Chapter 3

Sugarcane Production Technologies for Changing Climatic Scenario

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Abstract: Sugarcane is one of the most important industrial crops in global agriculture and it has come out as a multi-product crop profiting producers and consumers. Sugarcane provides about 80% of the global sugar production and it is cultivated in more than 90 countries encompassing nearly half of the world for both sugar and bioenergy. It is a C4 plant (i.e the first stable product of CO_2 fixation is 4 carbon compound) belongs to the family, producing high biomass compared to any other cultivated crop. Its stem is considered as the most useful economic product globally accounting nearly 80% for sugar production. For the low productivity of sugarcane many more biotic and abiotic factors are responsible. Moreover, to meet the persistent high production of sugar per unit area under the changing climatic regime, adoption of abiotic stress tolerant varieties with climate smart agronomic practices becomes indispensable. Among agronomic manipulations for the management of abiotic stresses, breaking soil compaction barrier using appropriate machinery and cultivating tolerant sugarcane varieties, scheduling irrigation based on cumulative pan evaporation, conserving soil moisture by way in-situ trash mulching, green cane trash blanketing using sugarcane harvesters and trash shredding machineries and use of soil amendments such as composted coir pith, bulky organic manure and application potassium and micronutrients through foliar sprays and usage of appropriate energy efficient machinery for ratoon crop management are important. In this chapter, the various strategies are discussed for sustaining the sugarcane production under climate change scenario.

Keywords: C_4 plant; CO_2 concentration; GHG; Crop Production; Climate change

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1. Introduction

Impact of climate change in agriculture will be one of the important deciding factors influencing the future food security of mankind on the earth. The climate sensitivity of agriculture is uncertain, as there is regional variation of rainfall, temperature, crops and cropping system, soil and management practice. The change in atmospheric concentration caused by the greenhouse gases (GHG) is observed to affect the plant metabolic activity and also production directly. Increase in CO_2 concentration can lower pH, thereby, directly affecting both nutrient availability and microbial activity. The changes in the crop yield depends not only change in rainfall but also on the changes in CO_2 concentration. Short- or long-term fluctuations in weather patterns, climate variability and climate change can influence crop yields and force farmers to adopt new agricultural practices in response to change in climatic conditions. Hence, understanding the weather changes over a period of time and adjusting the management practices towards achieving better harvest is a challenge to the growth of agriculture sectors as a whole. Sugarcane growers are facing multiple constraints. Water availability poses a major challenge and it is affecting the productivity and profitability of sugarcane growers and millers. The problem is going to further deteriorate due to variability of rainfall influenced by climate change. India will suffer to fulfil its rising sugar demand unless sugarcane growers are given options for high yields with a much less water.

In India, sugarcane is a significant crop. 35 million farmers grow sugarcane and another 50 million rely on employment generated by sugar factories and other allied industries using sugar. In Maharashtra, Uttar Pradesh and Tamil Nadu, sugarcane plays an important role in the state economy. During the past 10 years, India's sugarcane production has been fluctuating between 233 million tonnes and 355 million tonnes. The mean cane yield and sugar recovery in India is fluctuating around 80.0 t/ha and 10%, respectively. The industry is in serious difficulties due to low yields and fluctuations in production, despite India having the second-largest area of sugarcane cultivation in the world after Brazil. The problem is going to further deteriorate due to variability of rainfall influenced by climate change. India will struggle to satisfy its increasing sugar demand unless sugarcane growers are given options for high yields using much less water. Under such situation development of novel technology involves less input to produce more will be the viable option.

In India, sugarcane cultivation is confined in to two distinct agro-climatic zones – the Tropical (Gujarat, Maharashtra, Karnataka and Tamil Nadu) and the Sub-tropical (Uttar Pradesh, Punjab, Haryana and Bihar). Among the states, Uttar Pradesh occupies half (2.25 m.ha) of the total area followed by Maharashtra (1.04 m.ha). Though UP dominates in production with 134 MT followed by Maharashtra with 79 MT, in terms of productivity, Tamil Nadu leads with 105 t/ha followed by Karnataka (88 t/ha) and Andhra Pradesh (82 t/ha). However, despite its long tradition and widespread cultivation in India, sugarcane productivity is unimpressive, particularly in areas where the crop is irrigated. The average productivity of sugarcane is low with certain regions reporting yields as low as 40 t/ha only. Not only the cane yield is low, the sugar yield - typically at less than 10% of cane weight - is also less than satisfactory.

The reasons for such low productivity are:

- Water availability is unpredictable. The concern is not only the amount of water required, but also the lack of proper water management practices. Due to this, water is either wasted or sometimes not available at the right time.

- Unpredictable climate fluctuations, improper cultivation techniques, negligence in plant protection measures, an imbalanced nutrient management and other practices like monocropping often lead to low productivity and fetching low market value.

In addition, it is also very important to consider the enormous amount of water that goes into the sugarcane production. Around 25,000 kg of water is required to produce one kg of sugarcane. But every year, the water table is gradually decreasing. In future, these challenges will become even more complex with climate change inducing direct and indirect effects on crops, water, pests and diseases, and volatility in the international market. The impacts on crop production and mitigation strategies are listed in Table 1.

2. Key issues in Crop Production under climate change Scenario

- Increase in temperature in heat waves and cold waves directly affect crop performance
- Extreme rainfall causing more floods, droughts, which reduces crop yield and indirectly affects water availability in sugarcane agriculture.
- Inundation of costal area by sea water
- Increased incidence of pest and diseases
- Rapid oxidation of soil organic carbon and its effect on soil fertility

2.1. Technology intervention

The Sustainable Sugarcane Initiative (SSI) like the System of Rice Intensification (SRI) is a realistic approach to sugarcane production that is based on the concept of 'more with less' in agriculture. SSI reduces the overall pressure on water resources while concurrently increasing the productivity of water, land, and labour.

