productivity and soil health. When compared to traditional sugarcane production systems, the Sustainable Sugarcane Initiative (SSI) is a pivotal innovation in sugarcane planting techniques that includes raising sugarcane settling in protrays, transplanting sugarcane settling in wider row spacing of 150 cm, water conservation through micro irrigation, growing short-duration intercrops, and adding organic inputs to restore soil fertility with sustainable cane yield. SSI has become a feasible technology among farmers for sustainable production due to its effective and efficient use of water and seed cane.

The tillering potential in SSI is quite high, but it has yet to be fully realized (WWF-ICRISAT, 2009), and improved crop geometry has a significant interplay between tiller and cane production, because row spacing influences tiller growth by way of effective utilization of incident solar energy, as well as its conversion to biomass and stalk yield. *Perse c*ane yield is a function of the stalk population per unit area (number of millable canes) and single cane weight. The optimization of crop geometry in sugarcane is extremely crucial for sustaining cane productivity. The most conducive plant growth environments are provided by optimal crop geometry, which increases the number of millable canes and cane weight. Closer spacing result in a higher plant population in the early stages, closer planting at 50 cm row spacing, on the other hand, may protect crop from lodging and resulted in a 22t ha^{-1} increase in cane yield over 75 cm spacing in windy areas. (Singh *et al*., 1994). In general, the optimum inter row distance is determined by the variety's tillering capacity, the time of planting, the soil's fertility status, and stress conditions such as drought. To accommodate the site's specific microclimate, 75-100 cm row spacing is common in India, whereas wider spacing is used in countries such as Australia, Brazil, Mauritius, and South Africa. Row spacing is wider (> 1.2 m) in areas where mechanized cultivation is practised, while narrower row spacings (0.6 m - 1.2 m) are used in countries where human labour is extensively used for sugarcane cultivation. Several modifications to sugarcane planting geometry have been developed and tested for sugarcane-based intercropping systems wherein results of trial conducted by Darpana Patel *et al*. (2017) also revealed that row spacing of 30-120-30 cm produced significantly more number of millable canes(106680), cane equivalent yield, and sugar yield (106.9 and 12.97 t ha^{-1}, respectively) than 60-120-60 spacing. Various planting methods and intercropping systems had a significant impact on the number of millable canes. Sugarcane planted with traditional spacing (90 cm in furrows) yielded less millable canes than sugarcane grown with a sole paired row system (60 x 60 – 120 cm) (Zarekar *et al*., 2018). Likewise, sugarcane paired row planting with 145/30 cm spacing produced considerably more millable canes and yield than regular row planting (Dilip Singh and Jain, 1994). In contrast, Singles and Smit (2002) observed a linear increase of 5.29 tillers m^{-2} for every one metre decrease in row spacing and a 13 percent increase in stalk dry mass at 12 months for a 1 m drop in row spacing. Furthermore, Radiation Use Efficiency (RUEs) ranged from 1.72gMJ^{-1} (for 2.66m Row Spacing) to 1.24gMJ^{-1} for 0.73m row spacing, indicating that RUEs are higher in wider rows spacing. This could be because wider rows intercepted more radiation than narrow rows, and increased intra-row competition in narrow row planting could lead to water and/or nutritional stress. Bull and Bull (1996) also presorted the similar response of 4.9 tillers m^{-2}. The foregoing discussion indicate that crop geometry optimization using SSI techniques is critical for maximizing sugarcane yield potential of sugarcane elite genotypes. In this context, Tayade *et al*. (2021) found that VSI 12121 and Co 12012 sugarcane genotypes were climate resilient in terms of better juice quality, superior heat use efficiency, energy use efficiency, and increased cane productivity under a wider row planting system with 120 cm row spacing in tropical Indian conditions. The effect of row spacing on sugarcane internode development was examined by Khalid *et al*., (2015), wherein, 120 cm row spacing allows for more internodes per tiller (12.13), followed by 90 cm row spacing (10.86), and 60 cm row spacing produces the lowest internodes per tiller (10.33). In another trial, Khandagave (2011) also noticed that 120 cm row spacing produced significantly more cane yield (111.8 t ha^{-1}) than 90 cm row spacing (102 t ha^{-1}) and 150 cm row spacing registered significantly more sugar yield (18.5 t ha^{-1}) than 90 cm row spacing (14.7 t ha^{-1}). Various planting methods and intercropping systems had a significant impact on the number of millable canes in sugarcane planted with conventional spacing (90 cm in furrows) yielded lesser millable canes than sole paired row system (60 x 60 – 120 cm) (Zarekar *et al*., 2018).

