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REVIEW

Prospects and challenges of conservation agriculture in Bangladesh for sustainable sugarcane cultivation

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Abstract
Sugarcane is an industrial crop globally used for producing biofuels and bioproducts and is the only source of white sugar in Bangladesh. However, labour-dependent cultivation and climate change are responsible for the higher production costs and lower yield of sugarcane, and these factors are barriers to sustainable sugarcane farming in Bangladesh. In this paper, the prospects of existing sugarcane farming practices are described, and some improved cultivation and management practices addressing the principles of conservation agriculture (CA) in overcoming these barriers are evaluated. Excessive tillage, burning of trash after harvesting, and mono-cropping have been identified as crucial factors that increase sugarcane production cost, deteriorating soil health, and decreasing cane yields. Several improved conservation tillage machines used for cereals, pulse, and other crops are becoming more accessible to farmers in Bangladesh, but these machines are not used for sugarcane crops. Minimum tillage can also be a resource-saving tillage option for cultivating sugarcane but is limited in sugarcane production owing to the absence of suitable machinery. However, the irrational removal and burning of the residue in the sugarcane farming systems may have adverse effects on the environment. Intercropping not only increases economic benefits but also minimises the negative impact of mono-cropping. We suggest that minimum tillage, residue mulching, and intercropping should be applied as profitable and sustainable cultivation practices in sugarcane farming. Therefore, both research and extension activities addressing the use of appropriate CA technologies, including conservation tillage machinery improvements, could help to achieve sustainable sugarcane farming in Bangladesh.

Keywords Sugarcane farming · Soil–water conservation · Minimum tillage · Residue management · Crop rotation

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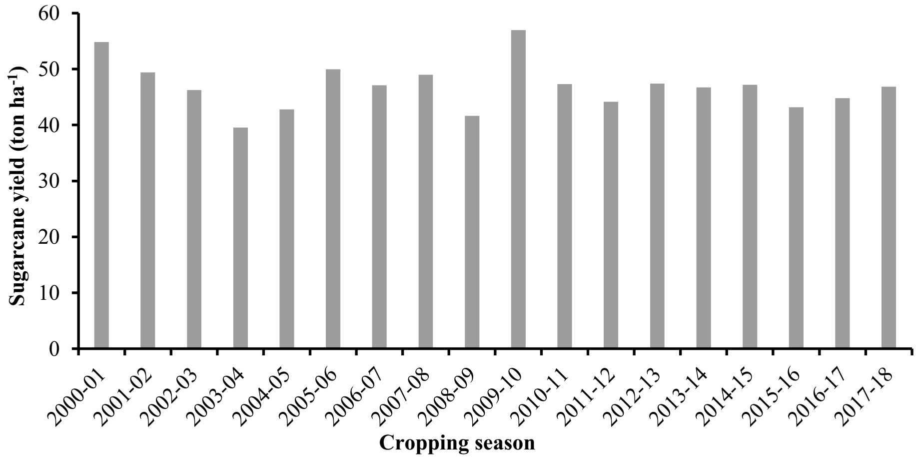

Fig. 1 Yearly average yield of sugarcane per unit land in Bangladesh (Data source: BSRI, 2019)

1 Introduction

Sugarcane (*Saccharum spp.*) is an annual commercial field crop grown in tropical and subtropical areas (Grof & Campbell, 2001; Humbert & Bonnet, 1969). Sugarcane is a vital source of white sugar that contributes approximately 86% of sugar production globally (OECD/FAO, 2019). Moreover, it is a high biomass energy crop utilised for producing biofuels and bioproducts. Sugarcane is the primary source of jaggery or gur (unrefined noncentrifugal sugar) and is the only crop used for sugar production in Bangladesh. Sugarcane cultivation covers 1.2% of the agricultural land of the country (BSRI, 2016). Although cane sticks and sugarcane juice are popularly consumed in Bangladesh, the current production of sugar and jaggery can meet only 25% of the national demand, while imported sugar satisfies the remaining 75% (Rahman et al., 2016). Cultivation area and yield per unit area are both essential in increasing the country's national production of sugarcane, which can reduce sugar importation estimated at approximately 105 million US dollars per year (Rana et al., 2014), and this amount increases each year. The annual average yield of sugarcane per hector land in Bangladesh is shown in Fig. 1. During 18 cropping seasons (2000–2018), the national yield of cane per unit area varied from 40 to 57 ton/ha, and the average yield was 47 ton/ha (Fig. 1), where Peru had the highest yield (112 ton/ha), and the world's average yield in 2016 was 71 ton/ha (FAO 2017). In contrast, Brazil is the world largest sugar producing country with an annual contribution of 635 million tons of sugarcane, while the rest of the world produces 1483 million tons (OECD/FAO, 2019). Therefore, compared to the world's standard, the sugarcane yield in Bangladesh is low and needs to be increased through the application of adequate farm management strategies. However, Bangladesh Sugarcrop Research Institute (BSRI) has released 46 higher sugar content with high-yield sugarcane cultivars, including the latest variety having a sugar content above 12% and a yield potentiality of approximately 100 ton/ha (DAE, 2019). Therefore, further research efforts are required to improve sugarcane yield per unit area through varietal development, better management of soil and water resources, improvement of cropping systems, and development of trouble-free sugarcane marketing networks from the farms to sugar mills.

The cane grown in the mill zone area (catchment area of sugar mills) is used for sugar production in the mill, and it covers 50% of the total cane-growing area (Rahman et al., 2016). On the one hand, mill authorities purchase canes from contracted farmers, and a limited quantity of canes are grown in farms of the mill. On the other hand, smaller-scale farmers grow sugarcane in non-mill zone areas, and these sugarcanes are mainly used for producing jaggery and juice and for chewing. Recently, farmers allocate their less productive lands for sugarcane production, where they cannot cultivate highly valued and short-duration crops successfully (Rahman et al., 2016). This is because farmers have to wait for 12–15 months to receive returns from sugarcane, which is difficult for small-scale farmers in Bangladesh. Moreover, the planting, weeding, and harvesting of sugarcane are achieved through full-manual labour in the country, which increases the production costs. Therefore, farmers in Bangladesh show more interest in rice-based crops and short-duration vegetables (such as potato, eggplant, and chill), instead of the sugarcane crop, for their consumption and commercial purposes. Table 1 lists the recent ten cropping season data (2008/2009 to 2017/2018) for both sugarcane cultivation area and total production in Bangladesh, which decreased from 0.15 to 0.07 million ha and 6.4–3.4 million tons, respectively. Among the South Asian Association for Regional Cooperation (SAARC) countries, India is the highest producer of sugarcane (70 ton/ha), followed by Pakistan (60 ton/ha), Nepal (45 ton/ha), and Bangladesh (42 ton/ha) (OECD/FAO, 2019; Pandey & Devkota, 2020). Furthermore, sugar recovery (sugar that is finally produced from cane) of the country also declined to 5.8% during this period. Consequently, reliance on imported sugar increased from 1.3 to 2.7 million tons to satisfy the demand of the growing population. Hence, domestic sugarcane production needs to be improved by considering the increasing sugar consumption trend, growing populations, and decreasing cultivable lands. Therefore, it is crucial to practice sustainable sugarcane farming to achieve sufficient and stable yield of sucrose per unit area, as well as increase the profit of sugarcane farmers and minimise the dependence on imported sugar.