Table 1. Impact on Crop Production and mitigation strategies

Scenarios	Key Impact on crop production	Mitigation strategies
Rainfall & Temperature	1.Increased frequency of floods during monsoon and decreased in winter precipitation, 2.Lower number of rainy days 3.Decline in water resources 4.1°C increase in last centenary leads pronounced global warming 5.Increased incidence of pest and diseases 6.Loss of soil organic carbon 7. Yield reduction	1. Coservation and effective use of water 2. Integrated pest management (IPM) and Integrated diseases management (IDM). 3. Conservation farming methods 4. Developing suitable varieties for climate change scenario through conventional breeding and using biotechnology tools

2.2. Sustainable Sugarcane Initiative (SSI)

Sustainable Sugarcane Initiative is a method of sugarcane production which involves using less seeds, less water and optimum utilization of fertilizers and land to achieve more yields. Driven by farmers, SSI is an alternate to conventional seed, water and space intensive Sugarcane cultivation. Table 2 shows the comparison between the conventional and SSI methods of sugarcane cultivation

2.2.1. The major principles that govern SSI can be stated as below:

- Providing sufficient moisture through water saving efficient irrigation technologies viz., skip Furrow, alternate furrow and subsurface drip irrigation
- Practicing intercropping with effective utilization of land and water

2.3. Water management

- Produce more per mm of water and all other inputs
- Raise cane crop even under marginal lands

- Raise crop in problem soils and water
- Minimum tillage
- Create micro catchments for water harvesting
- Multi-ratooning
- Produce higher cane yield with less water

Table 2. Comparison between Conventional and SSI methods of Sugarcane Cultivation

Particulars	Conventional method	SSI method
Water requirement	More (flooding of field)	Less (maintenance of moisture in the furrows and adoption of drip Irrigation)
Mortality rate among plants	High	Low
Accessibility to air and sunlight	Low	High
Scope for intercrop	Less	More
Spacing	1.5 to 2.5 ft between rows	5 ft between rows
Planting	Direct planting of setts in the main field	Transplanting of 25-35 days young seedlings raised from bud chips

2.4. Overall benefits

- In conventional method, cost of setts occupies the major part of cost of cultivation
- By practicing SSI, this seed cost can be reduced up to 75%
- Reduction in the plant mortality rate
- Increases in the length and weight of each cane
- It is easy to transport the young seedlings for longer distance
- Intercultural operations can be carried out easily due to wider spacing
- Increased water use efficiency
- Improvement in accessibility to nutrients with optimum use of fertilizers
- More accessibility to air and sunlight
- Reduction in cost of cultivation and
- Extra income from intercrops
- Wider spacing facilities mechanization

3. Water requirement and conservation

3.1. Water Requirement

Water requirement of a crop is the quantity of water needed for normal growth, development and yield and may be supplied by precipitation or by irrigation or by both. Sugarcane is mostly grown as an irrigated crop. Depending on climate, the water requirement (Table 3) of sugarcane is 1500 to 2500 mm, evenly distributed over the growing season.

Table 3. Water requirement of sugarcane crop through irrigation

States	Total water requirement (cm)	Approx. rain water consumed (cm)	Net water requirement through irrigation (cm)
Uttar Pradesh	140-145	55-60	85
Uttarakhand	140	55-60	85
Punjab	150-160	55-60	95-100
Bihar	140	70-90	50-70
Andhra Pradesh	170-180	55-60	115-120
Tamil Nadu	179-215	60-65	119-150
Karnataka	200-220	60-65	140-155
Maharashtra	240-350	60-70	180-280

3.2. Water conservation

This encompasses reducing losses of water due to leaks, properly scheduling irrigation and investing in irrigation technologies like trickle tape. High irrigation efficiency will save water in the midst of low rainfall and also reduce cost of production when yields are expected to be low due to moisture stress. Under tropical Indian conditions water requirement for sugarcane crop is very high i.e. 2500 mm and 32 to 40 irrigations are scheduled at 7-10 days interval. Dhanapal et al. (2018) developed efficient water saving technology wherein 8 irrigations can be saved. Application of 10 t/ha composted coir pith or 5 t/ha of sugarcane trash in furrow at the time of planting and scheduling irrigation in sugarcane at 75% of recommended level of irrigation saved 387, 344 and 255 mm irrigation water during plant, first and second ratoon crop; in addition, it gave higher irrigation water use efficiency (0.82 t/ha/cm) over scheduling irrigation at 100% level.

3.3. Irrigation management

In India sugarcane is cultivated under assured irrigated condition and depending upon the crop duration its water requirement fluctuates between 2000 to 3000 mm. The crop duration ranges between 12 to 18 months which needs huge amount of water to produce higher quantity of biomass and cane yield. The results of earlier experimentation demonstrated visage positive linear correlation between ET and cane yield. Scarcity or superfluous amount of irrigation water influences cane yield and juice quality and thus sugar output, besides predisposing the crop to attack of several pests.

The drought or soil moisture stress in tropical Indian sugarcane agriculture is more common and the states like Tamil Nadu, Maharashtra and Karnataka facing serious water shortage problem which impacted the cane acreage. However, climate smart irrigation practices such as skip furrow irrigation, use soil amendments, deficit irrigation scheduling, micro-irrigations, pit method of planting, trash mulching and scheduling of irrigations at critical of the crop could save the irrigation water and sugarcane crop from physiological abiotic stresses.

3.4. Micro irrigation

Water for irrigation is a limited and continuous resource and its effective management is critical, not only in reducing wasteful usage, but also in reducing production costs and sustaining productivity. Demand for available water resource is fast exceeding the economic supply. There are different types of micro irrigation like easy drip, micro-tube drip, conventional drip and conventional sprinklers. Of these drip and sprinklers are more common. Various studies in India have shown a considerable return to farmers' investment in micro irrigation technologies (Sarkar and Hanamashet, 2002). However, Narayanamoorthy (2003) opines that crop production based solely on micro irrigation use is rarely found. For adopters, micro irrigation use is often complemented with flooding/furrow method of irrigation at least once during the cropping season. To promote micro irrigation in India, sincere efforts have been made by the Government of India and state Government.

3.5. Drip Irrigation

It is defined as the concise, gradual application of water in the form of discrete or continuous or tiny streams through mechanical devices called emitters or applicators located specific points along water delivery lines. There is no conveyance loss. Many researchers have attempted to study the impact of drip irrigation (Narayanamoorthy, 2003, 2004 a,b, 2005, 2008, 2022, Narayanamoorthy et al., 2024) and have found it to be advantageous in many fronts. The potential benefits of drip irrigation include higher yields (Camp 1998), improved trafficability (Steele et al., 1996) and lower water use (Camp, 1998).

The drip irrigation system has been proven to be technically practical, especially for farmers depending groundwater sources. Despite these potential benefits, drip irrigation may still experience water losses comparable to those from conventional irrigation systems due to poor design and/or management. Given the high installation costs often required for drip irrigation, it is crucial that systems are designed and managed correctly if the benefits of using drip irrigation are to be fully exploited. Drip irrigation with paired row planting increased cane yield by 13.9% with better juice quality over normal furrow irrigation (Narayanamoorthy et al., 2024). In an experiment with drip irrigation in Maharashtra, drip recorded maximum cane and CCS yield (111.24 and 14.59 t/ha, respectively). Narayanamoorthy, et al., 2024 reported an yield increase of 23 % in drip cultivation compared to the farmers method of irrigation. Pawar et al. (2013) was observed marginal improvements in yield and water used in different irrigation methods (Table 4).

