Chapter 17
Environmental and Economic Benefits of Sustainable Sugarcane Initiative and Production Constraints in Pakistan: A Review

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Abstract Sugarcane crop has a vital role to play in the economy of developing countries. The crop requires a high amount of water during its development. Therefore, it becomes necessary to adopt innovative, ecofriendly, and water-efficient methods for its cultivation. In this chapter, sugarcane production constraints have been discussed to promote sustainable sugarcane production with special reference to Sustainable Sugarcane Initiative (SSI) techniques. The constraints include high input costs, poor production practices, water scarcity, lack of implementation of modern technologies, less incentives, climate change, and delay in payment to the farmers. Sugarcane production can significantly be increased by using SSI with less input costs, efficient water utilization, reduction of weed losses, and controlling the infestation of pests and diseases. There is a need to take proper steps for increasing the production and profitability of sugarcane by timely irrigation, cost-effective inputs, better-quality seeds, and preventive measures against post-harvest losses. The capacity building of sugarcane farmers is also recommended.

Keywords Sugarcane production · Traditional methods · Input cost · Sustainable Sugarcane Initiative · Economic stability

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17.1 Introduction

Sugarcane is an important economic and commercial crop in the world (Grivet and Arruda 2002). It has a significant role in socioeconomic developments as it improves the income of the growers and creates employment opportunities for masses; It create employment opportunities to more than half a million people globally (Raza et al. 2019a, b). Due to its economic and medicinal value, it is cultivated worldwide and gives high-yielding products. Sugarcane belongs to the family Poaceae; the crop has fibrous, stout, and jointed stalks; it is about 3 m height and rich in sugar (Maloa 2001). The decreasing trend of sugarcane production has been observed from the last couple of years globally. Unfavorable climatic conditions, agricultural transformation, and low returns from the market, as well as decline in planting area, have been expected to lead to the lower production of sugarcane in the upcoming years. The most noticeable decline in production has been recorded in Brazil the leading country in sugarcane production and contributing more than one third of the overall sugarcane production in the world (James 2008). Sugarcane is considered one of the important cash crops, grown all over the world. Among the sugarcane producers, Brazil is the leading sugarcane-producing country with an annual production of 739,300 thousand metric tons (TMTs) and contributes about 39% of the world's total sugarcane production (Walton 2020). India ranks the second-largest producer and contributes almost 19% of the overall sugarcane production in the world with an annual production of 341,200 TMTs (Masuku 2011). China is the third- and Thailand is the fourth-largest sugarcane producers in the world with an annual production of 125,500 and 100,100 TMTs, respectively. Pakistan stands at the fifth position among other sugarcane-producing countries with an annual production of 63,800 TMTs (Aman and Khan 2021). Sugarcane is considered an essential raw material for sugar production in Pakistan, and it is expected to produce 5.9 million metric tons in 2021–2022. Non-availability of minimum support prices, delays in payment dues and water scarcity are prompting some farmers to switch to other crops such as cotton and corn instead of sugarcane.

Sugarcane contributes approximately 60% of foreign exchange earnings and almost 18.9% of the national gross domestic product (GDP) in Pakistan (Chandio et al. 2016). Agriculture provides the basic necessities of life to almost 68% of the total population living in rural areas, and unfortunately, 62% of which is living below the poverty line (Aslam 2016). The total area cultivated in Pakistan is approximately 22 million hectares (Mha) and includes rice 13.14% (2.89 Mha), wheat 41.73% (9.18 Mha), maize 5.14% (1.13 Mha), sugarcane 5.18% (1.14 Mha), and cotton 13.45% (2.96 Mha). These major five crop covers almost 78.64% (17.30 Mha) of the overall cropped area and reflect that these five crops represent a large area of cultivated land (Mari et al. 2011). In Pakistan, among the five major crops, sugarcane occupies the second-largest among the cash crops. It has industrial importance in the sugar industry and other byproducts that are produced from sugarcane.

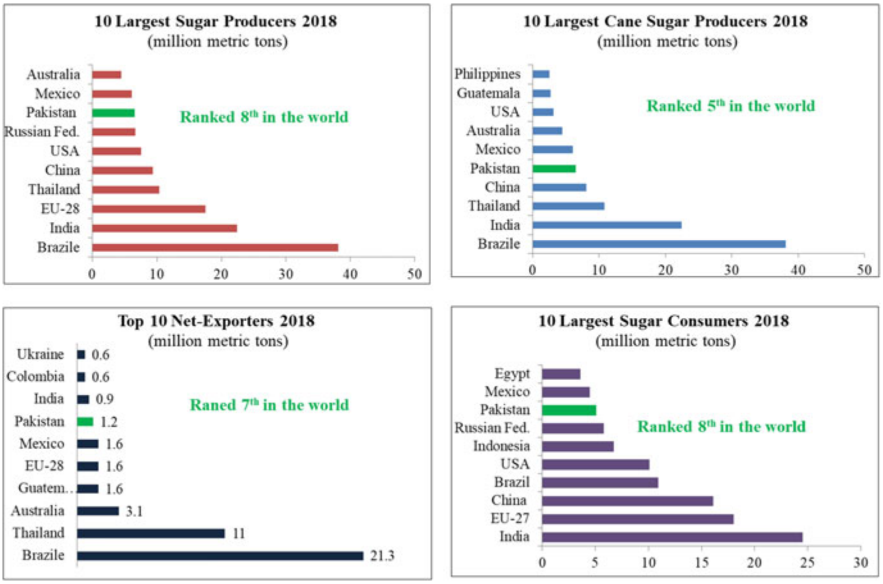


Fig. 17.1 Pakistan sugar in the global perspective. (Adapted from PSMA annual report, 2018)

The total cultivated land area of sugarcane around the world is 27 Mha with a total production of 1333 million tons (Natrajin 2005). In the world ranking, Pakistan is the eighth-largest consumer of white sugar, seventh-largest net sugar exporter, seventh-largest cane sugar producer, and fifth in sugarcane production with an annual production of 83.3 million tons. Figure 17.1 shows the status of the Pakistan sugar industry with reference to the global sugar industry. The total area, production, and yield for sugarcane crops in Pakistan have been shown in Figs. 17.2, 17.3 and 17.4. During 2016–2017, its total cultivated area was 1.217 million hectares with a production of about 73.6 million tons, and its role in GDP and the value addition of agriculture are 0.7% and 3.6%, respectively (Azam and Shafique 2017). In Pakistan, sugarcane is grown in three climatic zones, tropical Sindh, subtropical Punjab, and temperate Peshawar valley. Punjab is the major contributor with almost 62% share in sugarcane production, while Sindh and the North-West Frontier Province (NWFP) also contribute about 26% and 16%, respectively. Sugarcane is the second major provider of sweetness after honey in Pakistan (Qureshi and Afghan 2005), and it provides the raw material for the second agro-based industry after textiles. However, in recent times, sugarcane is recognized for its role in sustainable energy production (Gheewala et al. 2011). Moreover, unprocessed sugarcane is consumed as food and feed for animals in leading producing countries such as Brazil, India, and Cuba (Girei and Giroh 2012). Furthermore, sugarcane juice is used as a raw material and also used for wax (Lamberton and Redcliffe 1960). Wax is a vital part of the cosmetic and pharmaceutical industries, and it is considered as a better substitute for expensive carnauba wax (Singh et al. 2015). However, some

