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Research Paper

Response of sugarcane to tillage and intercropping

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ABSTRACT

Sugarcane productivity can potentially sustainable by rhizosphere improvement though tillage and crop diversification. To achieve this goal, an experiment was set up at the Agricultural Research Station, Navsari Agricultural University, Hansot to assess the impact of intercropping and tillage practices on sugarcane in *vertisols* for 2 successive years (2018 and 2019). The experiment was arranged in split plot design consisting three main plot treatments of tillage [Sub-soiling (45 cm depth, 2 m) + harrowing, Deep Ploughing (22.5 cm depth) + harrowing, and harrowing with cultivator] and four sub plot treatments of intercropping [three intercrops: Fenugreek, Gram, Indian bean, and control] replicated four times. Sugarcane variety CoN 07072 was planted in furrows at 100 cm row spacing. Subsoiling + harrowing influenced sugarcane yield significantly followed by deep ploughing + harrowing and augmented the average yield by 66.8 and 48.0 per cent, respectively compared to harrowing only. Subsoiling also improved the infiltration rate of soil. The intercropping had no significant influence on sugarcane yield or soil physicochemical parameters. Furthermore, subsoiling (down to 45 cm, 2 m) combined with harrowing resulted in higher growth and production, lead to maximum net realization and BCR. Further here Indian bean may be grain as an intercrop in sugarcane for enhancing true farm profitability benefit cost ratio.

***Key words*:** Deep ploughing, Infiltration rate, Intercropping, Sub-soiling, Sugarcane

Sugarcane (*Saccharum* spp.) is a tropical plant, Worldwide, sugarcane is grown for its sugar, biofuel and raw material for electric energy generation (Antunes *et al.*, 2019). Because, it has the potential to replace fossil fuels and lower greenhouse gas emissions, ethanol and electricity will probably become more in demand in the energy industry (Goldemberg *et al.*, 2014, Leal *et al.*, 2013). Sugarcane is an important cash crop grown in 1.92 lack hectares area with average productivity of 76.50 t/ha in Gujarat state and more than 80% of its concentration is in South Gujarat (SBI, 2023).

Low sugarcane production is a result of the promotion of an intensive cropping system and intense mechanization, which involves heavy machinery from planting to harvesting leads to compaction of the soils. This is especially true in south Gujarat's coastal regions, where rotavator and harrow are used for preliminary tillage work (Patel *et al.,* 2018). On the other hand, hard pan in plow sole is the result of long-term, repetitive harrow and rotavator activity. Therefore, sub-soiling and deep ploughing play a vital role to overcome the problem of hard pan. Ploughing and subsoiling, in particular, have not received much attention when considered soil management technology for crop production. Since soil compaction is more challenging to address than surface compaction, it is more concerning when it occurs below (>20–25 cm) tillage depths (Thakur. 2012). Severe root limitation and the loss of both transmission and water storage pores are potential effects of subsurface compaction (Rathore *et al.,* 2024). In the first layer (0–20 cm deep), compaction was at its highest, while in the layer deeper than 60 cm, it was either minimal or nonexistent. The tillage pan is broken directly beneath the row by the subsoilers, this allows root growth into the subsoil area, and loosen a 6–12-inch strip of surface soil in untilled soils. It was hypothesized that the reason for the favourable yield responses to in-row subsoilers could be attributed to both fracturing the surface soil and the tillage pan. Subsoiling facilitates penetration and prevents sheet and rill flow production before it reaches scouring velocities. By creating a network of deep fissures and cracks in the subsurface, a subsurface fertilizer enhances soil structure and allows roots, air, and water to move downward to a deeper depth in the soil profile, improving plant resistance to brief anaerobic conditions (Dhanya *et al.,* 2023; Kumar *et al.,* 2024).

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Sugarcane is highly dependent on external nutrient (Roy *et al*., 2006). Only 10–40% of the total N fertilizer provided is absorbed by the sugarcane (Otto *et al*., 2016). Concerns have been expressed as a result of these systems' low N-use efficiency and the negative environmental effects (Thorburn *et al*., 2017; Wang *et al*., 2022; Kumar *et al.,* 2023). To maintain sugarcane production levels that is commercially viable and support sustainable development. Numerous researches have been conducted recently to examine the impact of intercropping companion plants, like legumes. Intercropping can result in a more sustainable use of land by reducing the total area needed for food production while also supplying extra ecosystem services (Pelzer *et al*., 2012). Legumes can lower N fertilization and N_2O emissions through intercropping (Jensen *et al*., 2020). Legumes may also help suppress the need for herbicides by competing with weeds (Verret *et al*., 2017; Jadhav *et al.,* 2022). Thus far, no quantitative study has examined the effect of tillage on sugarcane yield response to legume intercropping. Therefore, the goals of this study were to: i) evaluate the impact of tillage on intercropping and sugarcane yield; and ii) measure the impact of legumes intercropping on sugarcane yield.