Table 4. Yield and water used in the different irrigation methods

Irrigation systems	Yield (t/ha)	Water applied (cm)	Water saving (%)
Drip	162.36	111.25	49.21
Overhead sprinkler	157.02	159.74	27.07
Raingun	150.05	171.37	21.76
Microsprinkler	154.11	152.42	30.41
Micro jet	153.0	149.42	31.78
Surface	134.06	219.02	

(Source: Pawar et al. 2013)

In Coimbatore, Tamil Nadu, experimental results over a plant and ratoon crop indicated that the yield did not increase with drip irrigation in comparison to conventional irrigation though there was a saving of water to the tune of 40% (Table 5).

4. Nutrient Management

4.1. Fertigation

Fertigation is the application of water soluble solid fertilizer or liquid fertilizer through drip irrigation system as and when required by the crop directly to the root zone of the crop. Soil type, water quality and type of fertilizer used govern the adoption of fertigation for sugarcane.

Table 5. Comparison of irrigation methods

Sl. No.	Location	Irrigation method			Water saving /yield increase in drip (%)
		Conventional furrow	Surface drip	Sub-surface drip	
Water requirement (mm)					
1.	Coimbatore	1990	1112	1112	44
2.	Coimbatore	1670	1198	1198	28
3.	Pune	2153	1075	938	50-56
4.	Rahuri	2160	914	-	57
5.	Padegaon	2240	1762	1425	21-36
6.	Akola	1574	1151	-	27
7.	Bhavanisagar	1462	1177	-	20
8.	Pune	2741	1376	1273	50-53
9.	Nasik & Sholapur	2383	1754	1624	26-32
Cane yield (t/ha)					
1.	Coimbatore	94.7	90.1	98.0	4
2.	Coimbatore	78.7	95.1	80.4	2-17
3.	Pune	128.1	175.5	143.8	12-36
4.	Rahuri	114.7	130.6	-	12
5.	Padegaon	108.9	116.5	112.6	4-6
6.	Akola	125.3	111.6	-	-11
7.	Bhavanisagar	102.4	150.2	-	32
8.	Pune	95.1	107.6	99.5	4-12
9.	Nasik & Sholapur	104.7	122.9	120.3	13-15

Sugarcane removes substantial amount of plant nutrients because it is a long duration and high biomass accumulating crop. On an average, a crop of 100t/ha cane yield exhausted 205 kg N, 55 kg P, 275 kg K and 30 kg S. Nitrogen fertilizers are used almost twice as efficiently when applied via drip irrigation system. Improvement in N efficiency has not been reflected in an increase in yield and therefore, it may be possible to decrease the amount of N fertilizers applied currently when applied through fertigation (Table 6).

Table 6. Comparison of fertilizer use efficiency in different irrigation methods

Nutrients	Fertilizer Use Efficiency		
	Soil Application	Drip + Soil application	Drip + Fertigation
Nitrogen	30-50	65	95
Phosphorus	20	30	45
Potassium	50	60	80

(Source: Sezhian and Balasubramanian, 2008)

In an experiment studying the effects of various levels of potash application through drip irrigation on yield and quality of sugarcane using the variety Co 86032 over three crop seasons in Maharashtra, application of nitrogen and potash fertilizers through drip irrigation not only saved 30 percent of nitrogen (N) and potassium (K) fertilizer, but also increased yield by 19.1 % and more than doubled water use efficiency, as compared to the control using the recommended application of chemical fertilizers and conventional irrigation (Narayanamoorthy et al., 2024). Experimental results from Sugarcane Breeding Institute, Coimbatore also point to a 25% saving in nitrogen and potash fertilizer when supplied through drip compared to the conventional application of the recommended dose of fertilizers (Pawar et al., 2013).

In Rahuri, Maharashtra, when water soluble fertilizers were used, sugarcane yields increased to the extent of 13.5 t/ha. However, the higher costs of the water-soluble fertilizers overshadowed this effect and improved the net income very marginally and decreased the B: C ratio sizably (Pawar et al., 2013).

5. Mitigation and adaptation strategies of sugarcane to climate change

5.1. Technological intervention for abiotic stress management

Since climate change is projected to reduce sugarcane yields in the next century, it is need of the hour to come up with mitigation strategies that can lower the effects. A number of mitigation measures can be drawn from understanding the potential effects of climate change relying much on climate models. However, the projections of climate change using models are uncertain because of errors that may be encountered in these models (Mall et al*.*, 2004). Water stress generated by high temperatures and low rainfall can be mitigated by growing varieties that are tolerant or resistant to drought. Inman-Bamber et al*.* (2012) reported that sugarcane cultivar differences in drought adaptation exist. Therefore, evolution of sugarcane varieties with drought resistance and search for genotypes, which possess inherent capabilities of drought tolerance has been on the forefront of sugarcane research. Researchers should therefore continue to breed sugarcane varieties or cultivars that adapt to drought conditions or greater water use efficiency. Hence, each year genetic potential of advanced breeding material (AVT clones) is being exploited for adverse environments like drought and salinity wherein the competitive advantage for one cultivar over another is likely to be greater (Gomathi et al*.*, 2011, 2020). Traits such as higher NMC, maintenance of better leaf production, higher single cane weight and rapid stem elongation contribute to cane yield under drought (Gomathi et al*.*, 2011, 2014, 2020).

1. Early Planting: In the tropical belt, November to January planting is better than March- April planting to overcome the problem of moisture stress.

2. Seed rate and spacing: Higher seed rate (or) closer spacing is to establish a higher stalk population to make up the greater less of individual stalks, row spacing can be narrowed down to 60 (or) 75 cm to give 15- 20% higher cane yield over normal spacing.
3. Seed treatment: Soaking the setts in a saturated lime solution for one hour before planting (dissolve 80 kg of lime (calcium carbonate $CaCO_3$) in 400 lit of water.
4. Trash mulching: Trash mulching (5-7 t/ha) helps in conserving soil moisture, checks the weed growth and reduces the soil temperature by 2ºC.
5. Deep trench system of planting: Deep trench system of planting helps deep root development and efficient use of nutrients and moisture.
6. Foliar application of urea and potassium**:** Foliar application of urea and KCl each at 2.5% (2.5 kg urea + 2.5 kg MOP in 100 litters of water) at 15-20 days interval maintains the crop turgidity.
7. Protective irrigation**:** During drought available water can be given in alternate furrows alternatively.
8. Use of anti-transpirants**:** Kaolin acts as a reflectant and reduces the transpiration loss.
9. Rain gun/mobile sprinklers may be used to give protective irrigation at critical period.
10. Tolerant varieties: Varieties CoC 671, Co 8208, Co 85007, Co 85004, Co 86032, Co 85019 and Co 87263, Co 99004 (Damodar), Co 2001-13 (Sulabh) and Co 2001-15 (Mangal), Co 0218, Co 0325 and Co 0328, Co 0403, Co 06015 and Co 06022 are suitable for water limited condition. (Gomathi et al*.* 2015, 2020, Vasantha et al. 2022 a,b c).