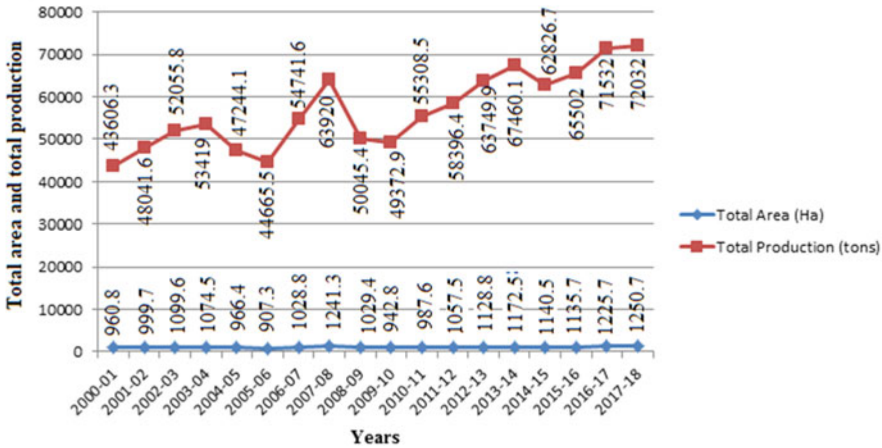


Fig. 17.2 Total area (Ha) and total production (tons) of sugarcane crop in Pakistan

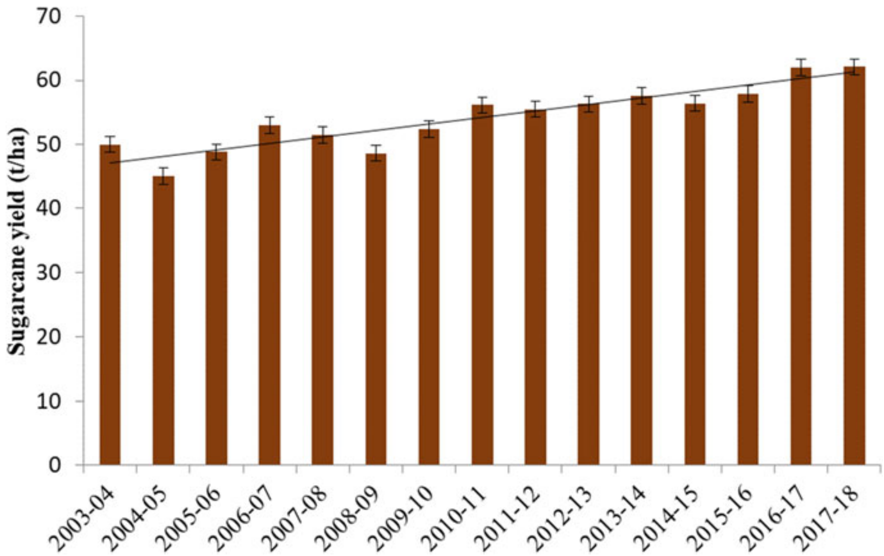


Fig. 17.3 Total yield of sugarcane in Pakistan from 2003 to 2018

important byproducts of sugarcane are refined sugar, molasses, brown sugar, jaggery, biogas production, pulp, biofertilizer, ethanol (Xu et al. 2005), and paper making (Prasara-A and Gheewala 2016). In India, sugarcane is commonly used in the treatment of anuria, hemorrhage, jaundice, dysuria, and other urinary diseases, respectively.

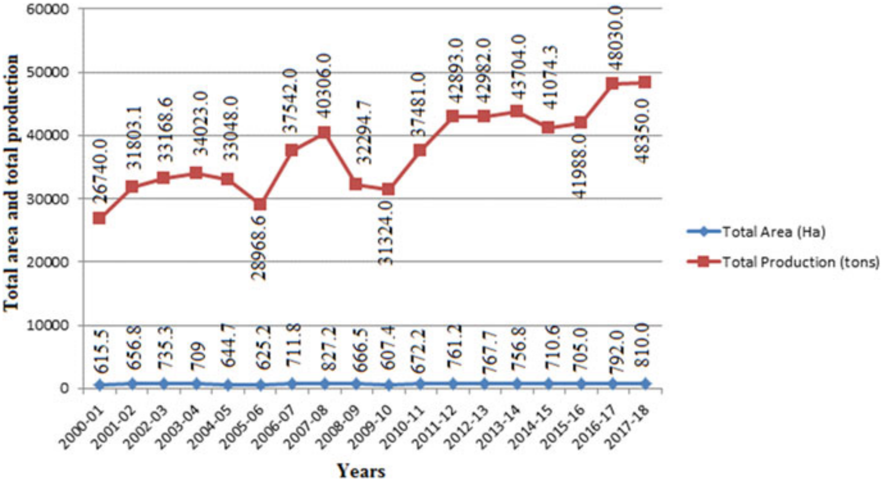


Fig. 17.4 Total area, production, and yield of sugarcane crop in the Punjab province of Pakistan

17.2 Sugarcane as an Energy Source

Pakistan is facing a challenge to energy crises in recent times (Knox et al. 2010). Sugarcane can be used as a reasonable source to overcome the energy crisis in Pakistan (Solangi et al. 2019). Bioenergy has gained better attention as a substitute for fossil fuels. Bioethanol obtained from sugarcane can offer advantages to the environment, human health, and economy of Pakistan (Pereira and Ortega 2010). In the residential region of São Paulo, ethanol replaced gasoline in Brazil resulting in major improvements in air quality. On the basis of lifecycle, it decreases the emissions of greenhouse gases if proper agricultural practices and suitable feedstock are used (Macedo et al. 2008). Ethanol is produced mostly in Brazil from sugarcane and in the USA from corn. In 2008, Brazil produced 22.5 billion liters of ethanol, the European Union 2.7 billion liters, and the USA 34 billion liters mainly from sugar 106 beet (Low and Isserman 2009). For the production of ethanol in 2008, Brazil used 3.4 million hectares of land, while the USA used 8.13 million hectares (Goldemberg and Guardabassi 2010).

17.3 Overview of Sugarcane Production in Pakistan

In Pakistan, ethanol is produced at a very small scale in sugar industries, and it is being used for its own sustainability. Figures 17.5 and 17.6 show the total yield and average recovery of sugarcane in the Punjab province of Pakistan. The average per hectare production of sugarcane is ranging from 620 to 700 maund per acre which is very low in Pakistan as compared to other sugarcane-producing countries (Rai and

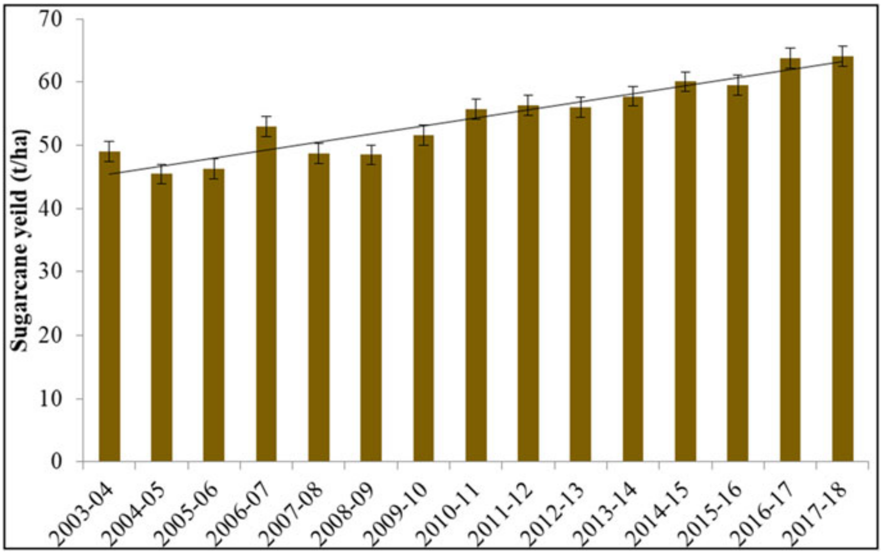


Fig. 17.5 Total yield of sugarcane in the Punjab province of Pakistan for the periods 2003–2018