MATERIALS AND METHODS

An experiment was conducted at Agricultural Research Station, Navsari Agricultural University, Hansot, Bharuch 393030 during the *rabi* season of 2018 and 2019 on sugarcane variety CoN 7072. Centre is situated (21°34' N latitude and 72°48' E longitude) in the South Gujarat Agro-climatic area and is 10 meters above mean sea level. The soil of the experimental field was clay in texture with pH (7.78) and electrical conductivity (0.425 dS/m) in the normal range, low in organic carbon (0.39%), medium in available phosphorus (32.8 kg/ha) and high in available potassium (372 kg/ha). The mean temperature ranged 18.3 - 35.4 ^{o}C; the mean RH ranged 51.3 - 78.2%; total rainfall of 561.1 mm. Split plot design was used to set up the experiment, with distinct tillage techniques being implemented in the main plot consisted of sub-soiling (45 cm depth, 2 m) + harrowing, deep plowing (22.5 cm depth) + harrowing, and harrowing. The subplots treatments of intercrops included fenugreek, gram, Indian bean, and control (no intercrops) with four replications.

The experimental site's vegetative cover was manually cleared prior to cultivation. After that, the land was divided into plots and the margins of each allotment were bunched to retain water. Six rows of sugarcane made up the gross plot size of 8 × 6 m (48 m^2); the net plot area was 6 x 4 m (24 m^2). The sugarcane was planted in a furrow during the second week of October after the subsoiling. The same day, intercrops were sowed between the two rows of sugarcane. When planting sugarcane, the interrow spacing was set at 100 cm, while the intercrops were spaced 30 cm apart. Tender, healthy, young stalks of eight months old sugarcane was used for planting (7 t/ha). The stalks were cut into setts each containing three eye buds, planted continuously end-to-end without intra-row spacing in shallow sunken bed. The drilling of intercrop was done at 30 cm row spacing, where three rows maintained in between gap of 100 cm and one row sown at both sides of plot, total seventeen number of rows in a plot were maintained.

The recommended dose of fertilizer for sugarcane *viz*., 250 kg N/ha, 125 kg P/ha and 125 kg K/ha were used for field experiment. At the time of planting, 15 per cent dose of N and entire dose of P and K were applied by placement method just before planting of sugarcane crop. Remaining N were applied in three split doses 30, 20, and 35 per cent at an interval of six weeks from each preceding dose through urea, single super phosphate and muriate of potash. In case of intercrops, *Cicer arietinum* (Gram, *var*. GJG - 5) and *Dolichos lablab* (Indian bean, *var*. GNIB - 21) were fertilized with 20+40, whereas *Trigonella foenum-graecum* (Fenugreek, *var*. GF-1) by 40+25 N+P kg/ha as basal application. Following the monsoon season, a total of twelve irrigations were added to the crop. Periodically, plant protection measures and intercultural activities were carried out in accordance with recommendations.

Growth and yield attributes were recorded from randomly selected and previously tagged five plants in each net plot. In the second half of February, intercrops were harvested, uprooted, and cleaned. The yield per net plot was then calculated and shown on a hectare basis. Moreover, the sugarcane was cutting at ground level during the third week of November, when it reached maturity. Millable cane's dry leaves and green top were kept apart. The weight of millable canes from each net plot was recorded separately with the help of platform balance and the cane yield per hectare was worked out. The weight of green tops and trash (dry leaves) per net plot was recorded and converted on hectare basis. The conversion of legume yield and cane yield into sugarcane equivalent yield (kg/ha) was determined based on the prevailing market prices as below:

SEY (kg/ha) = Sugarcane yield (kg) + [Intercrop yield (kg)×Intercrop Price(₹/kg)/Sugarcane Price (₹/kg)]

Soil samples from 0 to 20 cm was collected by core sampler of 8 cm diameter from five spots in the experimental field before planting of the crop. Samples were used for determination of bulk density as per given formula.