5.2. Waterlogging management

Climate change is projected to result in floods in some areas or years. Since floods result in waterlogging conditions, salinity and raised water table, reducing yields significantly (Glaz et al. 2004), it is therefore important to adapt sugarcane production to such conditions. Drainage systems in the fields that are likely to be affected (flat) areas may need to be installed. Once the drainage improves, excessive salts causing salinity can be leached by irrigation (Clowes and Breakwell 1998). Varieties that adapt to waterlogging and saline conditions may be grown.

1. Proper drainage system should be provided
2. Early and deep planting is beneficial.
3. Seed rate and Row spacing: Normally 38 to 40 thousand healthy three-bud setts/ha are used for planting.
4. The row-to-row distances should be widened and deepened to 135 cm to make drainage channels in between them at the time of water logging.
5. Split application of nitrogen (2-3 times) helps in minimizing nitrate leaching, the chances of which are more under water-logging.
6. Foliar application of 5 per cent urea during water logging increases the yield of cane.
7. Foliar application of potassium and phosphorus along with nitrogen causes greater root proliferation and stiffness of cane.
8. Sugarcane matures earlier in waterlogged areas, early harvesting facilitates to get maximum amount of sucrose.
9. Waterlogging tolerant varieties

- Varieties were evaluated for their ability to with stand waterlogging conditions. Amongst these 19 exotic hybrids and 30 Indian hybrids were found to be tolerant.
- Co 8231, Co 8232, Co8145, CoSi 86071 and Co Si 776, Co 8371 & Co 99006 by SBI.

- At Anakapalle, promising clones 93A 4, 93A11, 93A 145, and 93A21 have been identified under water logging conditions.
- In the Kolhapur region of Maharashtra, Co 8371 has been found to perform well under river flood.
- Some of the Bo varieties like Bo 91 and varieties Co 87263 and Co 87268 are suitable for flooded conditions of Bihar, while Co T1 8201 and Co T1 88322 are grown in Kerala in Tiruvalla are water logging is very common (Gomathi et al., 2011, 2014, 2015).

5.3. Salinity Management

In India about one fourth of the acreage is affected by salinity and or alkalinity to varying degrees. Soil salinity and poor-quality irrigation water coupled with moisture stress during high water demand period (in summer months), largely coinciding with rapid growth phase of sugarcane results in very low yields. It is estimated that 33% of cane area in Tamil Nadu, 40% of cane area in Andhra Pradesh and 48% in Karnataka experience either soil salinity or saline irrigation water and yield losses reported were about 40 %.

1. Seed rate: Higher seed rate of 25% is recommended to compensate for germination loss and to ensure adequate crop stand.
2. Trench planting: Following “modified trench system” of planting in saline soils and salt water irrigated areas has recorded improved yields of around 15 per cent. In this method, while earthing up, furrows are not converted in to ridges; instead, a furrow is maintained along the row. The irrigation water is let in the cane row itself.
3. Use of organic manure: Organic manures viz, pressmud (10-15 t/ha), farmyard manure (25 tlha),

etc., improve the availability of essential (Zn, Fe, Ca and Mn).

4. Amendments: With increase in soil Ph the requirement of gypsum also
5. Irrigation with good quality water: During critical growth stages (up to 150 days of crop age) irrigation with good quality water is beneficial.
6. Mulching: Trash mulching reduces loss of moisture through evaporation thereby minimizing the effect of ions in the soil. Trash upon incorporation adds organic matter and nutrients.
7. Green manures: Growing green rnanure as inter crop and *insitu* incorporation of green manure highly beneficial to improve productivity – in salt affected soils.
8. Nutrient management: 25% Additional nitrogen dosage has been found to improve yield under salinity conditions. Application of top dressings of nitrogen and Potassium fertilizer through pocket manuring is advantageous and helps in improving yield significantly. For this small hole of about 10 cm deep and 10 cm away from the clump fertilizers placed and covered.
9. Varieties: Among the popular varieties tested, Co 86011, Co 7717, Co 7219, Co 8208, Co 85004, CoC 671, Co 6806, Co 94008, Co 85019, Co 94012, Co 97008, Co 99004, Co 2001-13, Co 2001-15, etc., were found suitable for salt affected soils (Gomathi et al., 2014, 2015, Vasantha et al., 2022 a,b,c,d,e,f)

Besides breeding new varieties of sugarcane to mitigate effects of climate change, scientists can also use biotechnology to reduce abiotic and biotic stresses associated with sugarcane (Cheavegatti-Gianotto et al., 2011). Genetically modified sugarcane is expected to have a potential of increasing yield, drought tolerance and insect resistance of sugarcane. Biotechnology also releases varieties faster than conventional breeding of sugarcane.

5.4. Soil carbon management

Soil organic carbon is derived from plant inputs, especially leaves and fine roots, and plays a fundamental role in the global carbon cycle. The stock of carbon in a soil reflects the balance between the inputs from plant residues and losses due to decomposition, erosion and leaching.

Intensively cropped soils have low organic carbon content, due to disturbance, erosion and regular periods of minimal organic matter input during fallow and in early stages of crop growth. A change in land use from forest or grassland to cropping will, therefore, generally lead to loss of soil carbon, by 50% or more. There is significant potential to increase C stocks in these carbon-poor soils by adopting improved land management practices. Small increases in soil C over large areas can significantly mitigate the rising atmospheric concentration of carbon dioxide. Furthermore, in addition to mitigation of greenhouse gas emissions, increasing soil organic matter has a positive impact on soil health, productivity and resilience (Singh and Rengel, 2007).

5.4.1. Management practices that can increase soil organic carbon stocks include:

- *Retention of forest slash and crop residues rather than burning* to increase organic matter input and protect against erosion of the carbon-rich surface soil. The effective control of diseases that harbour on crop residues needs to be considered when this practice is adopted.
- *Application of fertilizer to overcome nutrient deficiencies and so enhance plant growth* and therefore litter inputs. Fertilizer rates and timing should be matched to the requirements of the crop/forest to maximize efficiency of fertilizer use and limit leaching and runoff. However,

greenhouse gases are emitted in the manufacture of fertilizer, particularly nitrogen fertilizers (Vallis et al., 1996), and application of nitrogen fertilizers can cause nitrous oxide emissions, so these emissions should be balanced against the soil carbon gain.

- *Application of organic amendments*. Recycled organics such as manures, biosolids, composts and char are likely to be more effective than fresh plant residues in raising soil C because the carbon is present as relatively more recalcitrant forms.
- *Minimised cultivation disturbance to reduce mineralisation and erosion losses*. Minimising soil disturbance will conserve soil carbon, particularly on erodible soils. Reduced or zero tillage planting techniques increase soil carbon in many cropping systems, though in Australia positive impact of minimum tillage on soil carbon has only been found in wetter temperate regions.
- *Modification of grazing management to maintain pasture cover*. Maintaining pasture cover minimises erosion losses, and maximises organic input to soil.