Intercropping is the practise of growing one or more crops in addition to the main sugarcane crop. Sugarcane's long growing season, slow initial development, and greater row spacing make it possible to cultivate a variety of short duration crops in the interspaces. Productivity improvements per unit area per unit time, improved use of available resources (land, labour, water, and nutrients), decrement in losses due to pests, diseases, and weeds, and socioeconomic factors i.e. greater stability, economics, human nutrition, and biological aspects are some of the benefits of intercropping (Vandermeer, 1989). When two or more crops are planted in close proximity in an intercropping system, the interactions can be complementary, resulting in higher yields, or competing, resulting in stress and lower yields. Typically, yield advantage emerges in intercropping system because the component crops differ in their use of growth resources in such a way that when grown together, they are able to complement one another and make better total resource usage than if grown separately. Better resource use efficiency and yield advantage (LER, ATER, AG, and CR) were observed for sugarcane-based intercropping when 100% recommended nitrogen was applied.All sugarcane-based intercropping systems had profound impact on the number of millable canes and cane yield except sugarcane + finger millet as the effect was negative. The depletion of soil available N was substantial in the sugarcane+finger millet intercropping system, whereas there was an addition in the sugarcane+soybean and sugarcane+sunnhemp systems (Geetha and Tayade, 2022).There are both temporal and spatial complementarities in sugarcane-based intercropping systems wherein, Thiruvarasan (2017) found that sugarcane+blackgram (1:3 ratio) intercropping resulted in significantly higher germination (94%) and tiller output (182%) than a single sugarcane crop. When sugarcane was intercropped with sunnhemp, Geetha *et al*., (2017) found that the cane yield was considerably higher (173 t ha^{-1}) than when sugarcane was grown alone. To be considered beneficial, an intercropping system must meet at least one of the following two criteria:

i) Intercropping must provide a full yield of the main crop as well as a portion of the intercrop yield.
ii) The total yield of the main crop and the intercrop must be greater than the yield of the sole main crop.

In sugarcane-based intercropping systems, the first condition is usually favoured because any reduction in cane yield is unacceptable to both cane growers and sugar mills. However, research work on the interactions of diverse crop geometries and sugarcane-based intercropping systems, with an emphasis on the sustainable sugarcane initiative (SSI) method of sugarcane planting, is scarce. With this background, we hypothesized that the additive crop could influence competitive ability and quality of component crop and yield of the intercropping system. As a result, in the present investigation, only an additive system of intercropping is proposed, in which the population of the base sugarcane crop is maintained at the same level as in solo cropping and a reduced population of an inter crop is introduced to harness agronomic yield advantage.

MATERIALS AND METHODS

Experimental design and intercrops and crop geometry allocation in main and subplots: Many researchers have investigated the economic yield advantage in sugarcane intercropping systems around the world, but the treatment setup used in this study was novel, and the interaction between different crop geometries and sugarcane intercropping in the sustainable sugarcane initiative (SSI) has not been explored yet. Three short-duration intercrops-blackgram, greengram, and sunnhemp-were added to the experiment in order to get benefit from biological nitrogen fixation and significant improvement of soil health through crop residue incorporation. Short-duration pulses like greengram (ADT 3), blackgram (VBN 5) and sunnhemp (CO 1) mature as intercrops in 60–75 days, and they won't compete with the sugarcane crop for soil moisture, nutrients, or solar radiation.The sugarcane variety TNAU sugarcane Si 8was used for field experiment during both the years. It performs well in all soil types and extremely well under garden land condition. It is an early maturing variety with high sucrose content, higher yield, multiple ratooning capacity and highly suitable for wider row spacing.

Strip plot design (SPD) was used for the experiments, with four treatments in the main plot and four treatments in the sub plot replicated three times. The net plot size that was chosen was 27.0 m^2 (9.0 m X 3.0 m). The main plot treatments comprised of crop geometry *viz.,* M_1- 150 x 60 cm Single row planting, M_2-150 x 60 cm Double row planting, M_3- 180 x 60 cm Single row planting and M_4-180 x 60 cm Double row planting. The subplot treatments were S_1-Sole crop of Sugarcane, S_2-Sugarcane + Green gram, S_3-Sugarcane + Blackgram and S_4-Sugarcane + Sunnhemp (Fig.1).

Experimental site, Soil and Climate: The experiment site i.e. Sugarcane Research Station, Sirugamani, in the Cauvery delta zone of Tamil Nadu, India, is located at 10^0 56'N latitude and 78^0 26'E longitude, at an altitude of 78.12 m above mean sea level. The field experiments were laid out during the special seasons of 2016-17 and 2017-18. The soil at experimental site was a well-drained clay loam in texture. With EC 0.29 dsm^{-1}, pH 8.58, and organic carbon 0.58 percent, the soil had 234, 15.8, and 467 kg/ha of $KMno_4$-N, Olsen P, and NH_4OAc-K, indicating a low, medium and high in available nitrogen, phosphorus and potassium content, respectively. The experimental site has a semiarid climate (Fig 2. and Fig.3) with an annual average temperature of 26.30°C. The average annual rainfall in Sirugamani is 780 mm, which falls over a five to six-month period in 45 rainy days.

Detail of tillage and Surface drip fertigation system layout: Initially the land was ploughed with tractor drawn disc plough followed by tractor drawn cultivator and rotavator in order to bring the fine tilth soil. After uniform leveling, trenches were dug out at a width of 40 cm at 125 cm apart. The trench depth was maintained at 20 cm.

Surface drip fertigation (SDF) system layout: The bore well was fitted with 12 HP submersible motor pump. Surface drip fertigation unit was installed in the experimental site with plots measuring of 12 m length and 9 m width for all the treatments. Surface drip fertigation units consisted of water filtration unit at the base of system with hydro cyclone filter (20 m^3) and disc filter (2.0”) with a mesh of 200 microns filtrations capacity, ventury (3/4”), water meter (2”), bypass valve (2”), pressure gauge, air cum vacuum release valve (40 mm) and control valve (2”). After filtration unit, PVC main line (75 mm OD) and sub mainline (63 mm OD) were installed to take water from filtration unit to the experimental field. Separate sub mains of 40 mm OD and control valves (PVC Ball valves) of 1” were fitted to each plot to impose fertigation as per schedule.