Bulk density (Mg/m³) = Dry soil weight (Mg)/soil volume (m³)

Representative homogeneous samples were analyzed for determination of organic carbon (Walkley and Black, 1934), available N (Alkaline permanganate method), 0.5 M sodium bicarbonate ($NaHCO_3$, pH 8.5)- extractable P and NH_4OAC extractable K, following Jackson (1973). Initial soil pH and electrical conductivity were also recorded. How measure the infiltration rate place gird 1-2 inch methodology.

For chemical assessment, randomly chosen plant samples were collected treatment-wise. Samples were analyzed for nitrogen by modified Kjeldahl's method (Jackson, 1973), phosphorus by di-acid digestion and yellow colour development method (Jackson, 1973) and potassium by flame photometric method (Jackson, 1973). The uptake was further calculated by using the formula nutrient uptake (kg/ha).

Nutrient uptake (kg/ha) = Nutrient content (%) x Dry matter (kg/ha) /100

The gross realization and net realization were calculated, based on the prevailing market prices of all the inputs and grain and straw yield of wheat during the years of investigation. The benefit cost ratio was calculated by using net realization (₹/ha) divided by cost of cultivation (₹/ha).

B: C ratio = Net return (₹/ha) / Cost of cultivation (₹/ha)

The pooled analysis of the two years data was carried out as per procedure suggested. The data recorded for various parameters were statistically analyzed using analysis of variance test (ANOVA) as applicable to split plot design and the comparison of treatment means was made by least significant difference (LSD) at P=0.05.

RESULTS AND DISCUSSION

Growth attributes

The treatment involving sub-soiling at a depth of 45 cm, 2 m distance + harrowing significantly increased plant height, number of tillers (Table 1); this treatment was statistically comparable to the treatment involving deep ploughing (22.5 cm depth) + harrowing for the number of tillers at final earthing up. Lower the bulk density and better aeration due to sub-soiling was responsible to make favourable soil environment for better root growth and development, thereby producing higher number of tillers and plant height as confirmed by Singh *et al.* (2012) and Mandal and Thakur (2010). Further, minimum plant height and numbers of tillers were recorded with harrowing only.

Different intercropping systems did not significantly affect the total plant height and number of tillers per meter row length, however maximum plant height was seen when no intercropping technique was used (Table 1). Due to competition for light and space between the plants of these intercrops and cane plants, there may have been a decrease in growth. Cane plants growth was little smothered because of the initial slow emergence of the crop and the relatively quick growth of the intercrop, which resulted in higher plants and a dense canopy. On the other hand, without intercrop resulted in less competition for light and space when combined with good weed control. Similar findings were reported by Patel *et al.* (2014) regarding non-significant differences in growth caused by various intercrops in sugarcane.

Yield and yield attributes

The cane length, internodes/cane, millable cane/m row, cane weight, and millable cane yield were all significantly boosted by subsoiling at a depth of 45 cm and a distance of 2 m combined with harrowing. Subsoiling improved the rate of soil infiltration and enhanced nutrients availability by raising the microbial population and activity of soil enzymes (Kibblewhite *et al.*, 2008; Karaca *et al.*, 2010), ultimately had a significant impact on yield attributes and improved sugarcane yield. Similarly, Mandal and Thakur (2010) found that subsoiling alone increased the cane weight, number of millable canes, and cane yield compared to traditional ploughing. Moreover, reported that subsoiling (at 45 cm depth) boosted cane yield upto 30%. Singh *et al.* (2012) also saw improvement in commercial sugarcane with cross sub-soiling at 1.0 m. In contrast, intercrops were

Table 1. Yield and its attributes influenced by tillage and intercropping in sugarcane

Treatment	Plant height (cm)	Tillers/m row (No.)		Millable cane length (cm)	Internodes/ millable cane (No.)	Millable cane/m row (No.)	Cane weight (kg)	Millable cane yield (t/ha)		
		90 DAP	Earthing up					1st year	2nd year	Pooled
Tillage										
Sub soiling + Harrowing	305.5	17.9	24.4	231.7	24.2	11.7	1.17	116.2	118.7	117.4
Deep ploughing + Harrowing	291.9	17.0	23.5	218.7	22.9	10.0	1.06	102.5	105.9	104.2
Harrowing	272.6	11.1	16.5	169.9	19.1	8.05	0.86	73.1	68.3	70.7
SEm±	3.66	0.27	0.30	2.75	0.27	0.22	0.02	1.56	2.32	1.55
CD (P=0.05)	11.1	0.82	0.92	8.35	0.83	0.68	0.05	5.4	8.0	4.70
Intercrop										
Fenugreek	287.1	15.3	21.4	207.0	22.2	9.66	1.03	91.1	92.5	91.8
Gram	291.0	15.4	21.5	207.3	22.5	10.1	1.06	96.9	98.6	97.8
Indian bean	290.3	15.3	21.5	202.6	22.3	9.76	0.97	97.1	98.7	97.9
Control (No intercrop)	291.6	15.2	21.4	210.1	21.4	10.1	1.05	103.9	100.8	102.3
SEm±	4.47	0.31	0.31	3.62	0.31	0.27	0.02	3.96	5.06	3.13
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