Many studies in Europe and USA with predominantly cool climate have shown that soil organic C content tends toward a new equilibrium within 20–30 years after a change in management, such as from conventional tillage to no-till. However, studies in Australia and Asia in climates ranging from sub-tropical/tropical to semi-arid/arid conditions indicate that longer periods are required.

Land use and management practices that sequester soil carbon can impact on emissions of the greenhouse gases N_2O and CH_4, and the interactions between these gases and carbon balance can be complex. For example, if nitrogen-based inorganic fertilizers and/or organic amendments are applied to enhance plant growth, this may lead to carbon sequestration in vegetation and soil, but such benefits could be partially or completely offset by increased emissions of N_2O. In addition, higher rates of N application may suppress oxidation of CH_4 by soil methanotrophs, especially in aerobic soils, further reducing the net mitigation benefit. Although soil carbon management in agricultural systems is not currently recognized as an eligible offset under the NSW Greenhouse Gas Abatement Scheme, it may be included in the proposed National Emissions Trading Scheme. Inclusion of soil carbon management in any future emissions trading scheme will be dependent on development of cost-effective methods for estimating soil C change under changed land management practices.

5.5. Mitigation and adaptation strategies of sugarcane to climate change- cultural practice

Besides mitigating the direct effects of climate change, cultural practices that exacerbate climate change may be reduced for example sugarcane burning prior to harvest. Sugarcane burning before harvesting, a common practice is important for removing leaves and insects to facilitate manual cutting of cane. However, Levine (2000) argued that this practice releases greenhouse gases like carbon dioxide, methane, non-methane volatile organic compounds and nitrogen gases which increases effects of climate change.

Alternatively, sugarcane can be harvested without burning as it was the practice until 1940^{s} (De Resende et al., 2006). Burning practices prior to harvesting has been phased out in São Paulo State due to protocol that was signed to eliminate this practice by 2014 (Goldemberg et al. 2008). Self-trashing varieties may be used to complement harvesting without burning (Clowes and Breakwell, 1998). According to De Figueiredon and La Scala (2011), conversion from burning to green harvest can increase the amount of sugarcane residue and this may have an impact on soil properties. Sugarcane residue is important in weed suppression, increases the content of organic matter in the soil which increases water holding capacity; improve soil structure and biological activity in the soil. However, no burning of sugarcane prior to harvesting have got its problems like reduced tillering, reduced available nitrogen during wetter years and increase in certain pests and diseases. Another cultural practice that increases the effects of climate change is burning sugarcane trash. In Zimbabwe, after harvesting sugarcane, tops, burned and unburned leaves which make up trash is cleared from all ridges and placed in every eighth of the ridge in the field. This is done to allow free flow of irrigation and to reduce interference of trash with land preparation. The trash in every eighth of the ridge is burned. This practice exacerbates the effects of climate change since burning trash releases greenhouse gases. Alternatively, trash may act as mulch and can be windrowed to control wind and water erosion (Clowes and Breakwell, 1998).

Trash when decomposed may release essential nutrients like nitrogen that may be taken by the crop (Vallis et al., 1996). Therefore, use of organic nitrogen sources like sugarcane residues can improve the nitrogen content of the soil (Giller, 2001). However, N present in sugarcane residues are released slowly (Vitti, 2003). Potentially, use of trash can reduce nitrogen requirement of the crop from inorganic sources. Use of high rates of inorganic nitrogen increases the effects of climate change (UNESCO and SCOPE, 2007, Keating et al., 1997). Also salinity is associated with use of high rates of inorganic nitrogen. Furthermore, when sugarcane is ploughed out in preparation for a new crop, many operations which make up land preparation is involved. The operations may include pre-discing, ripping, ploughing, post-discing, land planning and ridging (Clowes and Breakwell, 1998). Many operations of land preparation usually result in more fuel being used. Therefore it is vital, that operations for Land preparation be kept at minimum. This also reduces the cost of production in the midst of sugarcane yield declining as projected by climate change. In addition, fossil fuel can be replaced by bio fuel to power transport vehicles in the sugarcane industry (Shumba et al., 2011).

5.6. New Agro-techniques for bud chip settling (BCS) and Tissue culture Plantlets (TCP)

Under water stress areas, compared to two budded setts planting the innovative method of planting of bud chip settling and tissue culture plantlets could save minimum five to six irrigation. Dhanapal et al. (2018) standardized agro-techniques for BCS and TCP planting under tropical Indian conditions. Initially disc ploughed the field once and then run the tractor mounted cultivator two times and to brought out the field soil to a fine tilth condition. Apply Farm yard manure @ 12.5 t ha^{-1} at the time of last ploughing, incorporated and levelled. Prepare the ridges and furrows at 120 cm apart uniformly using tractor drawn ridger. Scheduling of light irrigation (2/3 portion of the furrow) before transplanting of TCP/BCS should be done. Transplant settling/plantlets in main field in the centre of the furrow @18519 and 13889 settlings/tissue culture plantlets in 120 × 45 cm and 120 cm × 60 cm, respectively in two crop geometries. With newer crop geometry of 120 cm × 60 cm, tissue culture plantlets planting at 5.0 cm depth were found beneficial in improving cane yield (99.3 t ha^{-1}) over rest of planting agro-techniques. As far as bud chip settling are concerned, 120 × 60 cm crop geometry and planting at 2.5 cm depth was found most suitable in realizing the higher cane yield (90.7 t ha^{-1}).

5.6.1. Sett treatment

Sugarcane is vegetatively propagated and planting of two budded setts is in vogue. While cutting and sizing the setts there is higher likelihood of attack of insect, pest and diseases. Furthermore, at the time of planting when the setts are placed in the soil it comes in contact with soil borne pathogens and abiotic stresses such inadequate soil moisture, soil salinity also affects the germination. Looking to these facts, the objective of the setts treatment is principally to safeguard the setts from insect, pest, diseases drought and thereby get better germination and better crop stand. While planting, be sure to use disease free quality setts of 8 months cane seed crop. For disease management, treat the setts for 5 minutes in 0.1% Carbendazim (100 g in 100 litre of water) before planting and in many cases for seed crop setts treatment in Moist Hot Aerated Therapy unit at 54^{o}C for 1 hr is useful. In case of drought prone areas one can go for setts treatment which consists of different technologies, viz., soaking of setts in saturated lime water, application of FYM and foliar spray of KCl and Urea have been shown to be effective in mitigating drought in sugarcane (Chand et al., 2010).