Sustainable agriculture ensures future global food security, where conservation agriculture (CA) and precision agriculture (PA) are two modern farm approaches that contribute to developing a sustainable production system. Conservation agriculture practices have

Table 1 Status of annual total sugarcane and sugar productions in Bangladesh from 2008 to 2018 (Data source: BSRI, 2019)

Cropping season	Cultivated land (10^3 ha)	Production (10^3 ton)			Sugar import (10^3 ton)	Sugar recovery (%)
		Cane	Sugar	Gur*		
2008–2009	152.7	6358.5	80.0	461.6	1300	6.8
2009–2010	105.0	5977.6	62.2	371.0	1500	7.2
2010–2011	140.4	6640.3	101.0	385.0	1400	6.4
2011–2012	132.0	5829.1	69.4	377.0	1700	6.6
2012–2013	108.0	5119.0	107.1	355.3	1547	6.9
2013–2014	118.0	5511.0	128.3	377.5	1550	7.1
2014–2015	105.0	4956.0	77.5	320.1	2075	6.4
2015–2016	84.5	3649.0	58.2	300.0	2284	6.0
2016–2017	113.7	5213.0	60.0	470.0	2097	6.1
2017–2018	72.6	3403.0	68.6	470.0	2670	5.8

*Gur: unrefined non-centrifugal sugar

shown the benefits in enhancing soil, water, and air quality as well as minimising costs of operations (Altieri & Nicholls, 2005). Consequently, PA requires a site-specific crop and enhanced soil management practices, considering the application of techniques and principles of farm management for better production and profit. Sustainable sugarcane farming significantly depends on the conservation of agricultural soil (Gowing & Palmer, 2007; Hobbs et al., 2008). Therefore, the conservation of natural resources is a basis for the long-term sustainability of agricultural and natural eco-systems. Sustainable agriculture aims at overcoming the problems of current farming practices through the introduction of resource-saving, profitable, stress-tolerant, eco-friendly, and climate-smart production techniques.

Currently, sugarcane farming in Bangladesh requires high labour operations from the land preparation to harvesting, including the crop planting, weeding, fertilising, and pesticide applications. Hence, the low level of mechanisation, as well as the increasing cost of agricultural labour, is among the main problems associated with sugarcane farming in the country. Additionally, various abiotic and biotic stresses, such as soil quality, salinity, flood, drought, pests, diseases, and weeds, are adverse factors that affect the production of sugarcane in Bangladesh. Previous studies have attributed sugarcane yield losses to 40% through weed competition (Islam et al., 2016), 20% by pests (Akhter et al., 2016), and 15% through red rot diseases (Rahman et al., 1999) in Bangladesh. Moreover, soil health has a significant effect on sugarcane productivity and cane yield (Haynes & Hamilton, 1999; Meyer & van Antwerpen, 2001). Despite having favourable land and agro-ecological environments, sugarcane yield per hectare in Bangladesh is low owing to poor management practices and low organic-matter content (1.5%) in the soil (Bokhtiar et al., 2015). Therefore, the most critical factors that affect sugarcane productivity in Bangladesh can be highlighted as follows: (i) competition with short-duration and high-value crops, such as cereals and other vegetable crops, (ii) allocation of less productive land for sugarcane, (iii) lack of suitable conservation tillage machinery, (iv) low yield owing to the insufficient use of fertilisers, (v) inadequate effort to control insects, diseases, and weeds, (vi) biotic and abiotic stresses owing to climate change, and (vii) lack of an adequate mechanism for technology transfer. Thus, detailed investigations on the systematic approach to sugarcane cultivation in Bangladesh should be conducted in terms of sustainable agriculture technologies. In this study, the prospects and challenges of sugarcane farming in Bangladesh, as well as some resource-saving management approaches for sustainable sugarcane farming, are discussed and evaluated considering the current scenario. This sustainable conservation approach ensures that the costs relevant to soil eco-system loss and cane productivity of sugarcane crop in Bangladesh are minimised.

2 Challenges of sugarcane farming in Bangladesh

High production cost, low yield of cane, and lack of resource-saving cultivation technique reduce the profit of sugarcane farming in Bangladesh. In addition, delayed or irregular payment for cane by the sugar mill authority complicates sugarcane farming in Bangladesh. The use of inefficient crushers in non-mill (less productive area) zones increases processing losses and reduces the profit of gur (jaggery) producers owing to a lack of adequate technology. As a result, farmers are becoming less interested in sugarcane cultivation. Labour-dependent sugarcane farming, shortage of suitable farm machines (planters, harvesters, and crushers), and the increasing cost of agricultural labour lead to higher cultivation cost. Less productive land use for sugarcane growth, improper management practices, water stress due to climate change, and inaccurate application of inputs (seeds, fertilisers, irrigation water, and pesticides) are the major challenges limiting higher sugarcane yield. According to Sumner (2011), the yield decline of sugarcane is not only faced by Bangladesh, but several countries worldwide, such as Australia, the USA, Barbados, and Colombia (Haynes & Hamilton, 1999), and South Africa (Meyer & van Antwerpen, 2001). Therefore, the limitations of present cultivation and management practices in highly productive areas should be identified. These drawbacks need to be addressed by improving the management practices for sustainable sugarcane production in Bangladesh.

According to the Australian Centre for International Agricultural Research (2015), using only high-yield varieties is not the solution to the yield decline problem in sugarcane farming. Moreover, unnecessary tillage operations in planting, residue management through burning, and incessant application of synthetic chemical fertilisers have caused soil degradation, reducing the sugarcane productivity and cane yield (Wood, 1985). In contrast, various tillage operations carried out in Bangladesh during land preparation for sugarcane plantation are depicted in Fig. 2. Unnecessary tillage is a traditional practice of sugarcane cultivation in Bangladesh, which does not match with an economical method of land preparation considering time, cost, and labour (Fig. 2a). Sugarcane farmers prepare their fields through four or five passes of power tiller and then dig trenches manually (Fig. 2a and b). The use of tractor-mounted tillage is limited to sugarcane fields due to the low capacity of the farmers as well as small and fragmented land sizes in Bangladesh. Hossain et al., (1996) and Rahman et al., (2009) estimated that tractor-mounted tillage implements are utilised in preparing approximately 10% of sugarcane fields in the mill zone (high productive) area. Three types of tractor-mounted tillage implements are used in sugarcane fields to excavate trenches for planting canes as follows: (i) one pass of disc plough, (ii) two to three passes of disc harrow, and (iii) finally, trenching using a trencher (Fig. 2c, d, and e). All these tillage practices involve significant soil disturbance and, thus, increase

Fig. 2 Various conservation machinery and tillage methods followed for land preparation of sugarcane fields in Bangladesh

production costs and reduce the profit that contradicts the concept of suitable conservation tillage methods.