failed to significantly influence the yield and characteristics of sugarcane. The response was consistent with the findings published Kailasam (2008) which validate yield reduction when sugarcane intercropping with legumes. Although, Indian beans as an intercrop was shown to be supportive than fenugreek and gram when compared in terms of equivalent yield of sugarcane.

NPK content and uptake by cane stalk

Different tillage had failed to effect the NPK content (Table 2) and intercrops system. On the other hand, sugarcane stalk NPK uptake was significantly higher when adopted subsoiling at 45 cm depth, 2 m apart, and harrowing with a cultivator (Fig. 1). The reason for significant response of NPK uptake is, directly corelated with production and it was significantly higher with subsoiling and deep tillage practices. Opposite to this, intercropped did not demonstrate any appreciable increase in NPK absorption.

Soil parameter

Except for the infiltration rate, which was significantly impacted by subsoiling, the major soil properties bulk density, infiltration rate, EC, pH, OC, available NPK were not significantly impacted by tillage techniques and intercrops. Further, subsoiling at a depth of 45 cm and 2 m along with harrowing, resulted significantly higher infiltration rate which is comparable with deep ploughing at a depth of 22.5 cm and harrowing. The results further highlighted that the bulk density of the soil decreased with subsoiling, though the response was not signifcant. Moreover, increased level of tillage *either* with subsoiling *or* deep ploughing followed by hrarrowing, increased the infiltration rate of the soil (Fig. 2). According to Singh *et al*.

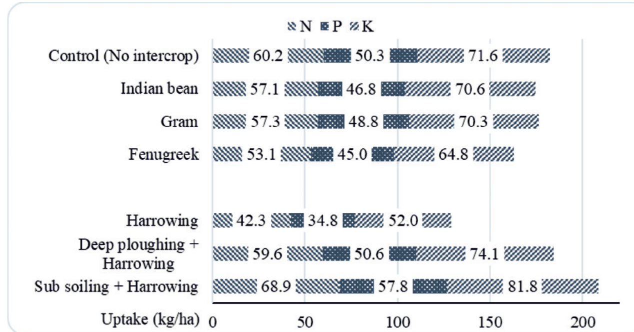

Fig. 1. NPK uptake by cane stalk influened by tillage and inter cropping

(2012), there were benefits to sugarcane root growth and biomass production as a result of the decreased bulk density and enhanced infiltration rate in response to subsoiling. The findings are reliable with those of Shukla *et al*. (2020), who observed that subsoiling increased the rate of soil infiltration while decreasing bulk density.

Likewise, there was no positive influence of different tillage and intercropping techniques on nutrient (NPK) availability (Table 2). However, maximum availability of soil nitrogen and potassium was recorded with subsoiling and deep poughing followed by harrowing. Generally, heavy tillage incresed the root prolifications and microbial activity that enhanced mineralisation of nutrients would have led to increased availability of nutrients in subsoiling and deep ploughing practices reported by Kumar *et al.* (2013) and Priya (2017), but in this case sugarcane production was higher in subsoiling and deep ploughing compared to harrwoing only that extract more nutrients from the soil's reserves and applied fertilizer added leads to deline soil NK status after harvest of sugarcane.

Table 2. NPK content in cane and soil properties influenced by tillage and intercropping in sugarcane (mean of 2 years)