5.6.2. Weed Management

Timely weed management in sugarcane is one of the important facets of climate smart agronomic practices to mitigate the abiotic stress in general and more explicitly the available soil moisture under water scarcity areas. Weeds compete with sugarcane not only for soil moisture but also for space; light and nutrients thereby affect the crop physiology and development. The scenario of weed competition in sugarcane is far greater than other short duration row crops because of slow early growth stage and availability of ample sunlight due to wider row planting. More than 200 weed species have been notified to infest the sugarcane fields and among them, 30 are of economic importance. The weed species makeup in the sugarcane field will vary depending upon the climatic conditions, soil type, cropping systems followed and management practices implemented for controlling weeds and cultivation of the crop. Pre-emergence application of atrazine at 1.75 kg a.i ha^{-1} followed by two post-emergence sequential applications of ethoxysulfuron at 80 g a.i ha^{-1}at 15 and 30 days after planting is useful for control of nutgrass.

5.6.2.1. Weed management in sugarcane under wide row planting

Early post emergence application of metribuzin at 1.25 kg a.i ha^{-1} at ten days after planting followed by post-emergence application of herbicides like topramezone at 29.4 g a.i ha^{-1} + atrazine 656.25 g a.i ha^{-1} or halosulfuron 67.5 g a.i ha^{-1} + metribuzin 750 g a.i ha^{-1} or tembotrione 120 g a.i ha^{-1} + atrazine 656.25 g a.i ha^{-1} at 65 days after planting were comparable with three hand weedings and recorded higher sugarcane yield, better weed control efficiency, net returns and BC ratio.

5.6.2.2. Weed management with new generation herbicide molecules

Weeds in sugarcane compete for water and thus sugarcane suffers from water shortage. However timely weed management practices could control the weeds and thus water loss can be minimized. New generation herbicide molecules like topramezone (29.4 g ha^{-1} + 250 g atrazine), tembotrione (120 g ha^{-1} + 250 g atrazine) and halosulfuron methyl (67.5 g ha^{-1} + metribuzin 750 g ha^{-1}) can be used as early post emergence herbicide (20 days after planting) for weed control in true seed seedling, bud chip settling and sugarcane setts (Tayade et al., 2019).

6. *In-Situ* Trash Mulching in Plant crops

Due to high C: N ratio and difficulties in handling of sugarcane trash after harvest of sugarcane farmers frequently burn it in the field itself. Impact of trash burning on sugarcane agriculture is multifarious in terms of air as well as soil pollution, health hazards, road safety etc. More precisely, practice of trash burning in sugarcane field is environmentally unsafe and leads to poor soil health and cane yield. If manage appropriately, sugarcane is a potential tool to mitigate abiotic stresses like drought, soil compaction and nutrient deficiencies in cane farming. Moreover, trash mulching in sugarcane could check the weed growth and reduce the crop weed competitions for soil moisture, light, space and available soil nutrients.

Improved germination and tillering in sugarcane are attributed to reduced evaporation, soil temperature and greater availability of soil available moisture. The results of the field experiment conducted at ICAR-SBI, Coimbatore, India, revealed that detrashing at 5, 7 and 10 months after planting and use of sugarcane trash for in- situ trash mulching in a plant sugarcane crop is highly beneficial in conserving soil moisture. Application of microbial consortium comprising Trichoderma and nitrogen fixer could fasten decomposition of sugarcane trash. Higher soil microbial carbon (SMBC), soil moisture (0.70 to 5.92%) and lower soil temperature (25.1 - 27.2°C) in the surface soil was observed in trash mulched plots than control. Overall favorable soil microclimate due to in situ trash mulching increased single cane weight, cane height, cane girth and NMC and cane yield (Tayade et al., 2016).

6.1. Green Cane Trash Blanketing in Mechanically harvested sugarcane

The practice of Green Cane Trash Blanketing (GCTB) under tropical Indian conditions in mechanically harvested cane fields improves and exploits soil and crop micro-environments to constrain germination, growth, and multiplication of weeds while minimizing the use of synthetic herbicides. Use of herbicides substantially reduced soil tillage and protect soil by way of green cane trash blanketing thereby improves soil health and sustains crop yields. However, high C:N ratio (73.1:1), immobilization of soil nutrients up to 100 DAR, high fibre content, lack of proper composting techniques and prolonged decomposition of sugarcane trash in the field are the main constraint in its recycling.

The result of trials revealed that in machine harvested plant and first ratoon crop 16.29 and 20.11 t/ha of sugarcane trash with appreciable amount of nutrients i.e. N (0.5 %), P (0.12 %) and K (0.73 %) was available for recycling for subsequent first and second ratoon crop, respectively. The practice of green cane trash blanketing couple with manipulation of upper soil layer by off-barring after machine harvested first ratoon crop, could reduce the soil compaction (2.21 MPa) in surface soil i.e., 0-15 cm thereby improved cane weight, cane height and overall sugarcane growth (Tayade et al., 2017). Effective application of anti-transpirants may also found useful in checking the water losses and add some benefit in terms of cane yield.

6.2. Soil Compaction in sugarcane farming

Sugarcane is a long duration exhaustive crop and requires heavy fertile soils. It may be grown on variety of soils with textures ranging from sand or heavy soils to organic soils. For better sugarcane crop, soils should be deep, well drained, well structured sandy loam to clay loam with adequate amount of organic matter. The soil should have crumb and reasonably friable. Maintenance of proper physical, chemical and biological conditions of the soil is necessary for ensuring higher growth, yield and quality of sugarcane**.** Chemical constraints in the soils, such as acidity and low fertility, relatively easy to correct or control, however, poor physical conditions like soil compaction due to intense mechanization when limiting, are much more difficult to ameliorate. Soil compaction has been recognized as a major physical threat to soil fertility throughout the world (Soane, 1994), that destroys structure, reduces porosity, limit water and air infiltration, increases resistance to root penetration and often results in reduced crop yield. Bailey et al. (1986) described that most of the soils are composed of about 50% solids (sand, silt, clay and organic matter) and about 50% pore spaces soil, however, because of compaction, the reduction of soil volume due to external factors, compression of soil particles into a smaller volume is observed, which reduces the size of pore space available for air and water.

Soil compaction can be a serious and unnecessary form of soil degradation that can result in increased soil erosion and decreased crop production. Compaction-induced soil degradation affects about 68 million hectares of land globally (Flowers and Lal, 1998) and sugarcane soils are not a exception for it because intensive sugarcane crop management with use of machineries during soil preparation, planting, intercultural operations and harvesting add traffic of machines and vehicle, causing changes both to physiochemical attributes viz. soil compaction, soil density, total porosity, water holding capacity and aggregate stability (Torres et al., 2015). Compaction has been identified as the primary cause of soil degradation because it negatively influences all other physical attributes (Materechera 2009, Gorucu et al. 2006), cause damage to the soil structure.