Intercropping is the production method of planting an additional crop in the same field between the free spaces of two rows of the main crops. These conservation practices have been successfully used for many years in low-input cropping systems worldwide for enhancing land use and improving water and nutrient statuses. Recently, sugarcane farmers in Bangladesh have introduced a type of intercropping system that does not only give a midterm return to the farmers but also increases the total profit. The farmers successfully produce potato, onion, garlic, lentil, and cabbage in their sugarcane fields as profitable intercrops (Rahman et al., 2016). A few recommended profitable intercropping practices and their benefits have been reported by previous researchers (Table 2). Nevertheless, it is necessary to discover more suitable intercrops and intercropping methods for sugarcane farmers in Bangladesh. Intensive management of intercrops in sugarcane fields can increase cane yield and improves soil health. Even some progressive farmers have started to cultivate two intercrops on their sugarcane fields successfully. This intercropping practice should be disseminated to country farmers to reduce the challenges of sugarcane farming in Bangladesh by considering the extra profits from the same crop field and improvement in soil health.

3 Sustainable sugarcane farming

Sustainable agriculture is a holistic approach that covers both socio-economic and environmental objectives (Sullivan, 2003). Sustainable agriculture also fulfils the needs of future generations and conserves agricultural productivity (Altieri & Nicholls, 2005). The World Business Council for Sustainable Development (2008) declared that agricultural productivity should be sufficient for present demand, as well as conserve biodiversity and natural resources simultaneously, to improve human well-being. Figure 3a illustrates the sustainable sugarcane production system, which focuses on the profit and the environment through the conservation of natural resources. Figure 3b depicts that a farmer's profit does not only depend on cane price, but rather, the application of appropriate technologies could increase cane yield and decrease production cost. Both yield and production cost are directly related to cultivation and management practices, such as tillage, cropping patterns, intercultural operations, residue management practice, and technological applications. Agricultural production is also significantly dependent on climatic conditions, as cultivation and management practice should effectively absorb the impact of climate change. Moreover, all management components of sustainable farming focus on conserving natural agricultural resources at agro-ecosystem levels, such as soil, water, and agricultural environment (Fig. 3c). Meyer and van Antwerpen (2010) stated that soil eco-system plays a critical role in sugarcane yield. In addition, advanced tillage operation, residue management practice, and optimum amount applications of other farming (nutrient and water) inputs are essential in increasing soil organic carbon and enhancing sustainable crop production (Follett, 2001). Favourable quantity of soil moisture is also an essential requirement for improved stalk and sucrose yields (Alamilla-Magaña et al., 2016). However, the use of excessive water for irrigation increases production costs and creates pressure on water resources. Therefore, sustainable agriculture is beneficially impacted on crop cultivation conservation in global environments compared to traditional agriculture.

Table 2 Various intercropping research findings on sugarcane crop conducted in Bangladesh

Reference	Intercropping crops	Findings
Hossain et al., (2015)	First intercrop: Potato, onion, tomato, cauliflower, and carrot Second intercrop: Mungbean	Potato and onion increased the cane yield and were more suitable in paired row canes
Alam et al., (2015)	Soybean and mungbean sequential intercropping	Profitable and increased soil productivity
Islam et al., (2009)	First intercrop: Lentil, chickpea, linseed, pea, and groundnut Second intercrop: Mungbean	Improved soil health and organic matter
Kashem et al., (2007)	First Intercrop: Potato, spinach, radish, coriander, and carrot Second intercrop: Sunhemp	Highest economic benefit observed from potato-sunhemp intercropping
Rashid et al., (2000)	Green manuring using cowpea, dhaincha, and sunhemp	Improved soil fertility, increased cane yield, and increased profit over pure stand cane

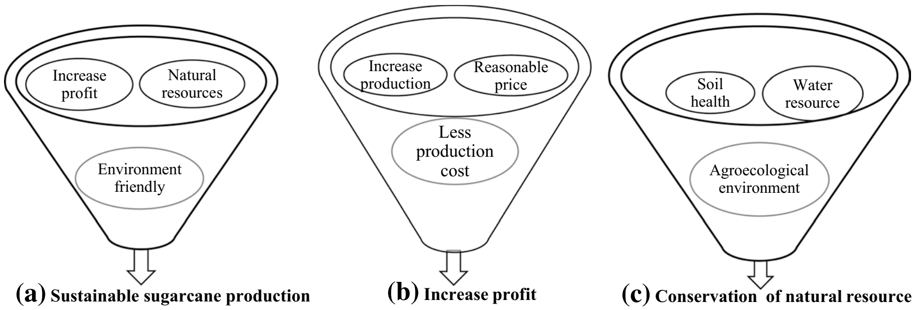

Fig. 3 Components of sustainable agriculture applying a profitable sugarcane cultivation system

4 Conservation agriculture approach

CA links with various components of farming practices, where soil and water resources are conserved at the agro-ecosystem level have long-term beneficial effects on crop agronomy and farm economy (Fig. 4). According to FAO (2014), CA is a natural resource-saving agro-ecological management approach that improves food security through enhancing productivity and increasing farmers' profits. Management components of CA contribute to improving the sustainability of agricultural productivity through biodiversity conservation and enhanced natural biological processes at the agro-ecosystem farming level, increased carbon sequestration, and climate change mitigation (Sanchez et al., 2019). Recent research (Jat et al., 2020) has reviewed the potential benefits of CA for achieving the Sustainable Development Goals (SDGs) in South Asia. CA combines a series of cultivation and management approaches for sustainable farming through the soil, water, and agronomic management practices, including minimum tillage, residue management, and crop rotation, as

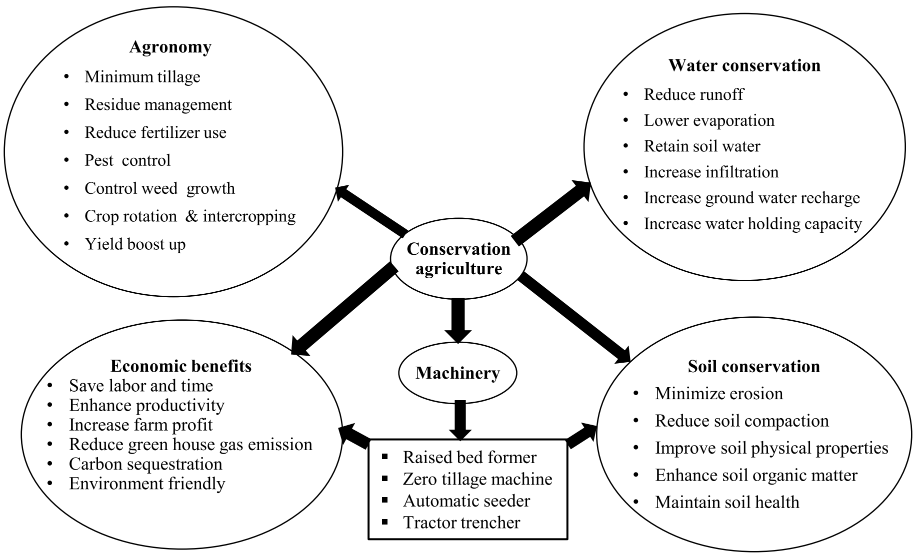

Fig. 4 Conceptual approaches and potential benefits of CA in sugarcane production at the eco-system level for achieving food security and sustainability