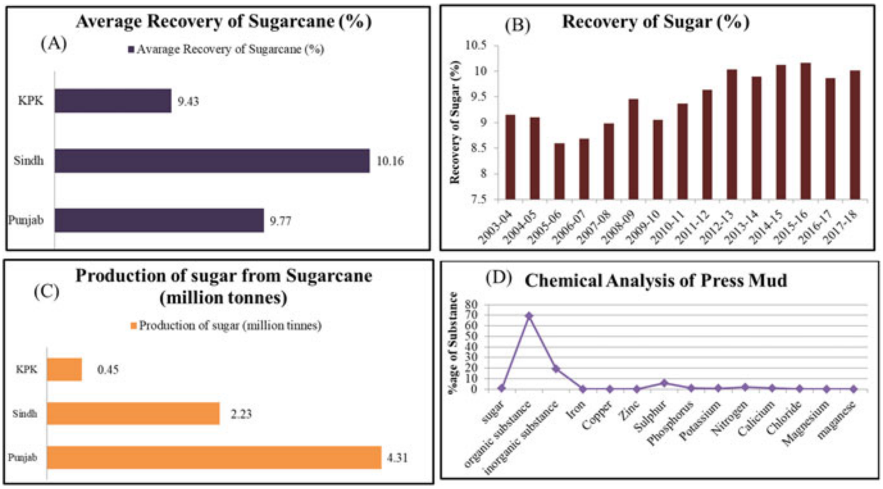


Fig. 17.6 (**a**) Average recovery of sugarcane, (**b**) recovery of sugar, (**c**) production of sugar from sugarcane, and (**d**) chemical analysis of press mud in Pakistan. (Adapted from PSMA annual report, 2018)

Shekhawat 2014). Similarly, its per acre yield is very low in Punjab as compared to other country provinces due to various factors. Among these factors, soil type, soil erosion (Iqbal and Ahmad 2005), cultural practices, plant material, climatic conditions, fertilizer, labor component, pest and disease management, lack of technology, and irrigation water have a considerable impact on sugarcane production (Lahoti

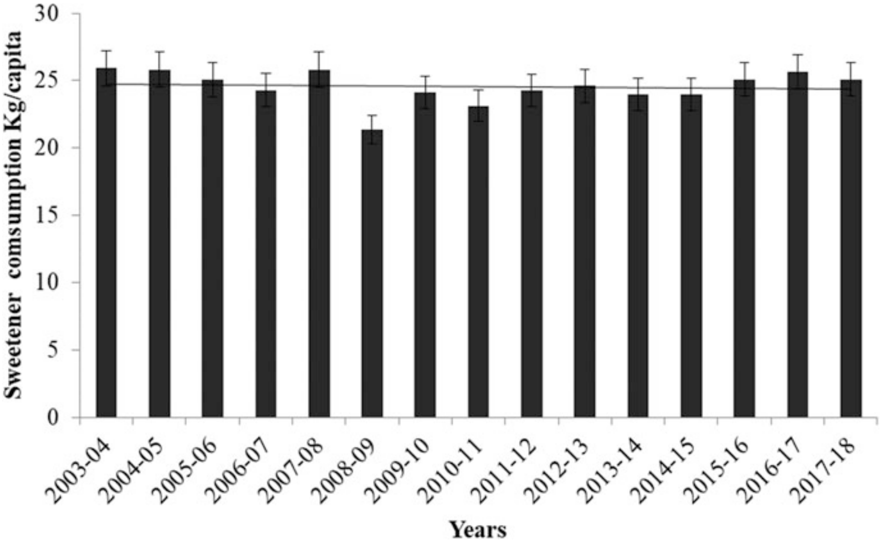


Fig. 17.7 Pakistan Sugar Mills Association (PSMA) sweetener consumption kg/capita. (Adapted from PSMA annual report, 2018)

et al. 2010). Similarly, high input costs like urea, DAP, FYM, irrigation, seed, pesticides, water shortage, and weedicides were also considered important factors in this regard (Sawaengsak and Gheewala 2017). Therefore, high input price directly affects the production of sugarcane. Similarly, distance to sugar mills, the operation of poor management, and post-harvest losses are the gap between potential and actual yield ultimately hampering sugarcane production (Fischer 2015). Sugarcane varieties are also the major factor of low production because these varieties perform effectively in the first year but not performing subsequently ultimately records low yield (Perera et al. 2003). Weeds compete with the crop for the available nutrients, sunlight, and water, which reduces the yield drastically and results in low-quality sugarcane (Girei and Giroh 2012). Hence, farmers are unable to get high sugarcane production due to many causes such as late planting, lack of financial resources, primitive or post-harvest measures, and environmental resistance (Rabelo et al. 2011). Pakistan Sugar Mills Association (PSMA) mentioned that the sweet consumption kg/capita, provincial shares in Pakistan, and area under cultivation are shown in Figs. 17.7, 17.8 and 17.9.

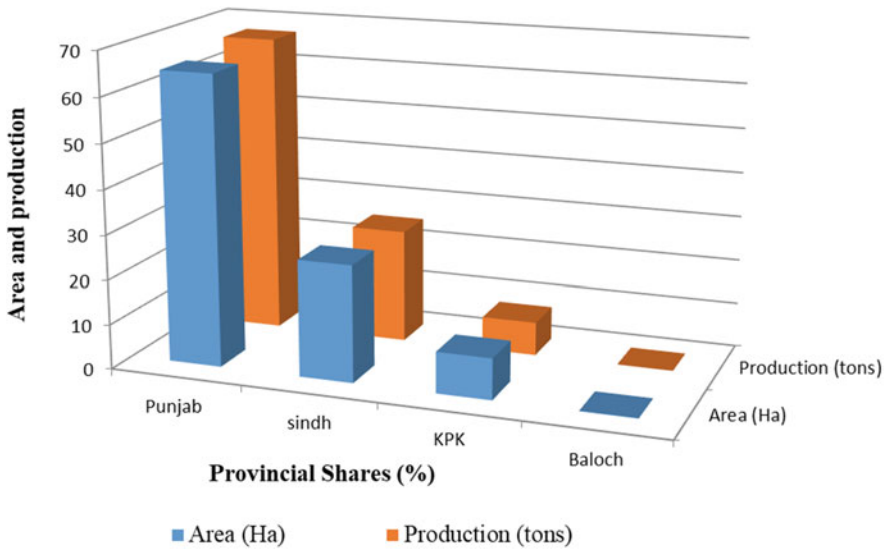
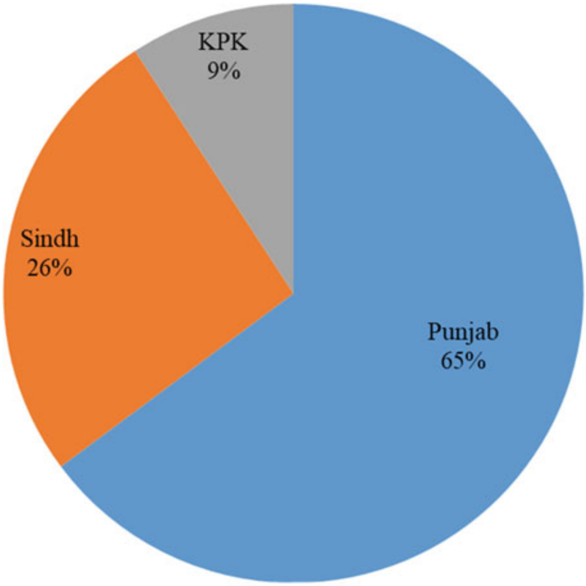