The inline drip laterals of 16 mm OD size LLDPE with emitters spacing at 50 cm apart with 4 lph discharge rate were laid out at a distance of 165 cm apart. Under SDF, the laterals were placed at the soil surface.

Whereas in SDF, the laterals were placed at 20 cm deep from the soil surface in the centre of every surface of trench. In each of the treatments, sugarcane rows are depending upon the treatments. The operating pressure of 1.5 kg cm^{-2} was maintained at the head unit and 1.0 kg cm^{-2} at the end of laterals.

For fertigation, a separate 0.5 HP motor pump was attached with 3/4" ventury for maintaining required pressure for ventury operation and desired suction rate (60 lph) while doing fertigation commonly. Due care was exercised to apply the required quantity of recommended dose of fertilizers commonly. Along the main line, an air cum vacuum release valve was fitted. At the tail end of the main and sub main line, flush valves of appropriate size were fitted.

Under SDF an end cap was provided at the tail end of laterals. After installation, trial run was conducted to assess mean emitter discharge and uniformity coefficient (95%) of the system. The design and layout of surface drip fertigation system in the experimental field.

Surface drip fertigation systems: The recommended dose of fertilizer adopted for sugarcane was 300:100:200 kg N, P_2O_5 and K_2O ha^{-1}. From this recommendation, the entire dose of phosphorus was applied as basal as single super phosphate and 100% of N and K were applied by fertigation as urea and muriate of potash in all the treatments as per the common schedule. The fertigation schedule was planned to meet the crop demand and requirement of the nutrients at different stages of crop growth**.** Fertigation was given as per the treatment schedule. Fertigation was scheduled once in ten days starting from 10 to 210 days after planting. The details of fertigation scheduled with major nutrient at 100% Recommended Dose of Fertilizer (RDF) are presented in table 2 and 3.

Fertigation schedules were prepared with major nutrient fertilizer grades according to growth stages and requirements of the crop. Major nutrient fertilizers quantities were dissolved at 1:5 ratio of fertilizer: water and nutrient stock solution was prepared. At every fertigation, drip system was run for wetting as a first step and then fertigation was done and finally flushing was done 5-10 minutes once in 2 days. Surface drip fertigation was carried out in three consecutive steps *viz.,* slightly wetting the root zone before fertigation, fertigating the field and flushing the nutrients with water.

Crop culture: Twenty-four days old single bud settlings were transplanted in the main field, and Table 1 shows the quantity of sugarcane settlings needed for one hectare of land. The sugarcane crop was irrigated using a drip irrigation system to conserve irrigation water (Fig.4). To evaluate the performance of different sugarcane-based intercropping, a sole sugarcane crop was also raised (Fig.5). The intercrops were raised as additive series *viz*., 3 rows under a row spacing of 150 cm in sugarcane and 4 rows under 180 cm (Fig.6, Fig.7 and Fig.8). The recommended schedule of surface drip fertigation for SSI was followed under surface drip irrigation system. The recommended dose followed was 300:100:200 kg/NPK/ha^{-1}. No additional fertilizers were applied to the intercrops. The growth parameter of tillers at 90 and 120 DAP was recorded. The yield attributes *viz.,* number of millable canes at harvest; cane yield and sugar yield at harves**t** were recorded.

Crop harvest and measurements on NMC, Cane yield and collection of data

Collection of data: For analyzing growth and development of the crop, five plants were selected at random from each net plot area in each treatment and were tagged to record various biometric observations. The average values were used for analysis. The procedures followed for collection of various parameters is given below.

Number of tillers (lakhs ha^{-1}): The mother shoots along with green tillers present in each net plot were counted for 10 m length and recorded as number of tillers at 90 and 120 DAP and expressed in lakhs ha^{-1}.

Number of millable cane (lakhs ha^{-1}): At harvesting, an observation was made on the number of millable canes per hectare (NMC), which is a significant yield attributing indicator in sugarcane. Thenumber of millable canes present in each plot were counted for all rows at harvest and was computed on hectare basis and expressed as number of millable canes in lakhs ha^{-1}.

Cane yield (t ha^{-1}): Harvesting of the twelve-month matured sugarcane crop was done. Cane was manually harvested using a hand axe in each experimental unit (treatment plot). All the millable canes in each plot were cut close to the ground level, the green tops and trash were removed and weighed in a 300 kg of weighing machine for each plot for all the treatments and the yield calculated on hectare basis and expressed in t ha^{-1}. Cane yield tonnes per hectare were calculated by weighing harvested canes separately in each experimental plot. Equivalent cane yield for the various sugarcane- based intercropping is the economic yield and calculated by multiplying the market price of the intercrop by its yield, dividing it by the price of sugarcane, and finally adding it to the sugarcane yield of that treatment.

Sugar yield (t ha^{-1}): The formula [(Sucrose percent 1.022) - (Brix 0.292)] was used to calculate the sugar percent of commercial cane. The formula [(CCS percent cane yield t/ha)/100] was used to compute CCS yield (t/ha). Where, CCS = Commercial cane sugar (%)

Statistical analysis of data: Considering the strip plot design, the experimental data on tiller count at 90 and 120 DAP, NMC and cane equivalent yield, were submitted to a statistical analysis protocol (Gomez and Gomez, 1984). The F test was used to determine the significance of the total difference between treatments, and conclusions were derived at a 5% probability level.