well as integrated fertiliser, weed, and pest management (Fig. 4) (Kabir & Rainis, 2014; Vanlauwe et al., 2014; Lal, 2015). From Fig. 4, it can be observed that land preparation with minimum soil disturbance using CA machinery in sugarcane farms will produce significant economic benefits to farmers by saving time and cost. The economic benefits of CA are also achieved by increasing production efficiency, improving soil health, and saving labour cost (Fig. 4). The agronomic management practice of CA may enhance soil productivity by improving soil physico-chemical properties through ameliorating soil organic matter content, water infiltration, soil nutrient status, and aggregate stability. In contrast, soil organic matter is the most vital component of soil that performs significant soil functions, including water-retaining capacity, soil aggregate stability, crop rooting environment, nutrient dynamics capacity, and fertiliser use efficiency. Furthermore, the environmental benefits of CA improve agricultural sustainability by improving soil and water quality and increasing soil biodiversity and organic carbon content.

Conservation tillage and residue management, the two main components of CA, are beneficial for sustainable sugarcane cultivation. These two components focus on stable yield, considering the agro-economic environment (de Beer et al., 1993; Wood, 1991). In addition, these CA components can increase Carbon sequestration in sugarcane fields (Segnini et al., 2013). Minimum tillage, legume break crops, and residue retention are CA components that have become popular in the Australian sugarcane farming system and are regarded as profitable and sustainable management practices (Garside et al., 2005; Stirling, 2008). Following this example, the introduction of minimum tillage machinery (including other CA-based agronomic management practices) can also be useful in achieving sustainable sugarcane farming in Bangladesh.

5 Importance of CA principles for sustainable sugarcane farming

Three main CA principles, i.e. minimum tillage, residue management, and cropping system, can contribute to increase sugarcane yield and promote sustainable sugarcane farming. These techniques have been considered and compared with current practices, which can be applied to improve the existing sugarcane farming system in Bangladesh.

5.1 Tillage

Traditional land preparation practices applied in sugarcane plantation involve vigorous soil disturbance, with eight to ten tillage operations (Braunack et al., 1999), which directly deteriorate the soil structure and soil aggregate stability. However, the benefits of excessive traditional tillage are short-term, and that the method is not cost-effective (Moberly, 1982), whereas minimum tillage causes less soil disturbance and is more economical (Arruda et al., 2016; Braunack et al., 2012; Moraes et al., 2017). Minimum tillage has several benefits in sugarcane farming, considering the economic and environmental aspects. The benefits of minimum tillage in sugarcane cultivation are conceptualised in Fig. 5, as follows: (i) reduce land preparation time that positively influences the yield through an early plantation, (ii) improve the physical properties of soil by enhancing the water-retention capacity and physical structure of soils, (iii) reduce land preparation cost by minimising the use of labour and fuel, (iv) reduce carbon dioxide emissions because of less burning of fuel, (v) maintain moderate greenhouse gas emission from the soil due to less disturbance of soil, (vi) reduce soil erosion due to less disturbance

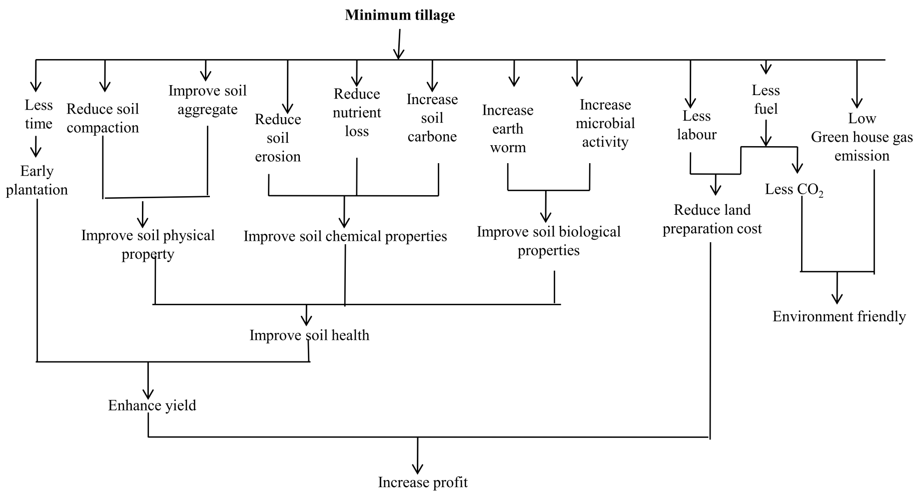

Fig. 5 Relationship diagram of different benefits of minimum tillage for enhancing soil environments

of soil, (vii) increase biological activities in the soil mass, and (viii) help to maintain higher organic matter content in the soil, thus, improving soil productivity. Hence, conservation tillage or minimum tillage is an established tillage method that has a significant impact on the properties of natural agricultural resources, such as soil moisture and soil health (Magdoff, 2007; Pretty, 2006). Minimum tillage technique saves 30–40% of water compared with traditional excessive tillage, and this can also save both time and labour cost (IFAD, 2005; FAO, 2006). In addition, the conservation or minimum tillage practice can maintain some agro-climatic environmental conditions, such as (i) optimal proportion of respiratory gas in the soil root zone, (ii) minimal oxidation of organic matter, (iii) hydraulic environment, and (iv) reduced weed growth through decreased germination of weed seeds (Kassam & Friedrich, 2009). Minimum tillage can also save fuel cost by up to 40% and reduce environmental pollution through 43% less emission of Carbon dioxide into the atmosphere in comparison with conventional tillage (Moberly, 1982); however, minimum tillage is a new and less popular concept in Bangladesh (Miah et al., 2010). Minimum tillage can help to increase soil organic matter and soil quality by enhancing soil aggregate stability (Arruda et al., 2015). In addition, minimum tillage increases the macroporosity of soils (Lana et al., 2017). Despite the several benefits of minimum tillage, few complexities occur during weed management and destruction of old crops for further cultivation. Minimum tillage promotes productive sugarcane farming by minimising soil erosion and boosting cane yield when the old crops are destroyed using herbicides (Iggo & Moberly, 1976). Moreover, the no-tillage practice in the sugarcane farming system increases the annual carbon retention rate by approximately 1.63 ton/ha/year (Segnini et al., 2013). Minimum tillage also increases the number of earthworms and reduces pathogenic nematodes living in sugarcane farm soils, which results in higher cane and sugar yields (Fig. 5) (Braunack et al., 2012). Therefore, minimum tillage might be better than the conventional tillage methods for sugarcane plantations, considering carbon accumulation, preservation of labile structures, low environmental impact on soils, and the economic benefits of sugarcane production. Although BSRI has developed a bed former cum trencher (Fig. 2f) for minimising the complications associated with deep tillage, the use of the equipment is limited only to BSRI experimental fields, and further evaluation is needed on a broader scale of farmers' levels.