Fig. 17.8 Provincial shares for sugarcane crops in Pakistan

Fig. 17.9 Total area under cultivation for sugarcane in different provinces of Pakistan. (Adapted from Pakistan Sugar Mills Association (PSMA) annual report, 2018)



17.4 The Current System of Sugarcane Production in Pakistan

17.4.1 Climate

Sugarcane is grown in tropical or subtropical climates with a minimum of 600 mm rainfall annually. Sugarcane in Pakistan is harvested in the southern, central, and northwestern zones. The range of minimum temperature during December to January is about 4 °C, and the maximum temperature is 38 °C from June to July. During the winter seasons, the minimum temperature hinders or stops the growth of sugarcane. The climate throughout the year normally favors crop productivity. But extreme conditions of weather especially a limited amount of rainfall are a serious concern to produce sugarcane crop interference in Pakistan.

17.4.2 Climate Change and Sugarcane Response

Among many other factors, climate change is one of the emerging issues in the world. It is anticipated that it has a negative impact on sugarcane production, particularly in developing countries due to lack of awareness, ineffectual forecasting, unsuitable vindication strategies on the effects of climate change, and more exposure to natural hazards. It poses a significant threat to farmers due to the lack of proper infrastructure, inappropriate strategies, and the adoption of traditional agronomic practices (Käyhkö 2019). In Pakistan, farmers' livelihoods and agricultural productivity are affected due to the climate change. Therefore, a precise understanding of climate change and adoption of appropriate mitigation strategies can reduce the economic losses of sugarcane. Thus, environmental awareness is an important step as it is responsible for the reduction in cane yield (Abid et al. 2019).

Cane production may have been negatively affected and will continue to be significantly affected by the increased frequency and intensity of extreme environmental conditions due to climate change. Similarly, changes in the environment lead to global warming having increased greenhouse gas emissions. Global warming is believed to be caused by increasing concentrations of CO_2 and other greenhouse gases (GHGs) in the atmosphere (Zhao and Li 2015). Cane is sensitive to rainfall, temperature, sunlight, and soil (Trenberth 2012). Global temperatures are thought to increase by 3–5 °C by the end of the twenty-first century (Chohan 2019). Different climatic conditions can lead to changes in the sea level, precipitation, floods, droughts, abiotic pressures, and above all a rise in temperature. Rising temperatures could be favorable for some crops such as C_3 plants and sugarcane in some parts of the present world.

Cane production in Pakistan is negatively affected by abiotic and biotic factors diseases and pests are important biotic factors. There are many reasons for rising temperatures in the ecosystem, and change in human activities and deforestation, burning of fossil fuels, and industrialization of the ecosystem are the main causes (Chohan 2019). These are the reasons for low or high rainfall, high temperatures, high pest pressure, more favorable environment for pest growth, disease infestation, higher water requirements, reduced soil fertility, and pollination services. According to the previous studies (Nazir et al. 2013; Hussain et al. 2018; Raza et al. 2019a, b; Moitinho et al. 2021; Triques et al. 2021; Singh et al. 2018; Marin et al. 2019; Farooq and Gheewala 2020), several factors are responsible for the lower production of cane, viz., harvesting cost, transportation, high prices of inputs, a number of harvests, burring of the sugarcane residues, increased greenhouse gases, carbon monoxide, global, abnormal rainfall, and drought stresses, and excess use of pesticides and fertilizers which affects the soil organisms, environment, and soil fertility. However, lack of awareness and adoption rate of the latest technologies were identified as the major reasons of these constraints during farm surveys.

Extreme weather conditions, floods, salinity, drought, and frost have been shown to be the major causes for the deterioration of cane production in Pakistan (Chohan 2019). Punjab, especially in southern Punjab has the highest sugarcane production mainly due to suitable ecology in the area for its production. Rahim Yar Khan is the largest sugarcane-growing area in South Punjab. Over the past decade, due to the failure of other crops such as cotton, farmers have been growing sugarcane as they have more availability in sugar mills, sugarcane logistic support, and more profitable products. But in recent years, the trend of growing the cane community has changed due to the effect of climate change, and they have switched to other crops. However, this situation is very worrying and alarming, and Pakistan has no other alternative for sugar production other than the cultivation of cane.

It is, therefore, very important to inform farmers about the negative effects of climate change and the necessity to adopt appropriate mitigation strategies against it. Hence, the level of awareness and adoption of agronomic measures, including resistant varieties; sowing time and planting methods; soil and land preparation; weed, pest, and disease management; water; and nutrient management, appear to be promising measures to increase sugarcane production and boost farmers' income levels and living standards. It has been hypothesized that climate change is causing a decline in the production of sugarcane.

17.4.3 Preparation of Land

Sugarcane rigger, cultivator, chisel, and subsoiler are used to get proper germination and better crop growth. The simple plow is significant for the good preparation of seedbed in the sugarcane field. For achieving optimal crop growth, the land is prepared in such a way because the crop of sugarcane is deep-rooted, and proper land preparation plays a vital role in the growth of the root system of cane. Sugarcane rigger, cultivator, chisel, and subsoiler are used to prepare the land which enhances proper germination and better crop growth. Deep plowing with subsoiler should be used to prepare the soil properly one time after every 5 years in order to pulverize and increase the rate of water infiltration in the soil (Memon et al. 2010).

17.4.4 Time of Planting and Seed Rates

Two planting seasons are usually practiced in Pakistan: spring sowing in February to March and September to November sowing for rabi or fall. From the first week of September, planting starts in the fall and continues to mid-October in Sindh and Punjab. In other provinces like Khyber Pakhtunkhwa, planting is done in October and November. Planted crop in September commonly produces 25–35% higher yield. In Pakistan, the planting time of sugarcane is generally carried out in the autumn and spring seasons. Planting of high yield and high sugar recovery is done in autumn compared to planting in spring (Nazir et al. 2013). Sets should be selected merely from the young, cultivated crop as a completed matured crop will have a large of dry scale buds. In the dry scale buds' case, it should be treated with a lime solution. By two to three buds, all the sets should be equal in size and should be cut with a sharp tool.

17.4.5 Methods of Planting

The most commonly planting method of sugarcane are the double-set, end-to-end, and overlapping methods (Nazir et al. 2013). In conventional methods, 3 budded sets of 16,000 or 48,000 buds are directly implanted in the soil to attain 44,000 canes per acre for the normal population, but unluckily, merely 15,000 mill-able canes are attained at the end, and the row space is maintained at 1.5–2.5 ft which is 45–74 cm. For the better improvement of sugarcane yield, healthy seeds are used which increases the cane yield by 20–25%. These varieties contain high sugar content and are mostly planted in Punjab (Table 17.1).