Soil structure is important because it determines the ability of a soil to hold and conduct water, nutrients, and air necessary for plant root activity. Roots system of sugarcane consist of rhizomes and fasciculate roots, 85 % of which are in the 0.0-0.50 m layer, and 60 % in the 0.20-0.30 m layer (Oliveira Filho et al., 2015). Souza et al. (2014) emphasizes that that the physical changes in soil structure caused by compaction mainly occur in the top 0.0-0.40 m layer. Without chemical or physical obstruction cane roots can reach depths greater than 2.00 m in the rhizosphere.

6.3. Factors governing soils compactions

Knowledge of the factors affecting compaction can be used to minimize the competitive effect of agricultural machinery on soil. The degree of compaction depends on a number of factors, including as soil water content, organic matter content, number of passes, axle load, and size, type, shape and inflation pressure of tyres (Soane et al., 1981a,b), porosity (or bulk density), texture, exchangeable cation composition, cementation, orientation of soil particles as a result of alternate wetting and drying, and the effects of overburden pressure or degree of confinement against the upward displacement of soil particle. In a 58 year old burning and trashing trial receiving fertilizer and no fertilizer van Anterwerpen and Mayer (1997) on Vertisol observed that penetrometer resistance was significantly lower in those treatments where no fertilizer treatment suggests that the loss of Ca from the profile under continual fertilization led to an unfavorable cation balance and resulted in increased resistance to penetration.

6.4. Soil and Crop responses to soil compaction

Soil compaction increases bulk density (light to medium soil: 1.5 to 1.7 g/m^3 and heavy soil 1.45 to 1.57 g/m^3 and penetration resistance. It decreases porosity, which is an important parameter affecting root development, gas exchange rates, nutrient availability and hydraulic properties (Maud, 1960), infiltration rate and finally reduced nutrient and water uptake. Soil compaction creates impedance to root penetration and proliferation due to less porosity, water, air, and roots move through the soil with more difficulty. Restricted root growth affects crop growth and yield directly and restricted water and air movement limits yield by reducing the effectiveness of subsurface drainage. Shallow root system makes the crop susceptible to drought during dry spell, because soil compaction create a less favourable environment for the development of root system of sugarcane (Otto et al., 2011, Kingwell and Fuchsbichler, 2011) restricting root growth (Souza et al., 2012). A common response of the root system to increasing bulk density is to decrease its length, concentrating roots in the top layer and decreasing rooting depth (Jurcova and zrubec, 1989, Lipiec et al., 1991, Medvedev et al., 2000).

In most of the experiments, soil compaction led to the higher concentration of roots in the top layers and reduced roots in the deeper layers. This concentration of roots in the upper layer of compacted soil can be due to more horizontal growth. In strongly compacted soil, such root distribution can be partly attributed to the horizontal orientation of pores. Deeper but reduced root growth was attributed to excessive mechanical impedance (3 MPa), especially in dry seasons and insufficient aeration (air-filled porosity <10%) in wet seasons (Lipiec and Hakansson, 2000, Medvedev et al., 2000). Roots compensate for the loss of length by thickening in compacted soils (Bennie and Burger, 1980). This results in weakened and poorly developed root systems, which may have a number of negative consequences. In sugarcane, Verma (2002) reported a magnified impact of soil compaction with successive ratooning wherein penetration capacity of plant root is reduced, and roots face inadequate soil aeration. It also reduces water intake into soil, decrease in dry weight of roots and shoots. Soil compaction thus promotes lodging particularly in unusually wet conditions, adversely affects soil-plant-water relations and finally affects crop emergence, growth and development. Torres et al. (1990) also reported a 29-42% yield decline from plant to first ratoon due to infield traffic during the wet condition. Similarly, Usaborisut and Niyamapa (2010) reported that the greatest reduction in yield of sugarcane compared to control filed was 22.90%, which was resulted from compaction following 15 Tractor passages.

6.5. Agronomic interventions for management soil compaction

6.5.1. Soil Tillage

Sugarcane cultivation systems involve a large number of operations with heavy farm machinery as tilling, mechanized harvesting and in-field transport, which raise the possibility of compaction and increased soil density. Repetitive in-field traffic during the crop cycle, which occurs under different soil moisture conditions (Oliveira Filho et al., 2015), hampers normal root development and crop productivity. This set of tilling operations reduces soil macroporosity, aggregate size, water infiltration, and increases soil density and resistance to root penetration (Vasconcelos et al., 2010), thus reducing the performance of the crop. It was observed that the cultivation systems of sugarcane can cause changes to the soil's physical properties and root development, which in turn, can affect the productivity of the crop. Research findings of Botha and Bennie (1982) and Berry (1987) suggested deep ploughing for loosening of compacted soil wherein, they observed 30 per cent higher yield in maize. Rip under row was found to be effective in reducing root impedance and improving access to soil moisture held at depth (Mallett et al., 1985). The new DPH tillage system (Desiccation + moldboard plowing + light harrow) improved penetration resistance (0.20 m soil depth) and root development. Root development was significantly lower with higher penetration resistance values in all evaluated systems. Sugarcane productivity was significantly higher in systems with greater soil disturbance.

6.5.2. Soil type and Time of Tillage

Avoid working wet soil and improve field drainage. Never till the soil under wet condition, as under wet conditions soil is more prone to compaction because of reduced soil aggregate stability. Mitchell and Berry (2001) while reviewing the soil compaction reported that, the more coarse-textured (sandier) samples were maximally compacted at about 0.033 MPa matric suction, and the finer-textured (30% or more clay) samples at about 0.10 MPa matric suction. In other words, the sandier soils were maximally compacted at relatively higher soil water contents than the clayey soils.

6.5.3. Sub-soiling/Chiselling

Tillage operation alters the bulk density and soil strength. Soil physical properties are affected by various tillage practices. These soil properties change the environment within the soil and make it favourable for the plant growth. The top-soil usually loosened during conventional tillage but at some depth just below the plough player, a compacted layer commonly called plough sole develops and is characterized by abnormally high bulk density. Under such condition, deep tillage (sub soiling, chiselling) has been reported beneficial for crop production by improving soil physical and chemical properties (Ahmed and Maurya, 1988).

Development of a hard pan beneath the plough soil in sugarcane growing areas causes yield stagnation and crop lodging. To improve upon soil physico-chemical characteristics and sugarcane productivity, sub-soiling especially 45-50 cm deep cross sub-soiling at 1.0 m is recommended for enhancing cane yield and sustaining soil health. Bennie and Burger (1980) suggest that the greatest benefit from deep cultivation will be achieved if penetrometer resistance is maintained below 1.25 MPa (measured at field capacity) throughout the season. Vary the depth of tillage or chiseling the soil so that it could help in breaking the developed compacted layer.