5.2 Conservation tillage machinery

CA aims to optimise crop production through resource-saving cultivation and management practices. CA technology can reduce production costs and increase crop yields through the rational use of natural resources (Roy et al., 2009). Therefore, CA can be practised to directly contribute to sustainable agricultural production in Bangladesh (Poddar et al., 2017). However, farmers in the country have recently started practising CA. For sugarcane farming, the practice of CA is minimal, indicating that the challenges of CA technology for sugarcane farming in Bangladesh should be estimated in contrast with other crops.

Various research and extension organisations in Bangladesh use CA machinery for different crops, and this practice is now becoming popular among small-scale farmers and co-operative-based cultivators. Barma et al., (2014) highlighted the importance of CA technology for the sustainable production of various field crops, such as rice, wheat, maize, oilseeds, and pulses, in Bangladesh. CA-based tillage technology was introduced in Bangladesh by International Maize and Wheat Improvement Center (CIMMYT) during the late 1990s for timely sowing of wheat using a two-wheel tractor (2-WT) operated seeder (Amin et al., 2002; Roy et al., 2004).

Later in 2007, a 2-WT operated no-till seeder was developed for planting different types of seeds through an Australian Centre for International Agricultural Research (ACIAR) funded project (Hossain et al., 2009). Bell et al., (2018) mentioned that a 2-WT mounted CA planter is useful for sowing seeds on small-size fields in Bangladesh. Four-wheel tractors (4-WT) are not suitable in Bangladesh because of the fragmented, small, and scattered sizes of farms (Roy & Singh, 2008; Sarkar et al., 2012). Hence, a 2-WT mounted versatile multi-crop planter (VMP) was fabricated for sowing a wide range of seeds, including cereals and pulse seed, on small farms with minimal disturbance of soil to adapt to diverse cropping and multiple planting systems (single shallow tillage, strip furrow tillage, conventional tillage, and raised-bed planting) (Haque et al., 2011). However, Hossain et al., (2015) reported that different CA tillage practices, such as raised bed planting and minimum tillage, are becoming popular to farmers in Bangladesh considering their benefits, including higher yields, less tillage operation costs, and requires minimum turning around the farmlands. Moreover, local agricultural machine manufacturers have begun to successfully fabricate different CA machines, such as minimum tillage seeder, raise bed planter, zero till drill machine, and strip-till drills in their local workshops. Farmers in Bangladesh have also started benefitting from using locally made machines. However, these CA machines are not practical for sugarcane plantation because sugarcane setts (the planting material of sugarcane) are planted in trenches, and its seed-sowing method is different from those of other crops. Therefore, minimum tillage trenchers and planters should be developed in Bangladesh to achieve minimal disturbance of soil and to reduce plantation costs associated with sugarcane land preparation.

5.3 Residue management

Sugarcane trash (residual straw) consists of green top and dry leaves, which are high-energy sources in relation to fossil fuels and moderate greenhouse gas emissions. In addition, sugarcane straw is an on-farm by-product that can be used as a valuable resource for soil conservation (Cantarella et al., 2013). Trash or residue management is a crucial component of CA that plays a vital role in balancing the eco-system through the conservation of soil and water resources, and this conservation contributes to sustainable sugarcane farming. During the harvesting of canes, sugarcane straw contains approximately 54% dry leaves and 46% tops and about 10–70% moisture content (Franco et al., 2013). Depending on the cane variety and management practices, the total dry weight of the trash varies from 8 to 20 ton/ha (Landell et al., 2013; Leal et al., 2013; Menandro et al., 2017), and the trash yield in Bangladesh is approximately 15 ton/ha. Annual decomposition rates of sugarcane trash in soil vary from 60 to 98% (Fortes et al., 2012; Oliveira et al., 2002), and the decomposed trash can be an essential on-farm source of organic fertiliser and micronutrients (Singh & Soleman, 1995; Trivelin et al., 2013). Thus, sugarcane trash mulch in fields can enhance the productivity of sugarcane through improving the chemical properties of soil in terms of soil organic matter content and nutrients. Moreover, sugarcane trash blanketing is a cultural practice applied to protect crops against annual weeds and reduce the herbicide rates in the field. However, trash can attract leaf feeders, such as Mythinma spp. and Spodoptera spp., which cause damages to sugarcanes. On the contrary, debates still prevail about the quantity of straw removal that can sustainably maintain eco-system services because multiple variables, including crop management practices, soil properties, and climatic conditions, influence the results. Sugarcane trash (residue) is mostly useful for producing biofuel, livestock feeds, and other bio-products, especially under rainfed conditions, when farmers face a scarcity of residues. There is a competition of CA practice and animal feeding for residue management, which is a significant problem in the dissemination of CA in dryland environments.

Farmers in Bangladesh and India do not prefer using crop residues as an organic mulch in crop fields; instead, they prefer to use animal feed and fuel (Mohanty et al., 2007). The residual part of the straw that is left in the field is usually burnt for further cultivation activities (Fig. 6a). Suma and Savitha (2015) reported that farmers burn by-products in sugarcane fields as an essential practice of ratoon management. Although sugarcane trash has some economic values for different purposes, such as bio-fuels for production of heat, energy, and electricity, some portions of the trashes should be left in the field to enhance various natural resources, including preserving soil–water, improves soil fertility, and prevents soil erosion (Fig. 6b and 6c). Recently, few sugarcane farmers in Bangladesh have become aware of the benefits of trash mulch in improving soil health and weed management (Hasan et al., 2013). Trash mulching is not only advantageous in improving the soil chemical properties but could enhance the hydraulic and physical properties of the soil for cultivating sugarcane. Mulching is a vital soil conservation approach practised in arid and semi-arid regions and may conserve water in agricultural farmlands (Kader et al., 2019).

(a) Trash burning at field **(b)** Trash mulching on field **(c)** Trash mulching on field

Fig. 6 Pictorial view of different residue management scenarios in a sugarcane field in Bangladesh

Mulch covering protects the soil from both water and wind erosion, increases water infiltration into the soil, retains soil moisture, controls soil temperature, and improves soil structures (Kader et al., 2017). Mulching also provides support for earthworms and improves soil biodiversity and carbon sequestration (Ghosh et al., 2010; Kader et al., 2017). Residue retention or mulching in sugarcane cultivation can protect the soil surface from the negative impacts of direct raindrops and sunlight (Busari et al., 2015; Kader et al., 2017).