17.4.6 Fertilizers

Fertilizers are the vital component for getting the optimum yield of sugarcane. In Pakistan, most of the farmers are using fertilizers in inadequate, imbalanced, and improper ways in a sugarcane field. In developed countries, only nitrogenous fertilizers are used for sugarcane production, but developing countries, like Pakistan, are utilizing a combination of different fertilizers such as potassium, nitrogen, and phosphate. The appropriate doses of balanced fertilizers are important to achieve the maximum yield of the sugarcane crops. Moreover, the use of

Table 17.1 Recommended varieties of sugarcane for the Punjab province

Varieties	Sugar (%)	Production capacity (maund)	Immunity
CPF-247	12.5	1400	Very good
SPF-245	11	1300	Medium
HSF-242	12.5	1500	Medium
CPF 243	12.55	1300	Medium
CP-77 400	11.90	1300	More
CPF 237	12.50	1400	Less
SPF-213	10.50	1300	Less
CP-72 2086	12.36	1065	More
HSF-240	11.70	1355	Less
SPF-234	11.60	1450	Less

Table 17.2 Duration of irrigation for sugarcane crops

Month	Number of irrigations	Duration of irrigation (days)
March, April	2–3	18–20
May, June	5	10–15
July, August	3–4	13–15
September, October	3	15–22
November–February	2	40–50

potassium is almost neglected in crops of cane. Table 17.1 exhibits fertilizer recommendations with respect to sugarcane crops for the Punjab zone (Nazir et al. 2013).

17.4.7 Irrigation

One of the aspects which are mostly neglected in this region is the application of irrigation methods. Lysimeter studies have exposed that the crop of sugarcane needs 88 to 118 kg water per kg cane and 884 to 1157 kg water per kg sugar produced, respectively (Shrivastava et al. 2011). It is difficult for some farmers to manage the enormous amount of water in fields due to financial weakness. Sugarcane crop gets into flooded conditions, and zones of the root remain merged in water (Giordano et al. 2019). It not only decreases the yield of sugarcane by decreasing sugarcane production but also causes waterlogging (Malik and Gurmani 1999). Furthermore, some areas are water-wracked, which leads to salinity (Watto and Mugera 2015). The mentioned number of irrigation and duration of irrigation for sugarcane crops is shown in Table 17.2.

17.4.8 Harvesting and Transportation

Most of the farmers cultivate sugarcane crops without soil analysis and seed treatment, which results in low yield and high production costs due to the absence of technology and modernization. Sugarcane is harvested when the crop attains the age of 12–14 months. The harvesting of sugarcane is done manually, hand-harvesting of sugarcane requires labor intensively, and one person can harvest on average 10,000 kg of sugarcane per day. When the crop of cane is 12–14 months old, it's the right time for harvesting.

Using a special type of tool, sugarcane is cut at ground level in the form of sticks. When sugarcane is harvested, it has a sugar content of almost 10%. The roots are left in the ground as they will ultimately grow and sprout to form the next crop. For loading, sugarcane is bound, topped, and stripped in bundles of 10 to 15 kg after cutting. Within 24–48 h of cutting, the harvested cane should be sent to the mill because late transportation will result in loss of sugar (Nazir et al. 2013). Figure 17.10 shows the flow sheet diagram of the conventional sugarcane cultivation method.

17.5 Sugarcane Crop: The Highest Consumer of Water

Pakistan has become a water-scarce country due to different reasons which ultimately has affected sugarcane production due to its high water demand. To complete one growth cycle, sugarcane requires 1500 to 2500 mm of rainfall/water. So, the crop needs 1500 to 3000 L of water to make a kilogram of sugarcane. Therefore, there is a need to conserve water for future usage for humans as well as for crop plants through the introduction of the Sustainable Sugarcane Initiative (SSI) for enhancing the production of sugarcane with minimum water requirement (Liu et al. 2018). The idea stands on the base of "more with less."

17.6 Sustainable Sugarcane Initiative (SSI)

The SSI is a method of sugarcane production with less water, fewer seeds, and optimum fertilization. The SSI technology has a definite economic advantage over the conventional method of cultivation. Through this method, the average yield of 118.14 tons per hectare can be obtained, whereas the yield from the conventional method was 64.74 tons per hectare. Farmers can achieve about 20% more productivity while reducing 30% of water and 25% chemical inputs using SSI technology (Gujja et al. 2009). The conventional method of sugarcane cultivation is one of the major issues in Pakistan because it requires more seed rate, less intercropping, high weeds infestation, a smaller number of tillers, and more water requirement throughout the cropping season. So, it is time to change the conventional method of

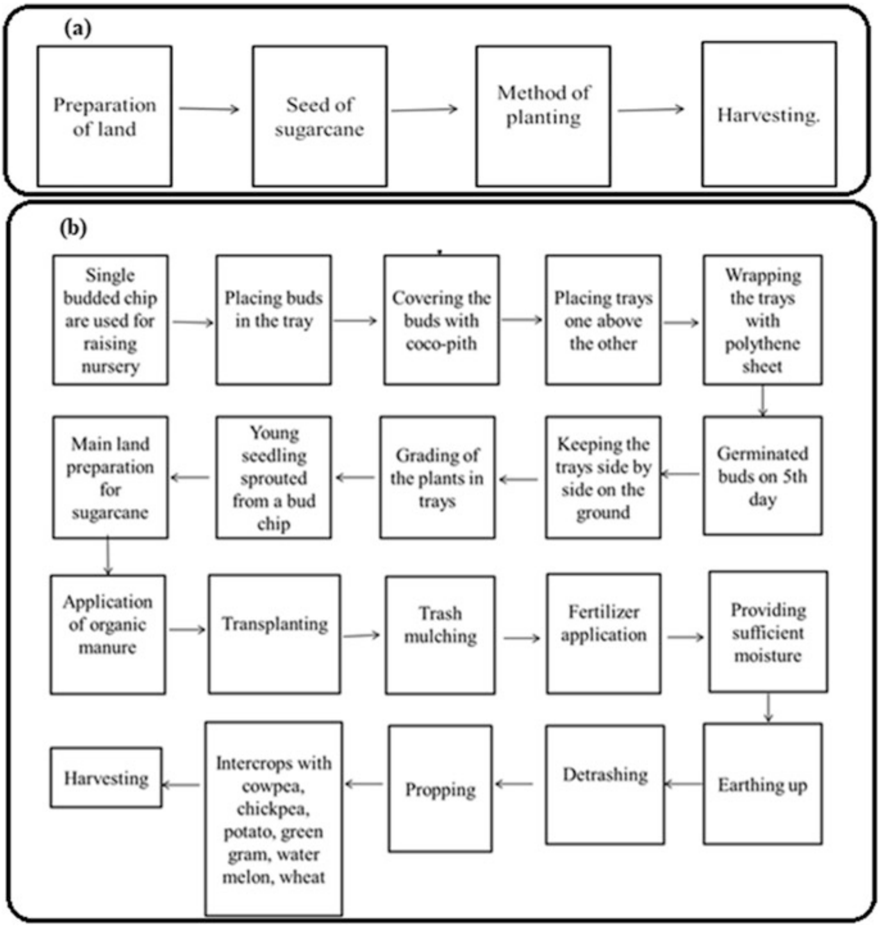


Fig. 17.10 Flow sheet diagram of (**a**) conventional sugarcane cultivation method and (**b**) SSI method for sugarcane cultivation

cultivation to a Sustainable Sugarcane Initiative method because SSI uses less seed, less water, more production, number of tillers, more accessibility to the air and light and optimal land use for higher yields. The major principles of the SSI method are single-budded chips raising nursery; young seedling transplanting (25–35 days old); 5 × 2 ft wide space-maintaining in the field; avoiding the accumulation of water and providing sufficient moisture; promoting plants protection method and organic measure; effective utilization of land by intercropping practice.