While studying on effect of different tillage system (Conventional cultivator 5 passes) on bulk density and sugarcane yield, Ashraf et al. (2003) reported that for sugarcane lower values of bulk density does not confer the good yield but deep tillage operation (chisel ploughing) with inversion of top most layer (Disc harrow) gives favourable environment.

6.5.4. Reduce Tillage Practices/Conservation Agriculture

Conservation agriculture is a concept of conserving and improving the crop production base, essentially maintaining soil health by adopting appropriate measure like using all the farm generated crop residues and organics like dung, animal urine, etc to enrich the soil nutrient and organic matter status, preventing soil erosion, use of minimum tillage practices so that soil maintains its physical, biological and chemical properties. In conservation agriculture with minimal soil disturbance, soil physical, chemical and biological properties are not disturbed and are allowed to maintain. It has been shown that deep tillage of soil before replanting land is unnecessary in most soil of the South African Sugar industry (Moberly, 1972).

Excessive soil manipulation by implement is detrimental to the soil structure with serious consequences on the emergence and yield of the crop (Sheik et al., 1978). When the soil is subjected to compaction, the proportion of pores (larger than 30 μ) decreases while the proportion of micro pore increases. The conservation agriculture should be practiced to reduce traffic on the soil, because one pass of the tractor increased soil strength from 0.57 to 1.43 Mpa and, after three passes, soil strength increased to 2.05 MPa. The greatest compaction occurs during the first pass (Bennie and Burger, 1979).

Results of field experiments conducted at SRS, TNAU, Cuddalore suggested that intensive mechanization, i.e., use of machineries such as ripper plough/chisel plough, power weeder, mechanical harvester-4000 series, trash chopper and bladder and stubble shaver in sugarcane significantly increased bulk density (1.59, 1.62 and 1.64 Mg/M^3) and decreased the hydraulic conductivity (9.81, 9.76 and 9.73 cm/hr) and water holding capacity (37.3, 37.2 and 36.0 %) than farmers practice (Chandra Sekaran et al*.*, 2012)

6.5.5. Crop Rotation

Mono-cropping of should be avoided and inclusion of deep-rooted crops in crop rotation may be given priority as it could minimize the ill effects of compacted layer formed due to compaction. Use a combination of fibrous and tap rooted crops in a rotation to penetrate soil development deep root channels and add organic matter to soil.

6.5.6. Drainage

Excessive use of heavy machinery and implements cause the soil compaction, which promote hard pan below the soil surface. This hard pan restricts the root penetration and excess irrigation water may not drain downward which cause suffocation and retard the plant growth. Therefore, improving drainage is important, so that a healthy environment to the crop can be provided by using proper tillage system.

7. Nutrient Management

Mechanical impedance, or physical resistance to root elongation and function, is often cited as a limiting factor to crop growth and yield. However, recent research has shown that the limiting factor is not physical resistance *per se* but is rather the restricted uptake of water and/or nutrients or inadequate gaseous exchange. Roots are less able to penetrate the soil and are generally shallow and malformed. Since their growth is restricted, they are less able to exploit the soil for nutrients and moisture. Nitrogen and potassium deficiencies are the most common hence; applying fertilizer will improve plant root access. This may include split application of nitrogen or band application of phosphorus and potassium. Foliar application of sea6 formulations (1%) + KCL under drought condition maintained comparatively better growth and physiological characters as that of control (Gomathi et al., 2020). Under drought condition, in Co 86032, foliar application of KCL (2.5%) and seaweed extract LBS 6 @ 2 ml/L was observed comparatively higher cane yield of 92.9 tonnes /ha and 89.5 tonnes /ha, respectively, with 18.0% and 16.5% of yield improved over untreated drought plot. In Co 0212, foliar application of KCL (2.5%) and seaweed extract LBS 6 @ 2 ml/L were recorded 99.0 and 93.5 tonnes/ha, respectively, with 18.5 and 15.2% of yield improved over untreated drought plot, respectively (Gomathi et al., 2020).

7.1. Application of organic manures and growing of green manure crop

Organic matter also leads to better and stronger soil aggregates that can help the soil withstand compaction pressure (Ekwue and Stone, 1995) also penetration resistance and shear strength decreased with increasing organic matter content. The increasing soil organic matter content helps in optimizing soil structure; reduce the potential for the development of compaction. Organic matter makes the soil more resilient to soil compaction (Ohu et al., 1986, Soane, 1990) by making the soil more elastic, thus limiting the ability of an applied load to compact the soil. It has been shown that soils high in organic matter have higher bearing capacity and are able to withstand farm traffic with less compaction compared to a similar soil with low organic matter. Follow the soil management and cropping practices to ensure the prevention of soil compaction. Regular application of FYM, bio-compost, crop residue recycling, green cane trash blanketing and green manure crop will improve organic carbon (Tayade et al., 2016, 2017). Therefore, management practices that add soil organic matter will make the soil more resilient to surface and subsurface compactions.

In India, addition of 20 t/ha FYM/ compost along with inorganic fertilizers applied on the basis of soil test, soil test crop response for targeted yield or on the basis of general recommendation for the region has shown positive effect on sugarcane growth and yield both in plant and ratoon crops. Response of sugarcane to bio-fertilizers (*Azotobacter/ Acetobacter/ Azospirillum/* PSB) was more pronounced in Peninsular Zone. Use of organic sources of nutrients in plant ratoon system brings about substantial enhancement of soil health parameters in most of the sugarcane growing soils.

7.2. Controlled traffic

Establishing permanent lanes for farm traffic is the best option. Indiscriminate driving of tractors and other farm machines across the field can lead to compaction of many sections of the field. Planning and discipline are required to establish paths for movement, but doing so will eventually result in reduced field compaction. It has been proven that traffic control increases yields in agricultural soils (Williford, 1980). In a normal year, as much as 90% of the field may be tracked by equipment. The philosophy behind controlled traffic is to restrict the amount of soil travelled on by using the same wheel tracks. Seventy to ninety percent of the total plough layer compaction occurs on the first trip across the field. By controlling traffic, the tracked area will have a slightly deeper compaction but the tracks will not be compacted.

8. Conclusion

Improved knowledge is needed to effects of changes in climate on yield and physical process such as rates of soil erosion, salinisation, nutrient depletion, insect pests, diseases and hydrological conditions. New research programme should be aimed at identifying or developing cultivars and management practices appropriate for altered climates. There is the thus urgent need to address the climate change and variability issue holistically through improving the natural resource base, diversifying sugarcane cropping system, adapting farming systems approach, strengthening of extension system and institutional support. Though, many model projections on future climate change scenarios are available, more precise scenarios with finer spatial dimension is required to assess the impact of climate change on sugarcane.

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