Trash mulch in sugarcane fields has several benefits (Table 3), including weed control (Hasan et al., 2013; Hoshino et al., 2017), nutrient availability, and higher yield (Ball-Coelho et al., 1993). Organic mulch supplies different types of micro- and macronutrients to the soil through its decomposition and thus facilitates sugarcane farming. Sugarcane trash is a vital source of organic carbon and plant nutrients that decomposes in the soil and used for producing organic manure and vermicompost. The integrated trash management provides sustainable soil health in sugarcane field through microbial enrichment (Suma & Savitha, 2015) and suppresses weed growth by shading the trash cover (Bajwa, 2014). In addition, the burning of trash in sugarcane fields is considered as a pest management practice. However, limited research findings on sugarcane trash (residue) management in the agro-climatic condition of Bangladesh have been reported, and further studies are required to achieve maximum benefits. Trivelin et al., (2013) found out that straw mulching on sugarcane fields increases the nitrogen stock of the soil in sugarcane farms and, consequently, reduces the need for synthetic nitrogen fertilisers. They also observed that sugarcane straw mulch could supply a considerable amount of potassium, which significantly minimises synthetic potassium fertiliser requirements for cane cultivation. Straw mulching in sugarcane farming is an effective method of nutrient recycling that could reduce the demand for synthetic fertiliser application and enhance the profitability and eco-friendliness of sugarcane farming. Improvement in the soil properties (chemical and biological) due to straw mulch not only depends on the straw quantity but also depends on soil type, environmental condition, and crop management practice (Carvalho et al., 2017). Straw mulching in sugarcane farms increases the soil carbon, soil microbial activity, and nematode population in the soil and hence improves soil health (Castioni et al., 2018; Stirling et al., 2011). Consequently, cane production is directly or indirectly dependent on the changes in soil quality (Bordonal et al., 2018; de Aquino et al., 2018; Lisboa et al., 2018). In contrast, applying sugarcane trash for mulching is beneficial for ratoon management, which could increase the ratoon cane yield by up to 20% (Hasan et al., 2013). Excessive removal of trash from the field has adverse effects on sugarcane-made products (Anjos et al., 2017; Resende et al., 2006) and, therefore, negatively impacts on sustainable sugarcane production (Christoffoleti et al., 2007; Sousa et al., 2012). Moreover, the burning of sugarcane trash not only creates environmental pollution through the generation of smoke but also deteriorates the soil health by the destruction of organic matter and valuable nutrients that are present in the trash (Mitchell et al., 2000). Despite the several advantages of straw mulch on the agro-ecological system of sugarcane production, improper management may cause a few disadvantages (Table 3). Improper straw management as 100% straw mulch cover over sugarcane field soil reduces plant tillering and the final plant population, affecting the final yield of sugarcane (Campos et al., 2008). Although some studies have shown that straw removal from sugarcane fields enhances plant tillering, straw removal has no effect on the final product in terms of plant population, cane quality, and cane yield (Lisboa et al., 2018). Moreover, other researchers (Ball-Coelho et al., 1993; de Aquino et al., 2017; Tavares et al., 2010) have demonstrated that straw retention on the soil of sugarcane farms under tropical conditions does not affect plant tillering significantly. Deviations in the findings of these studies may have occurred owing to genetic variations of cane variety,

Table 3 Effects of sugarcane straw mulching on soil ecosystem and agronomy of crop cultivation

Component	Effect of mulching focuses	References
Soil	Restrict soil erosion	Johnson et al., (2016); Valim et al., (2016)
	Increases water infiltration and water storage	de Aquino et al., (2017); Cherubin et al., (2018)
	Reduces fluctuations of soil temperature	Christoffoleti et al., (2007); Corrêa et al., (2017)
	Increases soil organic matter content and cation exchange capacity	Thompson (1966)
	Enhances carbon accumulation into soil	Cerri et al., (2011); Thorburn et al., (2012); Sousa Junior et al., (2018)
Weed	Controls weed growths of sugarcane field	Sparkes and Charleston (2003)
	Provides favourable microclimate for some weed species	Guimarães et al., (2008)
Pest	Pest infestation	Dinardo-Miranda and Fracasso (2013)
Yield	Positive contribution to sugarcane yields	Tavares et al., (2010); Oliveira et al., (2016); Carvalho et al., (2019)
	Reduces sugarcane tillering	Nxumalo et al., (2017)
	Straw removal did not affect the quality of the sugarcane stalk	Resende et al., (2006); de Aquino et al., (2016)
Environment	Reduces greenhouse gas emissions	Carmo et al., (2013)
	Reduce carbon dioxide emissions	Corradi et al., (2013); Teixeira et al., (2013)

differences in agro-climatic regions, and various crop management practices. Therefore, site-specific residue management practices, depending on the agro-ecological conditions of Bangladesh, should be developed for sustainable sugarcane production.

5.4 Cropping system

Sugarcane is a perennial crop, and for its profitability of ratooning, monoculture is the most common cropping practice for sugarcane farming worldwide (Dominy et al., 2001). However, long-term monocropping has several adverse effects on the productivity of sugarcane farmlands (Shoko et al., 2007) in terms of nutrient status of soil, such as phosphorus, potassium, exchangeable cations, pH, and organic matter content (Meyer & van Antwerpen, 2001). Furthermore, monoculture practice also reduces sugarcane production by increasing pest attack and disease infestation (Kamruzzaman & Hasanuzzaman, 2008), weeds, and parasitic nematodes (Rashid et al., 2006; Sparkes & Charleston, 2003). Thus, monocropping makes sugarcane farming to be more dependent on the application of chemical fertilisers, pesticides, and herbicides, which directly increase sugarcane production cost and worsen environmental degradation. In contrast, crop rotation practice in the sugarcane farming system contributes to sustained economic and stable sugarcane production vital for sustainable sugarcane production (Garside, 2003). Monocropping, therefore, should be avoided to promote favourable agro-ecology and to enhance sugarcane cultivation productivity. Legume intercropping, fallow, pasture fallow, green manuring, and cultivation of other crops in rotation with sugarcane are some cropping systems typically practised in sugarcane farming in Bangladesh to break the monoculture (Fig. 7). Intercropping is commonly practised in several sugarcane-producing countries, such as China (Solanki et al., 2017), India (Singh et al., 2018), Pakistan (Bajwa, 2014), Sri Lanka (Witharama et al., 2000), and Nepal (Pandey & Devkota, 2020). Potato, onion, tomato, garlic, chickpea, lentil, and mustard are profitable intercrops for sugarcane farmers in Bangladesh (Rahman et al., 2016) because it provides a mid-term income from sugarcane fields without affecting sugarcane production negatively. Legume intercropping practice reduces the cynodon dactylon (scutch grass) weed population (Campbell et al., 2019), improves soil fertility, and consequently increases cane yield. Bare fallow or pasture break and other crop breaks