17.6.1 Nursery Planting

In this technique, single-budded chips (5000 buds/acre) are used for raising the nursery. Certain buds are placed in a tray filled with coco pith, and then placed with one another and wrapped with polythene sheets to keep air, water, and sunlight from entering the trays. Chlorpyrifos 50 EC is used as a measure by drenching the soil around the trays to avoid termites of sugarcane. Single-budded seed gives surely a 70% germination percentage when treated with chemicals (Jain et al. 2009).

17.6.2 Transplanting

Then the seedlings are transplanted into the already prepared field after 25–35 days at larger spaces of about 5 ft between rows. It is important to note that in the SSI method, the shot growth rate is much faster than the conventional method.

17.6.3 Wider Spacing

A wider spacing of 5 × 2 ft as recommended in the SSI system allows better yield as more sunlight is penetrating in the crop canopy and intercultural operations become easier. The use of intercultural operations to get rid of weeds is recommended as it reduces the damage caused by weeds by up to 60% (Babu 2015). It was observed that this wider space also enhances the weight and height of individual cane. Conventional methods have the efficiency to produce 10–15 tillers, whereas by using SSI, more than 20–25 tillers/plant can be obtained. The cultural practices made it easier and effectively control weeds without using agrochemicals. This technique allows the movement of farm machinery for multiple operations (Shanthy and Ramanjaneyulu 2016). Therefore, the SSI technique is the best strategy to save water and provide soil moisture by using irrigation-efficient techniques such as drip irrigation (Arthi et al. 2016).

17.6.4 Water-Efficient Utilization

Low production of sugarcane is the major challenge among sugarcane farmers in Pakistan. The low average yield of sugarcane is due to a shortage of water during its production period. However, this problem can be overwhelmed through the adoption of SSI. In Pakistan, the water table is depleting continuously. Therefore, it cannot sustain the traditional methods of sugarcane production, as they need more water (Panghal 2010).

17.6.5 An Organic Method of Cultivation

In the SSI method, farmers should add more biofertilizers and organic manures and follow measures of biocontrol, and this method discourages high uses of weedicides, pesticides, and chemical fertilizers. Sudden shifting to organic farming is not suitable; instead, a steady decrease of the inorganic method and implementation of the organic method can be tried by farmers for long-period profits.

17.6.6 Intercropping with Other Crops

In SSI method intercropping of cane with watermelon, French bean, wheat, chickpea, brinjal, potato and cowpea and in adding to effective use of land, this practice will decrease the growth of the weed up to 60% and give extra income to farmers (Loganandhan et al. 2013).

17.6.7 Overall Benefits of the SSI Method

In SSI method, the seed cost can be decreased up to 75% drastically, the rate of plant mortality decrease, weight, and length of individual sugarcane increase, easily transport the seedling to longer distance due to wider space intercultural with other crops. Table 17.3 displays a comparison between SSI and conventional method of sugarcane cultivation (Arthi et al. 2016).

17.7 Model Application of Sugarcane Crop

Accurate crop simulation models are valuable tools for a wide range of applications, including the evaluation of various crop management strategies and the understanding of potential climate change impacts (Thorburn et al. 2014). Crop models are useful tools for increasing sugarcane productivity since they help with knowledge synthesis and application, as well as yield forecasting (Andrade et al. 2016). Field-scale models, such as ALMANAC (Kiniry et al. 1992), EPIC (Williams et al. 1983), Canegro (Marin et al. 2019; Inman-Bamber 1991), and APSIM (Marin et al. 2019; Keating, et al. 1999), as well as regional-scale ones, such as Agro-IBIS (Kucharik 2003) and LPJmL (Bondea et al. 2007), have been applied to energy crops under a wide range of environments. These models differ in the degree of parameterization needed and in their ability to simulate different cultivars and different stress conditions (Marin and Jones 2014; O'Leary 2000). These complexities can be a barrier to the application of sugarcane crop models, possibly because of the lack of

Table 17.3 Comparison between Sustainable Sugarcane Initiative and conventional method of sugarcane cultivation

Comparison	Sustainable Sugarcane Initiative method	Conventional sugarcane cultivation method
Number of sets for sugarcane cultivation	5000	20,000–30,000
Spacing between two rows	5 ft	2–3.5 ft
Planting	After 20–25 days, transplanting nursery is grown in the main sugarcane field	No need of transplanting
Water requirement	Less water required	More water required
Mortality rate of cane plant	Low rate	High rate
No. of tillers per plant	25–30	10–15
Ease for intercropping	More	Less
Accessibility of light and air	More	Less
No. of plants per clump	9–10	4–5
No. of weeds	Less	More
Uniformity	Grading can be done through nursery	No grading

understanding of their capabilities and limitations and because of the difficulties in using them. Another problem seems to be the general lack of model credibility (Marin and Jones 2014). For crop simulations to be reliable, high-quality field data is required for model development, and more effort is needed in the parameterization and validation of models (Surendran et al. 2012; Andrade et al. 2016). Some of the physiological development and growth parameters that appear in model functions vary among sugarcane cultivars and therefore need to be estimated from data in order to predict growth and yield (Marin and Jones 2014). Region-specific calibrations of models are also essential (Andrade et al. 2016). Model calibration is a fundamental step in achieving high accuracy in crop development and yield estimation. Among the several models available in the literature, the Canegro model (Singels et al. 2008), included in the software DSSAT (Hoogenboom et al. 2018), can be applied to help in the interpretation of experimental results and in long-term simulations, to estimate the internal variability of yield, and thus to recommend management practices for sugarcane (Nassif et al. 2012; Hoffman et al. 2018). Since there are differences in growth among sugarcane cultivars, the accuracy of the model depends on its adequate parameterization, being performed according to each genotype.

17.8 SSI Method of Cultivation

17.8.1 Selection of Bud

For raising a healthy nursery, young mother canes are used in the SSI method, which have a good length of 7–8 in and are 7–9 months old. Canes with spots, fungus, and growth disease can be noticed and spotted. The required quantity of canes is cut, and buds are removed from the certain selected cane by a tool called a bud chipper. Bud chipper contains a fixed blade on the wood plank for cutting and a handle. Adjust a cane on a plank in such a way that cutting blade is over the cane and once the handle is pressed, a single bud chip comes off the canes. In this way, about 150/h can be easily cut off. The chipped buds will be treated through a chemical or organic solution. Per acre, 450–500 canes are required (Jain et al. 2009).

17.8.2 Treatment of Buds

Before planting, it is vital to treat the chipped buds with different chemical and organic solutions to avoid infestation. The buds are taken in a tube made of plastic or aluminum. Pour 10 L of water into the tube, and add 20 mL malathion or 5 g carbendazim and 500 g *Pseudomonas* or *Trichoderma*, 1 to 2 L cow urine, and 100 g lime. Put the bud chip in gunny or plastic bag, and dip the bag for 10 to 15 min in the prepared solution. For 2 to 3 h, the bud chip has to be dried in a shady place and then used for the plantation of the nursery (Jain et al. 2010).