RESULTS AND DISCUSSION

Tiller dynamics as influenced by crop geometry and sugarcane-based intercropping: The tiller count is an important growth parameter of sugarcane crop which is directly related to cane productivity. To assess the response of various crop geometry and sugarcane- based intercropping observations on tiller count recorded at 90 and 120 DAP. The total number of tillers increased consistently as the crop grew, as per the data in Table 4. For the 2016-17 and 2017-18 growing seasons, crop geometry and sugarcane-based intercropping had a significant impact on tiller production under SSI planting techniques at all growth stages (90 and 120 DAP) in both plant crops. In the 2016-17 and 2017-18 crop seasons, 150 cm double row planting produced significantly more tillers (174.8×10^3 and 156.6×10^3 tillers ha^{-1}at 90 and 120 DAP) and (110.57×10^3 and 84.52×10^3 ha^{-1} at 90 and 120 DAP), respectively, than the other crop geometries investigated. This could be, because double row planting accommodated larger settling numbers per unit area, as well as wider row spacing, which may have allowed for more light interception by the crop canopy, resulting in improved crop development and tiller production. Furthermore, the absence of inter and intra-row plant competition may explain the higher number of tillers per m^2 in 150 cm double row planting. The findings are in agreement with those of Sathiya *et al*. (2011) and Ehsanullah *et al*. (2011), who observed that wider row spacing resulted in a higher number of tillers m^{-2} than closer row spacing. According to Kumari (2006) and Zarekar *et al*. (2017) the tiller population was greater with paired row planting at 120 and 270 DAP, albeit it was comparable with conventional row planting. Planting at 180 cm in a single row (M_3) markedly reduced the number of tillers during both plant crops.

Sugarcane with sunnhemp (S_4) intercropping produced significantly more tillers than the majority of the sugarcane- based intercropping during both plant crops. However, there have been seasonal differences, with tiller production at 90 and 120 DAP, being higher during the 2016-17 crop season ($173.2\ \times10^3$ and 150.6×10^3 tillers ha^{-1}) over the 2017-18 crop season(94.38×10^3 and 88.88×10^3 tillers ha^{-1}). At all stages of crop growth, the interactions between crop geometry and sugarcane-based intercropping were found to be significant. Planting sugarcane at 150 cm in double rows and intercropping with sunnhemp (M_2S_4) produced the highest number of tillers (217.0 and 201.5 at 90 and 120 DAP, respectively) among the sixteen treatment combinations during the crop season 2016-17. Sugarcane with sunnhemp (S_4) had the most tillers over the other intercropping systems, followed by sugarcane with blackgram (S_5). This could be due to increased sunlight availability following the in-situ incorporation of sunnhemp at 45 DAP, as well as possibly increased nutrient availability. This result is consistent with Udayakumar (2003) findings. Planting at 180 cm in single row planting resulted in reduced tillers in all treatment combinations. At all stages of observation, the sole sugarcane (S_1) resulted in significantly decreased tiller production.

Number of millable cane: Crop geometry and intercropping systems had a significant impact on the number of millable canes at harvest in the SSI planting technique for both crop seasons 2016-17 and 2017-18. (Table 5). During the crop seasons 2016-17 and 2017-18, significantly more millable canes were observed under 150 cm double row planting (94.41×10^3 and 73.49×10^3 ha^{-1}) than with other crop geometry. This might be due to the better survival rate of tillers under wide row spacing than the other crop geometry. The number of millable canes per unit area is an important factor in determining the final yield in sugarcane (James, 1971) which is dependent mainly on the tiller production and survival. In normal row spacing, the tiller mortality rate was higher compared to wide rows. The positive response of sugarcane crop in terms of yield attributes to various plant geometries were reported by Mahadevaswamy and James Martin (2002), Soomro *et al*.(2009), Ghaffar *et al*.(2012). Mortality of tillers was associated positively with number of tillers in sugarcane was also observed by Bose and Thakur (1980) and Narwal and Malik (1981). Another possible explanation for the higher number of NMC in the 150 cm double row planting is that more sugarcane seedlings per metre row length are accommodated, resulting in more tillers through more efficient use of moisture, nutrients, and solar energy with less inter and intra plant competition. This finding is consistent with those reported by Malik and Ali (1990), Malik *et al*. (1996), Hussain *et al*. (2004), Chattha *et al*. (2007), and Zafar *et al*. (2010).During both crop seasons, the interactions between crop geometry and sugarcane-based intercropping were found to be significant with respect to NMC recorded at harvest. Among the different sugarcane- based intercropping, sugarcane intercropped with sunnhemp (S_4) recorded the significantly higher number of millable canes i.e. 89.90×10^3 and 71.43×10^3 ha^{-1} during the crop season 2016-17 and 2017-18.The second-bestsugarcane-based intercropping found to be the sugarcane intercropped with blackgram (82.05 ha^{-1}). With regard to intercropping systems, sugarcane with sunnhemp (S_4) recorded higher number of millable canes followed by sugarcane with blackgram (S_3) and both were on par with each other. This was due to better and increased conversion of tillers into millable canes.