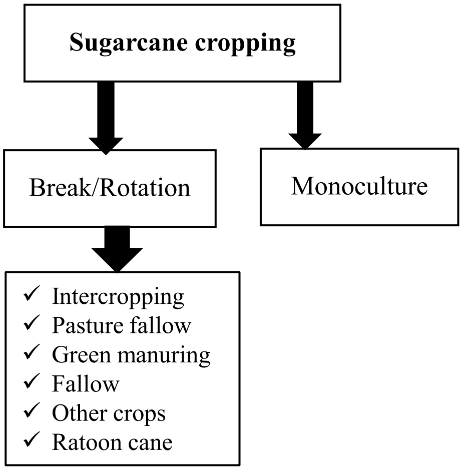

Fig. 7 Various cropping patterns practised in sugarcane farming in Bangladesh

are effective cropping practices to break the monoculture of sugarcane farming, improving the soil health and increasing the productivity of sugarcane farmland significantly (Bell et al., 2000; Kamruzzaman & Hasanuzzaman, 2008; Rashid et al., 2006). Green manuring in sugarcane fields increases soil organic matter content and improves the nutrient status of soil, leading to stable production on sugarcane farms. Green manuring (3.6–4.0 ton/ha) can reduce the adverse impacts of monoculture and yield decline syndrome of sugarcane farms (Rashid et al., 2000), and can also influence nematode dynamics (Berry & Wiseman, 2003; Pankhurst et al., 1999), which are essential for sustainable sugarcane farming. Crop rotation has several beneficial effects on sugarcane field; for example, legume crop rotation improves soil health, suppresses soil pathogens (Biederbeck et al., 2005; Rhodes et al., 1982), and reduces the cost of nitrogen fertiliser application through biological nitrogen fixation in the soil (Garside et al., 2005; Park et al., 2010). Legume-grass intercropping in sugarcane fields can decrease the adverse influence of monocropping through enhancing soil productivity by increasing the quantity of microbial biomass in the soil (Chai et al., 2005; Zhao et al., 2015). Didier et al., (2018) explained that in terms of cane production, sugarcane cultivation in rotation with legume fallows is better than the conventional monocropping system of sugarcane cultivation and the natural fallow technique using nitrogen fertilisers. Alam et al., (2014) also reported that onion seed crop-mungbean sequential intercropping with sugarcane is profitable and beneficial for maintaining soil health. The intercropping of sugarcane with potato and pulse may generate extra income for small-scale sugarcane farmers in Bangladesh. Sugarcane cultivation is highly profitable when potato and mungbean are used as successive intercrops in Bangladesh without any loss in cane quality (Islam & Islam, 2018). In addition, the mungbean is recommended as the second intercrop for sugarcane farming in Bangladesh because it improves the adjusted cane yield (up to 350 ton/ha) more than the sole cane yield (90 ton/ha) (Hossain et al., 2016; Islam et al., 2013). Therefore, legume intercropping with sugarcane can increase farmland productivity and farmers' net income, as well as reduce the demerits of monocropping, which could promote sustainable sugarcane production in Bangladesh.

5.5 Crop rotation

Depending on climatic locations, appropriate crop rotation is essential to enhance soil biological properties and increase soil nutrient. Crop rotation can be considered to overcome the stress of pest in CA-based sugarcane farming. However, few farmers in Bangladesh apply residue mulch and crop rotation, but most farmers are reluctant to use crop residue as mulch because crop residue has alternative applications as fodder and domestic fuel. Even farmers are unaware of the importance of crop rotation and usually depend on rice-based cropping systems due to short-duration and staple crop. Moreover, a lack of knowledge about the importance of CA among farmers and policymakers is responsible for its less extension. Although several experiments performed in the Indo-Gangetic plains (IGP) on rice-based cropping systems demonstrate the benefits of CA in terms of increased yield, productivity, economic return, and natural resource efficiency (Alam et al., 2015; Gathala et al., 2013, 2015; Kumar & Ladha, 2011; Laik et al., 2014), findings are unavailable for sugarcane. In this regard, BSRI recommended three sugarcane-based cropping sequences in Bangladesh, as follows: (a) other crop (jute/rice/pulse)—sugarcane—ratoon cane, (b) other crop (rice/jute/pulse)—sugarcane with intercrop (potato/lentil/vegetable)—ratoon cane, and (c) other crop (rice/jute/pulse)—fallow/green manure—sugarcane (BSRI, 2019).

Therefore, future studies on sugarcane cultivation in Bangladesh need to be focused on different and more specific crop rotation practices.

6 Effect of CA on stress management

Crop stress management is a crucial component of CA, which requires further attention. Moreover, the management of natural biotic stressors, such as weed, pest, and diseases, has significant impacts on the sugarcane yield. Weeds reduce cane productivity in many sugarcane producing countries, including Bangladesh (Islam et al., 2016), while conservation tillage can accelerate the growth of weeds, mainly perennial weeds. Weed also provides habitats for insects and disease-causing pests, which can decrease the crop quality, and consequently, decrease the risk of crop failure (Bajwa, 2014). For example, minimum tillage enhances weed infestation, while weed is the major constituent of the sugarcane field in Bangladesh at the early growing stage. Manual weeding is typically practised for sugarcane farming in the country, but it is becoming less profitable owing to the increasing cost of farm labour (Rahman et al., 2016). In addition, mechanical weed control though power tiller and tractor have not been widely accepted by farmers owing to insufficient mechanisation technology, which could result in the reduction of labour cost and proper utilisation of fertiliser and herbicides application during the sugarcane cultivation season. In contrast, Islam et al., (2016) found that the chemical control of weed is more efficient and profitable than the mechanical control of weed in Bangladesh. However, legume intercropping is also a popular method of weed control in sugarcane farming that protects the weed growth by up to 60% during the initial stage and helps in the optimum utilisation of land (Balasaheb, 2013). Furthermore, sugarcane trash mulch has both positive and negative impacts on the biotic stressor in terms of weed management and pest control. For example, trash mulch is an economical technique of weed control in sugarcane cultivation (Carvalho et al., 2017). The burning of trash can increase the weed population in sugarcane fields while using 75% trash as mulching is useful to control weed infestation (Hoshino et al., 2017). However, trash mulch on soil surface may sometimes attract harmful pests, as spittlebug (Mahanarva fimbriolata), sugarcane borer (Diatraea saccharalis), and sphenophorus (Sphenophorus levis), which significantly reduces the cane yield (Ravaneli et al., 2011). Therefore, the integration of intercropping, trash management, and crop diversifications might be a pragmatic approach to weed control in CA.

In the integrated pest management approach, combinations of several (mechanical, chemical, and biological) methods and adoption of new varieties can control pest in the sugarcane field. Akhter et al., (2016) reported that intercropping through the use of repellent crops can be a practical management approach for controlling pests in sugarcane fields. Sugarcane farmers in Bangladesh are unaware and sometimes also neglect the government recommendations on seed treatment, fertilisers, and disease and pest management. BSRI has released numerous biotic stress-resistant sugarcane varieties as well as advanced disease and pest management techniques (Rahman et al., 2016; Uddin et al., 2013) that could resist biotic stresses. Moreover, the climatic weather of Bangladesh fluctuates significantly, with rainfall and high air temperature, which sometimes occurs as water shortage (drought), flood, and water-logging. BSRI has developed several sugarcane varieties that are tolerant to drought (Isd 20, 23), waterlogging (Isd 34, BSRI Akh 43), salinity (Isd 39, 40), and flood (Isd 39, 40) (Rahman et al., 2016; Uddin et al., 2013). Therefore, an integrated weed, disease and pest management approach is required in CA practice to address the problems of biotic stressors for achieving the maximum benefits from sugarcane crops.