Treatment	Nutrient content (%)			BD (g/cc)	EC (dS/m)	*p*H	OC (%)	Available nutrients (kg/ha)		
	N	P	K					N	P	K
Tillage										
Sub soiling + Harrowing	0.294	0.246	0.347	1.415	0.352	7.66	0.400	201.1	27.0	383.2
Deep ploughing + Harrowing	0.284	0.240	0.351	1.389	0.358	7.57	0.391	199.8	28.9	384.7
Harrowing	0.285	0.234	0.349	1.405	0.359	7.68	0.408	205.7	27.4	391.1
SEm ±	0.003	0.003	0.003	0.009	0.004	0.05	0.003	5.70	0.56	6.08
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Intercrop										
Fenugreek	0.285	0.240	0.348	1.395	0.355	7.62	0.400	202.9	27.1	379.7
Gram	0.286	0.242	0.351	1.402	0.358	7.65	0.403	196.9	27.6	384.7
Indian bean	0.285	0.233	0.351	1.411	0.358	7.68	0.400	200.9	28.6	381.9
Control (No intercrop)	0.293	0.244	0.346	1.404	0.354	7.60	0.396	208.1	27.8	399.1
SEm ±	0.003	0.003	0.005	0.008	0.005	0.05	0.005	4.14	0.45	6.94
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

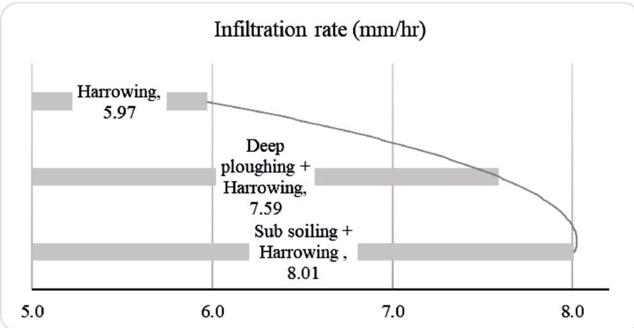

Fig. 2. Infitration rate influenced by tillage and intercropping

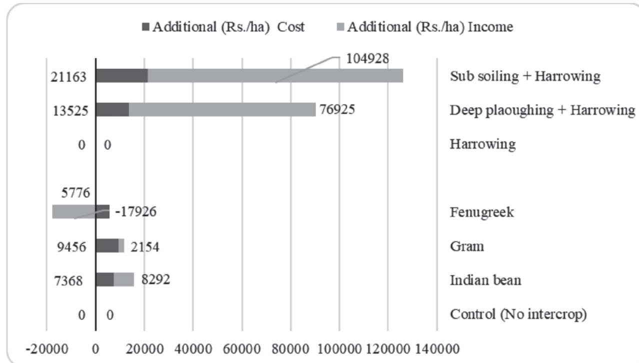

Fig. 3. Addition cost and net-return influenced by tillage and inter cropping

Economics

Sub-soiling at 45 cm depth with 2 m distance + harrowing fetched the highest net realization (₹169667/ha) and BCR (1.15), followed by deep ploughing + harrowing (₹141,664/ha and 1.01). Only harrowing resulted in the lowest net realization of ₹64739/ha and a BCR of 0.51 (Table 3). Growing of Indian bean as an intercrop produced the highest net realization of ₹147,274/ha with a B:C ratio of 1.02, followed by gram with a net realization of ₹141,136/ha and a B:C ratio of 0.96. Unexpectedly, intercropping of fenugreek resulted in the lowest net realization of ₹121056/ha and a B:C ratio of 0.85.

Moreover, subsoling + harrowing additionaly fatched ₹104,928/ha with the investment of ₹21,163/ha, followed deep ploughing + harrowing by securing ₹76,925/ha with the investment of ₹13,525/ha only compared to harrowing only. Moreover, investment in intercropping was not observed remunerative as cost of intercropped was much higher than actual return received from intercrops cultivation, specifically in case of fenugreek, returns was negative (Fig. 3).

Thus, the study indicated that subsoiling at a depth of 45 cm at a 2 m distance followed by harrowing with cultivator resulted higher and gainful sugarcane production, besides improve infiltration rate of soil. Furthermore, Indian bean performed better intercrop with sugarcane.

Table 3. Economics of sugarcane as influenced by tillage and intercrops

Treatment	Sugarcane equivalent yield (t/ha)	Cost of production (× 10^3 ₹/ha)	Gross realization (₹/ha)	Net realization (₹/ha)	Benefit: cost ratio
Tillage					
Sub soiling + Harrowing	117.4	147,313	316,980	169,667	1.15
Deep ploughing + Harrowing	104.2	139,676	281,340	141,664	1.01
Harrowing	70.4	126,151	190,890	64,739	0.51
Intercrop					
Fenugreek	97.8 (322)	143,004	264,060	121,056	0.85
Gram	106.6 (479)	146,684	287,820	141,136	0.96
Indian bean	108.1 (344)	144,596	291,870	147,274	1.02
Control (No intercrop)	102.3	137,228	276,210	138,982	1.01

Data in parathesis indicating inter crop yield.

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