Sathyavelu *et al*. (1991) and Nasir Ahmed (1999) observed that intercropping of sunnhemp as green manure in the standing crop of sugarcane increased the number of millable canes which in turn increased the cane yield. Intercropping of two rows of green manure crrop and incorporated on 45 DAP recorded maximum number of millable canes due to better and increased conversion of tillers into millable canes which ranged from 61.67 to 63.70 per cent. This finding is in conformity with the findings of Guru (1997). Similar findings of increased number of millable canes due to green manuring were also reported by Jayapaul*et al.* (2000), Udayakumar (2003), Roodagi (2001), Manimaran *et al*.(2009) and Ombase *et al*. (2018). Among the sixteen treatment combinations, planting sugarcane at 150 cm in double rows and intercropping with sunnhemp (M_2S_4) produced the highest number of millable canes (110.90×10^3 and 93.13×10^3 ha $^{-1}$ during 2016-17 and 2017-18, respectively). According to Asoka Raja and Mahesh (2013), the increased number of millable cane production under double row planting under zig zag methods of planting was mainly due to the high supply of plant nutrients and continuous availability of water in the effective root zone of the crop without any stress. Under 180 cm single row planting (M_3), there were fewer millable canes (65.82×10^3 ha $^{-1}$). Due to competition among tillers, high tiller mortality could only be envisaged in close row spaced crop geometry.

Cane equivalent yield: Crop geometry had a significant impact on cane equivalent yield during the crop seasons 2016-17 and 2017-18. Crop geometry of 150 cm double row planting (M_2) resulted in significantly higher cane equivalent yields of 132.85 t ha^{-1} and 152.56 t ha^{-1} than the other crop geometries. The present findings imply that the crop geometry with dual row (150 cm) was observed to be optimal for tiller growth. Sugarcane tiller growth is the primary sink for photosynthate. The tiller population was found to support the leaf canopy (Singels and Smit, 2002), which is a potential source of photosynthate. This could have resulted in a higher number of millable canes and longer canes. The wider inter row spaces available between single buds settling in two rows (45 cm) could have allowed for improved light interception and also promoted good earthing-up to reduce lodging under double row spacing. Wider spacing resulted in higher cane equivalent yield, which could be attributed to increased accumulation of photosynthetes as resources such as sunlight, water, and nutrients became more available. Similar findings were reported by Singh *et al*. (2012), which agree with our findings. By and large improvement in yield attributing characters such as number of millable canes, cane yield, top yield, trash yield, and sugarcane equivalent yield per hectare was observed by Zarekar (2016) when sugarcane was planted as a paired row planting (60 x 45 -150 cm) rather than normal planting of 150 cm spacing in single row planting. During both crop seasons, sugarcane with crop geometry of 150 cm single row produced 125.68 t ha^{-1} and 128.70 t ha^{-1} cane equivalent yields, outperforming the two crop geometries of 180×60 cm single row planting (M_3) and 180×60 cm double row planting (M_4). Sugarcane planted in a single row at 180 cm produced the lowest yield of any crop.

Cane equivalent yield (CEY) was influenced significantly by sugarcane intercropping systems. Sugarcane intercropped with sunnhemp (S_4) yielded greater CEY (138.92 t ha^{-1} and 139.04 t ha^{-1}) over both crop seasons than other sugarcane intercropping systems. During the 2016-17 crop season, intercropping sugarcane with blackgram (S_3) (115.6 t ha^{-1}) was comparable to sugarcane with sunnhemp. Higher cane equivalent yields in sugarcane + sunnhemp intercropping may be correlated to in-situ soil incorporation of sunnhemp at 45 DAP, which improves the availability of N, P, and K in the soil system and, as a result, boosts tiller development and survival, ultimately resulting in more millable canes. This was in line with the findings of Rao (1990), who found that applying green manure to a cane crop enhanced the availability of NPK from the soil, allowing for more uptake by the cane, and hence increased cane yield. Higher cane production in the intercropping system can be attributed primarily to the complementary effect of legumes (i.e. sunnhemp) in terms of organic matter addition and nitrogen fixation, which helped to increase NPK availability to the main crop of sugarcane. The results are consistent with results of Kailasam (1994) that also highlighted yield advantage in sugarcane- based intercropping. Certain pulses, such as greengram and blackgram, were also found to be beneficial intercrops with sugarcane by Sharma (2003) and Kannappan *et al*. (1990). Similarly, in the sugarcane ratoon rhizosphere, Tayade *et al*. (2019) found that green manuring with sunnhemp and in-situ trash management in sugarcane could improve soil health by lowering soil bulk density (1.26 kg dm-3) and soil penetration resistance (1.79, 1.82, and 1.75 MPa respectively). When compared to the control, it also contributed to the formation of soil organic carbon (0.52%), which enhanced ratoon cane production by 12.24 percent (99.02 t ha^{-1}) and sugar yield by 8.64 percent (12.83 t ha^{-1}). The positive effects of intercropping sugarcane with sunnhemp production could be attributable to the multi-community intercropping system's high efficiency in utilizing sunshine, heat, water, and mineral nutrition resources. The leguminous crop intercropped in the sugarcane field, in particular, could boost the N-fixing microbial population, hence increasing N availability to sugarcane (Solanki *et al*., 2017). Sole crop of sugarcane recorded lower cane yield compared to other intercropping systems under SSI practices. The interaction between crop geometry and intercropping systems was significant. The treatment combination of sugarcane planted at 150 cm in double rows (M_2S_4) and intercropped with sunnhemp produced higher cane equivalent yield (170.80 t ha^{-1} and 170.46 t ha^{-1}) during both plant crops.