7 Fertiliser and nutrient management

Fertiliser and nutrient management can be considered as vital components of CA (Dordas, 2015). The success of CA significantly depends on the adequate management of fertilisers and nutrients because they maintain nutrient levels in soils. Additionally, sugarcane is an exhaustive crop that consumes a large amount of nutrient and organic carbon from the soil. Most of the arable soils in Bangladesh contain low organic matter below 1.5%, while 2.5–3.0% organic matter is essential for productive soils (Rijpma & Jahiruddin, 2004). Thus, a sufficient quantity of essential nutrients can be fulfilled by using organic manure for the sugarcane crop. In addition, the appropriate use of organic and chemical fertilisers in sugarcane crop is a significant challenge to farmers in Bangladesh. Farmers in developing countries, such as Bangladesh, have practised the unsustainable use of fertilisers in the farmland owing to the lack of training in continuous innovations (Rahman & Zhang, 2018). Moreover, sugarcane farmers of Bangladesh are reluctant to use organic fertilisers and instead, use less-chemical fertilisers than the BSRI recommended dose because of the higher cost of fertilisers, lack of availability, and the financial conditions of farmers, which are critical constraints for maintaining the recommended fertiliser dose in sugarcane fields (Karim et al., 2016). Therefore, this leads to continuous depletion of soil nutrients present in the soil. Moreover, owing to the substantial depletion of soil nutrients, sugarcane soils become less fertile and fail to produce higher yields. Shukla et al., (2013) also suggested the improvement of cultural and nutrient management practices to conserve the soil health of sugarcane farms, as sugarcane removes substantial quantities of nutrients from the soil. Therefore, the nutrient replenishment through the use of organic manures and chemical fertilisers in the soil is indispensable for achieving higher cane yields (Bokhtiar & Sakurai, 2005). It requires intense attention for fertiliser management in a sugarcane farm to ensure a sustainable production through the successful adoption of CA.

8 Economic impact of CA on sugarcane crop cultivation

Various principles of CA have direct effects on farm economics. Minimum tillage machine minimises the energy requirements for land preparation and reduces the number of tillage operations from two or more to only one. Thus, the application of these principles reduces the cost of land preparation and minimises expenditure on fuel, labour, repair, maintenance, and machines. Minimum tillage also reduces the time used for land preparation, which enhances crop yield by facilitating early planting dates. Hence, minimum tillage is a natural resource-saving and profitable crop establishment option. As conventional sugarcane plantation involves vigorous tillage with trench preparation, the introduction of CA planters for sugarcane cultivation can significantly reduce the cultivation cost. Malik et al., (2005) found that the application of conservation tillage technology is profitable to both small- and medium-scale farmers. However, weed infestation may become worse owing to minimum tillage, which could lead to low cane yield. Thus, the weed control of CA-based sugarcane crop requires special research attention. Sorrenson and Montoya (1989) stated that conservation tillage combined with residue retention could increase farm profit by reducing the cost of production and increase crop production through soil productivity conservation. Residue mulch can also reduce the cost of irrigation and synthetic fertilisers through soil moisture conservation and nutrient status enhancement. Intercrop can increase the income of sugarcane farmers. Additionally, CA is an agro-ecological approach that is applied to increase yield, improve soil health, and maintain sustainable production. Therefore, CA can help to increase the profit of sugarcane farmers by reducing production costs and increasing returns. However, the economic benefits of CA on sugarcane farming outweigh its negative impacts, which indicate that sugarcane farmers can economically benefit if they adopt CA principles properly. Lalani et al., (2017) also mentioned that CA is economically valuable for different crop mixes and beneficial to farmers at different levels, including poor farmers.

9 Major constraints of CA in Bangladesh and future research

Minimum tillage planters should be developed in Bangladesh for planting sugarcane, which will minimise soil disturbance with lower cost and improved time involvement, considering the general socio-economic conditions of farmers. Researchers need to develop new tillage machines by considering small farm sizes and cost affordability. In developing countries like Bangladesh, where there appears to be a shortage of ideas about the potential benefits of CA to stakeholders (e.g. agriculture extension workers and farmers), this creates problems in CA practices, including land preparation and soil and water management. Hence, these problems need to be solved by the skilled workforce. Additionally, the performance analysis of newly developed CA machines by BSRI is required, and the field-level economic evaluation of CA technology is essential for farmers. Minimum tillage and trash mulch, two principal components of CA, are new methods sugarcane farmers in Bangladesh need to practice. Because of the possibility of facing challenges in applying these technologies, sugarcane farmers need to be educated by skilled professionals. The nutrient and water dynamics through the straw residues soils are still unclear due to the complex physical, chemical, and biological processes involved. Moreover, Bangladeshi farmers' perceptions of CA need to be analysed to understand their actual needs at the field level. Long-term agronomic assessments of sugarcane crops need to be further investigated. In addition, long-term research and extension scope of CA practices, including minimum tillage and crop residues, should be improved to achieve sustainable sugarcane farming in Bangladesh. A comprehensive study is required to estimate the long-term effects of minimum tillage and crop residue on soil physical, and chemical properties, and soil environment, especially in terms of greenhouse gas emission. Furthermore, the extension services department and researchers should develop a collaborative programme to establish CA technology for the sustainable production of sugarcane in Bangladesh.

10 Conclusions

Conservation agriculture is a promising sector in Bangladesh that can be applied to achieve sustainable sugarcane farming through conserving soil health, increasing water restoration, utilising tillage machinery, and enhancing farm profitability. The prospects of various soil–water conservation techniques, mainly, minimum tillage, residual management, and crop rotation, and their effects on sugarcane cultivation were evaluated in this study.

Furthermore, the key challenges, economic implications, and future research directions of CA in sugarcane farming were discussed that might help in increasing agricultural productivity in Bangladesh. However, unnecessary tillage, removal of residue, and long-term sugarcane cultivations in the same field degrade soil quality reduce cane yield, and, consequently, lower farmers' profit. All these techniques should be addressed by applying suitable CA technology to increase sugarcane crop yield. The use of few conservation tillage machines is becoming popular among farmers in Bangladesh for cereals, pulse, and other crops, but capable minimum tillage machines for sugarcane growers have not been introduced yet. We suggest that conservation machines should be utilised in sugarcane plantations, intercultural operations, weeding, and harvesting, which could save time and reduce labour cost. The retention of cane residue in farms may also increase crop yield and financial profit. Intercropping with sugarcane can improve soil productivity and the net income of farmers in Bangladesh. By considering the benefit of CA principles, both research and extension works need to be intensified to achieve sustainable sugarcane production in Bangladesh.

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Declarations

Conflict of interest Authors declare that there is no conflict of interest.

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