17.8.3 Nursery

Young saplings are raised up in the nursery under the shady net. It is an entirely covered structure meant to make favorable conditions like wind-free, warm environment and provide shades. Well-decomposed coco pith is taken for raising nursery, and in the tray, partly fill each cone with coco pith. In the cone of the tray, put the buds in a slightly oblique or flat site, and don't push/press it too hard. Confirm that the faces of bud side up. In trays, the bud chip is entirely covered with coco pith. After filling all the trays, place them all over each other, and have a vacant tray down and top. Roughly, 100 trays are to be positioned together and covered. To create humidity and high temperature, keep the bundles for 5–8 days in the same position, and put a small weight on them. By soaking the soil with chlorpyrifos 50 EC (5 mL/L), take actions to control the termites near the trays. The nursery area must be free from weeds. Bundles can be kept preferably inside a room or in a shade net and tightly covered. If the climate is too cold, then the electric bulb creates artificial warmth. For nursery management, this is the most critical phase. Within

3 to 5 days, under proper conditions (especially warm temperature), primordia (white roots) will come out, and in the next 2–3 days, shoots appear. Either on the fifth or eighth day, based on the climatic condition, the trays must be removed from the polythene sheet and placed on the ground to facilitate watering. The irrigating trays must be started in the evening on the basis of the moisture content of the coco pith for the next 15 days. Leaves will start sprouting, and shoots will start growing strong. After the appearance of two leaves, the use of water should be gradually increased depending on the moisture level in trays. The grading of plants must be done at about 20-day-old seedlings (during the six-leaf stage). For a day, water should not be given to lose the coco pith that allows the easy lift-up of young seedlings. Plants that have a similar height/age can be lifted and placed in one tray. According to their height, grading of plants is attained, and the dead or damaged plant can be detached (Jain 2011).

17.8.4 Preparation of the Main Field

The preparation of the main field is the same as the conventional method. The following step should be followed for better mainland preparation (Gujja et al. 2009).

17.8.5 Removal of Residues

It is very important to prepare the land for sugarcane crop and it needs to be addressed from the planting of the entire crop up to the harvesting. Stalks are to be docile and detached from the arena, and all the remains can be fused into the soil through a rotavator (Nagendran 2009).

17.8.6 Tillage

Tillage operations by a tractor are quick and effective, and it is advisable that one plow for good and already aerated soil conditions and two plows for rough and hard soil are being applied. After plowing, the soil must be kept for an interval of time under good climate for a week or two before going for more tillage operations (Panghal 2010). By using a rotavator or harrows, tillage operation can be carried out. The operations are to be repeated to make the soil bed free from crop residues, weeds, and clods. By using a tractor, the land should be deeply cultivated after tillage operation. If the land is rough, flattening must be done using a leveler. After leveling, to facilitate the easy movement of irrigation water, a gentle slope can be maintained.

17.8.7 Application of Organic Fertilizers

The SSI method boosts the use of organic fertilizer. It increases the content of macro- and micro-nutrients in the soil in an ecofriendly way. It supports the ideal use of some chemical manure that can protect the soil from hazardous effects and degradation. Organic fertilizer like well-rotten press mud/compost/FYM should be utilized (almost 8–10 tons/acre). The amount of organic fertilizer should be adjusted to supply 112 kg of nitrogen/acre with one or more sources. For every 1 kg/acre of *Pseudomonas* and *Trichoderma*, decaying cultures can be combined with the organic fertilizers. Organic matter provides energy and a food source for biological activity. Many nutrients are held in organic matter until soil microorganisms decompose the materials and release them for plant use. This will increase the fertility of soil to realize higher yields.

17.8.8 Construction of Furrows, Ridges, and Transplanting

The distance between rows must be 5 ft to make the furrows. The soil should be aerated by running a subsoiler installed on the plow. This will sustain in deep plantation, a good combination of the fertilizer and prevention of lodging (Galal 2016). From nursery to the mainland, the ideal age of the young seedlings for transplanting is 25–35 days. It is recommended to stop giving water at least 1 day before transplanting. This will loosen the coco pith in cones and aid in the easy lifting of seedlings for transplantation. The planting method is zigzag which can be followed to attain maximum tillers and use more spaces. For easy penetration of sunlight and profuse tilling, the plant-to-plant distance of 2 ft must be maintained. One or 2 days before transplanting, moisten the soil by irrigating the field. Similarly, after planting, instantly apply appropriate irrigation as required according to the type of soil. If the soil is not properly compacted, water will run and air spaces will fill up adjacent to the plant. If the compaction of soil is not good. It is significant to water the field with a small quantity of water instead of swamping (Gujja et al. 2009). The expected outcomes of the Sustainable Sugarcane Initiative are given in Table 17.4.

17.8.9 Reduction in Weed Loss and Mulching

Generally, weed infestation is high during the initial growth stages when the crop is not well established. Weeds suppress the main crop leading to the loss in the production of sugarcane. In SSI, a nursery of sugarcane is grown which reduces competition at initial stages with weeds, and the incident of weeds is reduced by up to 60%. Seedlings are grown in a controlled environment and provided with optimum nutrients until fully established. SSI supports wider spacing which allows the mechanical destruction of weeds in an organic way. In sugarcane cultivation, trash

Table 17.4 Different points of view for the expected outcomes of the Sustainable Sugarcane Initiative

Farmers	Factory	Government
Saving in seed (sets)	Higher cane recovery	Employment generation in rural area
Higher cane yield with net return	Increase in crushing day	Electricity saved can be used for some other purposes
Bringing additional area under cane	Reduction in production cost	Groundwater exploitation can be reduced
More crops in unit area and time	Potential for cogeneration	Higher returns to the government through tax collection from sugarcane industries
Saving on water, labor, and electricity	Additional ethanol production	
Raising cane crop with poor-quality water		
Cultivation cane in marginal and problem soils		
Timely and need-based fertilizer application		

mulching is vital as it aids in developing a competition-free environment in the absence of weeds. Mulching will grow earthworms which in turn will increase the water infiltration and aeration of the soil. Within 3 days of planting, cane trash can be applied at 1.5 tons/acre (Galal 2016).

17.8.10 Fertilizer Application Doses

In cane cultivation, nutrient management is very necessary for the growth of good crop. It is always better to know the quantity of the needed nutrients by testing soil and improving the soil accordingly. If it is not convenient, then phosphorus, potassium, and nitrogen can be applied at the rate of 25 kg, 48 kg, and 112 kg, respectively, by the organic or inorganic method. Muriate of potash, superphosphate, urea, and ammonium sulfate is applied to attain the requirement of nutrients. Under the presence of mulching, a plant can get efficient NPK amount from the soil and due to having a healthy environment during early sprouting, sugarcane becomes resistant against an attack of certain fungus. The mentioned quantity of manures can be applied in two to three split doses for efficient use. At the time of preparation of land, apply organic fertilizers and incorporate green fertilizers into the soil. Moreover, biofertilizers such as rhizobacteria and *Azospirillum* are used, 2 kg each on the 30th and 60th days after planting by mixing it with FYM (200 kg/acre).