Sugar yield: Crop geometry and sugarcane-based intercropping methods had a bearing on sugar yield in both seasons (Table 5). Sugarcane grown under crop geometry with double row planting in 150 cm produced higher sugar yields during both crop seasons (12.8 and 17.7 t ha^{-1}).Sugar yield is function of CCS percentage and cane yield, and higher cane yield observed in crop geometry with double row planting in 150 cm may have improved sugar yield as well. Kumari (2006) reported that paired row planting yielded a higher sugar yield that was comparable to conventional row planting, whereas, wide row planting yielded a lower sugar yield. Sugarcane with sunnhemp (S_4) produced higher sugar yields (15.0 t ha^{-1} and 16.60 t ha^{-1}) than sugarcane with black gram (S_3) (12.0 t ha^{-1}) and both were comparable. This could be attributed to the constant supply of nutrients and other favourable environmental conditions in sugarcane + sunnhemp, which resulted in better and earlier conversion of tillers to millable canes, as well as increased cane and sugar yields (Mahendran *et al.,* (2006). At ICAR-SBI, Coimbatore, India, Tayade *et al*., (2016) noticed that the trash mulching + green manure (Sunnhemp) treatment had a higher soil microbial biomass carbon content estimated at 180 DAP (112.25 g/g soil), better soil moisture and lesser soil temperature than the control (86.91g/g soil). Sunnhemp intercropping and soil incorporation enhanced cane yield by 10.0 to 15.6 percent compared to a pure cane crop in another study, resulting in a higher sugar yield. Furthermore, the sugarcane-sunnhemp intercropping system had uniform tiller to millable cane conversion with fewer late developed tillers, possibly resulting in uniform cane maturity and hence increased juice quality, resulting in greater CCS % and sugar yield (Roodagi, 2001).Under SSI techniques, there was no significant interaction between crop geometry and sugarcane- based intercropping systems on sugar yield.

Table 1. Sugarcane bud settling requirement under novel SSI planting technique.

Particulars	Crop Geometry with single row planting		Crop Geometry with double row planting	
Crop Geometry	150×60^{cm}	180×60	150×60	180×60
Number of sugarcane bud settling used for transplanting in main field per hectare	11,111	9,260	22,222	18,520

Table 2. Source of fertilizers and their nutrient content used for sugarcane the experiment.

Sl. No	Plant nutrients	Source of fertilizers	N (%)	P_2O_5 (%)	K_2O (%)	Solubility (g lit^{-1} at 20 ºC)	pH
1	Nitrogen	Urea	46	00	00	1080	Acidic
2	Phosphorus	Single super phosphate	00	16	00	667	Acidic
3	Potassium	Muriate of Potash (MOP)	00	00	60	340	Neutral

Table 3. Details of fertigation schedule used for sugarcane crop (Recommended dose of Fertilizer: 300:100:200 NPK kg ha^{-1}).

Days after planting	Urea (kg ha^{-1})	Muriate of potash (K_2O kg ha^{-1})	Days after planting	Urea (kg ha^{-1})	Muriate of potash (K_2O kg ha^{-1})
10	32.50	0.00	120	50.00	20.00
20	32.50	0.00	130	22.50	16.75
30	32.50	0.00	140	22.50	16.75
40	32.50	7.75	150	22.50	16.75
50	35.00	8.00	160	22.50	16.75
60	35.00	8.00	170	22.50	16.75
70	47.50	19.25	180	22.50	16.75
80	47.50	19.25	190	7.50	30.50
90	47.50	19.25	200	7.50	30.50
100	50.00	20.00	210	7.50	30.00
110	50.00	20.00	**TOTAL**	650.0	334.00

Table 4. Tiller dynamics in sugarcane as influenced by Crop geometry and intercropping

Treatments	Tiller (10^3 ha $^{-1}$)			
	Plant Crop I		Plant crop II	
	90 DAP	120 DAP	90 DAP	120 DAP
Crop Geometry				
M_1:150×60 cm single row planting	158.9	130.4	88.68	74.01
M_2: 150×60 cm double row planting	174.8	156.6	110.57	84.52
M_3: 180×60 cm single row planting	144.2	123.6	64.94	63.74
M_4: 180×60 cm double row planting	155.4	127.4	75.98	66.67
Sed	2.7	2.6	2.3	2.1
CD(p=0.05)	6.6	6.4	5.8	5.1
Sugarcane- based intercropping				
S_1: Sole sugarcane	152.8	128.6	75.99	62.56
S_2: Sugarcane + Greengram	154.1	129.1	81.40	66.55
S_3: Sugarcane +Blackgram	153.1	129.8	88.39	70.93
S_4: Sugarcane +Sunnhemp	173.2	150.6	94.38	88.88
Sed	1.6	2.1	2.8	4.1
CD(p=0.05)	4.1	5.3	7.0	10.2
Interaction effects				
M at S				
Sed	10.4	8.9	6.5	3.9
CD(p=0.05)	22.1	19.0	14.0	8.6
S at M				
Sed	10.2	8.8	6.7	5.3
CD(p=0.05)	21.5	18.6	14.6	12.3

Table 5: Effect of crop geometry and intercropping on NMC, Cane equivalent yield and sugar yield

Treatment Crop Geometry	NMC(10^3 ha^{-1})		Cane equivalent yield (t ha-^{1})		Sugar yield (t ha-^{1})	
	Plant I	Plant II	Plant I	Plant II	Plant I	Plant II
M_1:150×60 cm single row planting	86.53	65.08	125.68	128.70	12.0	13.4
M_2: 150×60 cm double row planting	94.41	73.49	132.85	152.56	12.8	17.7
M_3: 180×60 cm single row planting	65.82	54.30	114.61	107.97	11.3	11.1
M_4: 180×60 cm double row planting	85.10	58.39	117.45	110.37	11.7	11.9
Sed	2.32	2.06	2.15	1.64	0.6	0.5
CD(p=0.05)	5.68	5.03	5.27	4.02	NS	1.2
Sugarcane- based intercropping						
S_1: Sole sugarcane	79.58	57.80	94.00	101.04	10.4	11.5
S_2: Sugarcane + Greengram	80.33	58.39	119.73	132.55	10.4	12.3
S_3: Sugarcane +Blackgram	82.05	63.63	137.94	126.97	12.0	13.7
S_4: Sugarcane +Sunnhemp	89.90	71.43	138.92	139.04	15.0	16.6
Sed	1.72	1.27	2.90	1.01	0.4	06
CD(p=0.05)	4.22	3.12	7.09	2.48	0.9	1.6
Interaction effects						
M at S	4.08	2.68	6.89	3.06	1.0	1.3
Sed	9.03	6.18	14.70	6.73	NS	NS
CD(p=0.05)						
S at MZ						
Sed	3.77	2.14	7.15	2.77	0.9	1.4
CD(p=0.05)	8.20	4.76	15.44	5.95	NS	NS

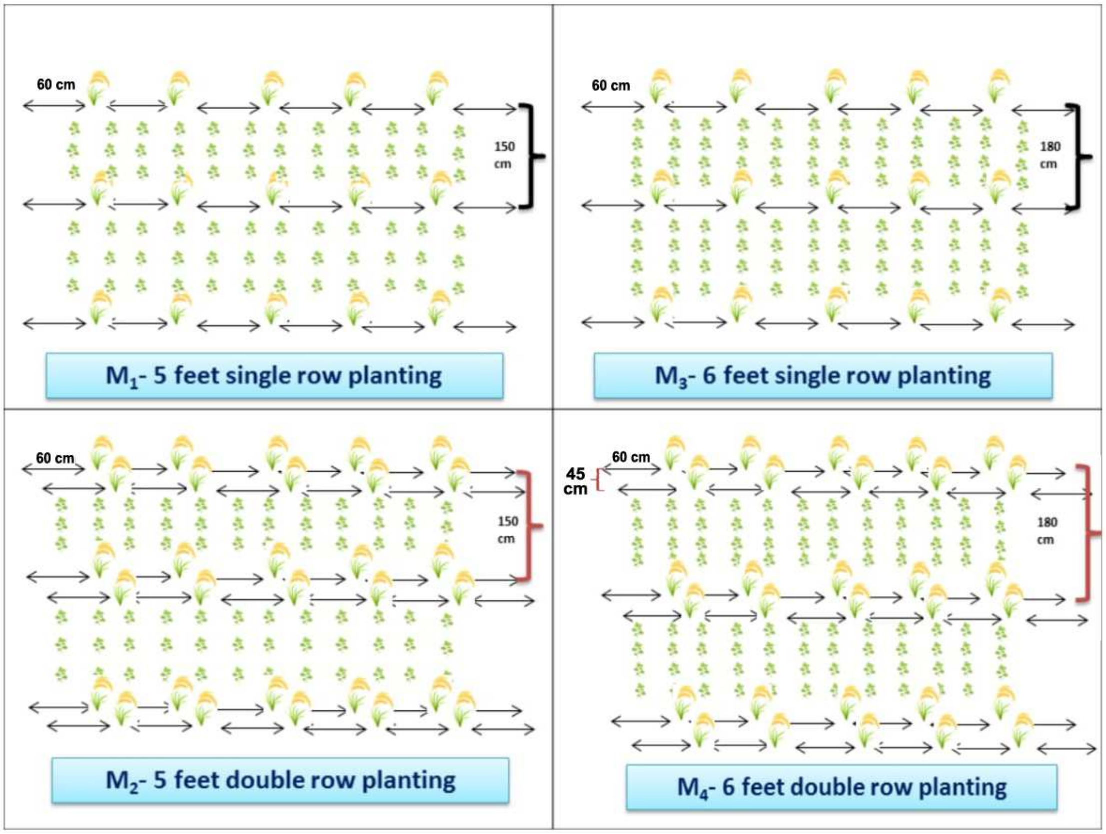

Fig1. Schematic diagram showing different crop geometry for sugarcane-based intercropping in SSI planting techniques:M1-150 cm single row sugarcane planting; M2-150 cm double row sugarcane planting; M3-180 cm single row sugarcane planting; M4-180 cm double row sugarcane planting.