17.8.11 Water Management

Flooding in the field is not preferred compared to providing enough water on the required time. In the conventional methods, flooding is done, which supplies more water than the biological demand of the crop resulting in water excessibility, which may affect the growth of the crop. After transplantation, the irrigation frequency may differ depending on crop age, availability of moisture, rainfall, and type of soil. The frequency will be less for clay, and for sandy soil, it will be more. Irrigation is recommended, during the grand growth period (101–270 days) once in 7 days, during the tilling stage (36–100 days) once in 10 days, and during the maturity period (from 271 days till harvest) once in 15 days. Furrow irrigations help in water conservation hence increase water use efficiency. Alternate furrow irrigation means after 7–15 days as per the age of the crop and the moisture content, irrigating the odd numbers of furrows of initially followed through irrigating the even numbers of furrows. This will ensure up to 50% saving of water. Due to the raising of single seedlings and wider spacing in the SSI method, drip irrigation can be practiced efficiently (Gujja et al. 2009).

17.8.12 Earthing Up, De-trashing, and Propping

Earthing up means strengthening the crop stand using soil at the root zone. Generally during a crop period, full and partial two earthing up followed. Fractional earthing up is prepared after the application of the first fertilization, top dressing basically to cover the manure and to provide waterfront to the newly established roots. In this case, a small amount of soil from each furrow side is taken and placed over the manure band. This can also be prepared by the application of a country plow or bullock-drawn tool. Full earthing up is planned after coinciding with peak tilling the second top dressing. For irrigation, the freshly made furrows will be later used (Shanthy and Ramanjaneyulu 2016).

De-trashing means the elimination of additional and unfruitful leaves from the plants. Many leaves are produced by cane, and on average, a normal stalk bears 30–35 leaves in good condition. But only eight to ten leaves are sufficient for effective photosynthesis and the basal leaves do not participate in the method and finally they get dry. However, they would contest for the nutrients or could be utilized for the growth of stalk. The removal of dry leaves is important in the fifth and seventh months and mulch should be applied in interspaces for proper growth.

Propping means supporting the cane to avoid falling. It is generally done by attaching the cane to the leaves. At SSI, on one side of the field, it is suggested to provide a border such as a wooden structure to support housing products. In this way, it is possible to prevent the attachment of the middle leaves around, and thus the creation of its leaves will help in the growth of the crop and save work.

17.8.13 Protection of Plant

Light earthing up, with better water management besides trash mulching, is done on the 35th day. When the age of the crop is 45–60 days, 50 fertilized *Sturmiopsis* parasites/acre are released. When the age of crop is 4–11 months old, at 20 m' distance, the cards pasted with eggs of *Trichogramma chilonis* at 10 cards/acre should be distributed. Sugarcane can be prevented from moths through a variety of ways such as moth destruction by parasite *Isotima jevensis* Rohn, destruction and picking with hand, and selection of bud chips with resistant and disease-free varieties. Male moths can be trapped and destroyed against the third or fourth broods of the pest, release of parasite *Isotima javensis* Rohn, destruction and picking with hand, and selection of bud chips with resistant varieties and disease-free. Similarly, higher yield can be realized by the destruction of affected clumps, optimization of soil moisture, healthy buds, and crop rotation.

17.8.14 Intercropping and Harvesting

In the SSI method of sugarcane with wide spaces between the rows, intercropping in sugarcane with watermelon, cowpea, wheat, brinjal, chickpea, French bean, green gram, potato, and various other crops can be tried. Intercropping may be tried depending on location-specific factors. In the initial stage, intercropping controls up to 60% of weeds and increases the income of the farmer. They act as active mulch and preserve moisture and decrease the attack of the pest by being substitute hosts in several cases. The addition of green manures results in incresed the soil fertility when intercropping is incorporated. In most cases, the harvesting of sugarcane is done with collaboration in the industry. The desired level of sucrose content in the plants will be reached on the tenth month of 1-year crop duration, and they will be prepared for cutting within the next 2 months (Gujja et al. 2009).

17.9 Benefits of the SSI Method

In the tropics and subtropical part of India, this method of cultivation gives higher yield of almost 20–25%. As compared with the traditional method, maturity will be earlier, and crop growth will be healthy. Between the rows and clumps, equal and sufficient spacing allows air circulation and sufficient light improving the growth of the crop. This method permits a farmer to pay individual attention to the crop's pits or crops. It has been found useful under saline water and saline soil irrigated conditions, and it gives better ratoon crops. Age of all shoots will be the same; therefore, there are uniform accumulation of sugar in cane and growth of cane. An important factor is that the seedlings are placed at depth, which will be always moist;

therefore, the yields will not get affected in drought cases or cases of water non-availability (Loganandhan et al. 2013).

In this method, the cost of seed is reduced up to 75%, by using of optimum inputs, controlling weeds up to 60%, reduces delta of water and increasing revenue by efficient use of land. Sugarcane growers are facing the challenges of the high cost of production due to the conventional methods. There is a dire need to replace the conventional method of production with SSI to ensure high productivity by the sustainable use of resources. It leads to the substantial increase in sugarcane productivity, reduces the cost of production, and increases the farmer's income with cumulative effects of sustainable development (Rao 2014). Thus, the focus should be on increasing the production and proper utilization of agriculture practices for the wellbeing of farmers (Loganandhan et al. 2013). This is applicable by the adoption of new innovative methods such as SSI and the involvement of newly developed biotechnological tools (cultivars, gene enhancement) in sugarcane cultivation. The conceptual framework for sugarcane production is to enhance the income level of sugarcane farmers by utilizing available land resources in a more profitable manner. Alongside the need to improve yield and productivity of sugarcane along with disease resistance, the current scenario demands the resistant varieties to mitigate climate change which induced direct effects on the growth and development of sugarcane (Sundara 2011).

17.10 Conclusions

The focus on sustainable development is increasing worldwide. Certified schemes for SSI have become very popular in developed countries. Different countries are using different methods for sugarcane cultivation like the Roundtable on Sustainable Biomaterials (RSB), Better Sugarcane Initiative (BSI), Renewable Energy Directive (RED), Global Bioenergy Partnership (GBEP), and Sustainability Assessment of Food and Agriculture systems (SAFA). In Pakistan, there is no strategy for the cultivation of sugarcanes. There are different factors which are responsible for the low average production of sugarcane. Presently, Pakistan ranks as the third-largest groundwater consumer, accounting for almost 9% of the global groundwater withdrawals. For competitive water users and policymakers, water scarcity has become an increasingly social and economic concern. Almost 50–70% of water is lost due to surface evaporation, transpiration by weeds, and run-off leaching beyond the root zone. At any time, water becomes a limiting factor; when growth is decreased, it ultimately results in decrease in yield. Climate change and excessive use of pesticides are the main reasons for higher input costs, destroying natural biodiversity and causing threat to human health in developing countries. Sugarcane farmers are facing a myriad of challenges that directly or indirectly impact sugarcane production. So, there is a need to introduce sustainable agricultural techniques using the government to enhance the productivity of sugarcane. For this purpose, SSI should be initiated in Pakistan with the special regard to minimize the input costs by reducing the usage of chemical pesticides on sugarcane crops to make them environmental friendly. Therefore, the possible ways to increase sugarcane production to meet the demand of the increasing population are enhancing the capacity building of farmers regarding the proper utilization of resources, proper awareness regarding production practices, and motivating them to adopt new resistant varieties which are more resistant against sugarcane pests and diseases and to adopt innovative technologies such as SSI.

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