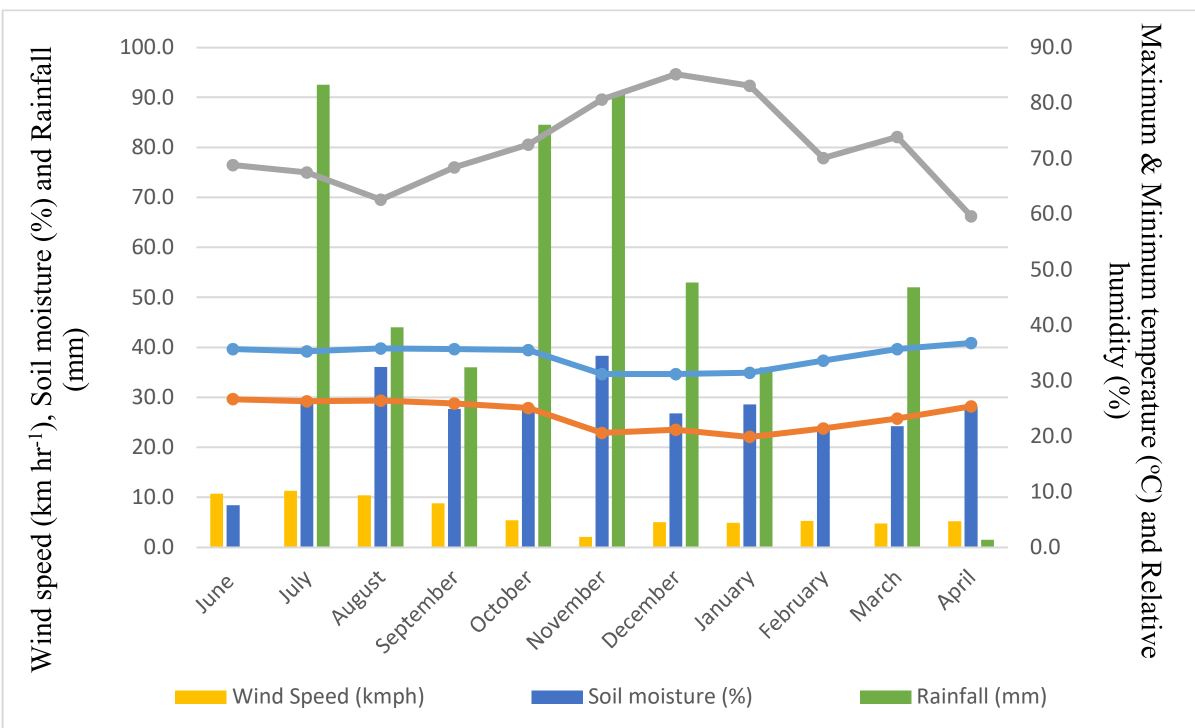

Fig 2. Weather parameters recorded during the cropping period (2016-17)

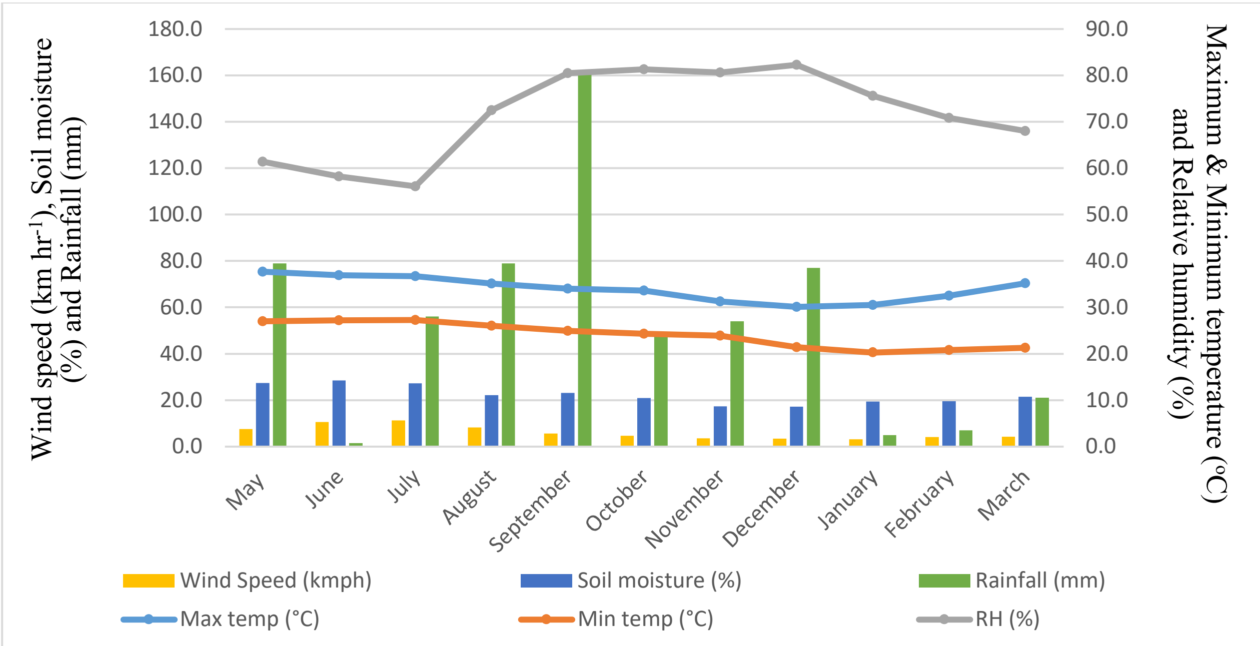

Fig 3. Weather parameters recorded during the cropping period (2017-18)

Fig4. Overall field experiment site with fertigation unit

Fig 5. Sole Sugarcane (S_1) under SSI planting technique

Fig6.Sugarcane+Greengram intercropping system (S_2) under SSI planting technique

Fig7.Sugarcane+Black gram intercropping system (S_3) under SSI planting technique

Fig 8. Sugarcane +Sunnhemp intercrop system (S_4) under SSI planting technique

Conclusion: It can be concluded from the results of the experiments that planting sugarcane in the crop geometry of double row planting with 150 cm row spacing and in-situ incorporation of sunnhemp on the 45th day after planting can improve growth and yield attributes, as well as cane equivalent yield and sugar yield.

Conflict of Interest: The author declares no potential conflict of interest.

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