Conservation Agriculture for Enhancing Productivity, Resource Use Efficiency & Environmental Quality of Sugarcane Cropping System

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FOREWORD

Agriculture remains vital for India's diversified economic growth, development and livelihood of her people. However, over exploitation of natural resources, decline in productivity, low resource use efficiency and loss of biodiversity are the major concerns, which are challenging the sustainability of Indian agriculture. Additionally, land degradation and crop residue burning in conventional agriculture has severe environmental impacts. To overcome these agrarian challenges, the role of conservation agriculture (CA) is well recognized worldwide. In India, persistent efforts towards promotion of CA technologies have resulted in progressive adoption of zero-till drill particularly in irrigated rice-wheat system of the Indo-Gangetic plains. This sets a bench mark for extension of CA technologies to other cropping systems where it is possible to apply three basic principles: minimum soil disturbance, soil cover and crop rotation.

Sugarcane is one of the major industrial crops playing significant role in the economy of many of the countries including India, which contributes about 25% of world sugarcane production. However, continuous low and stagnant productivity of sugarcane is major concern for country's sugar economy. Excessive tillage, abiotic stresses (water logging, drought and salinity), trash burning and mono cropping are identified as crucial factors that increases production cost to both the farmer and environment. Hence research on adaptation of CA technology is on top priority for improving resource use efficiency in existing sugarcane cropping system. The present bulletin is part of larger effort to develop and promote CA technologies in India under research project "Consortia Research Platform on Conservation Agriculture" funded by ICAR, New Delhi. It aims to provide technical overview and compilation of outcomes of CA research conducted during 2015-2020 at ICAR-NIASM in sugarcane cropping system. It is designed to explain the scope of CA in sugarcane, experimental approaches and interaction effects of minimum tillage, planting geometry, micro-irrigation and residue management practices for improving cane yields, soil health and water productivity. The bulletin also presents the tangible and non-tangible benefits and agronomic recommendation originated from the long-term CA studies. Further, it highlights the demonstrated benefits of multipurpose machine developed under project, particularly with respect to nutrients and water use efficiency and higher productivity in an environmentally sustainable approach. This bulletin is expected to serve as a reference guide for the policy makers, researchers, sugarcane growers and industrialists, private entrepreneurs and consultants associated with sugarcane economy of the country.

I sincerely acknowledge the contributions of the Consortia Leader, CRPCA, IISS, Bhopal and the project team. I highly appreciate the efforts made by ICAR-NIASM team in preparation of this bulletin. Acknowledgements are due to Indian Council of Agricultural Research, New Delhi for providing all support and guidance.

(H Pathak)

PREFACE

Agriculture in India plays a central role in its economy and employs almost half of its population besides meeting the food demands of ever increasing population. The Green Revolution remains the most defining phase of Indian agriculture in the last century. While the input-intensive and technology-focused approach helped India avert potential famines and meet its food security needs by reducing cereal imports, its long-term impacts are now visibly evident in terms of degrading top soil, declining groundwater levels, contaminating water bodies, increasing emissions of greenhouse gases, and reducing biodiversity. In the face of increasing extreme climate events such as acute and frequent droughts, floods, extreme temperature-there is a need to investigate and invest in alternative sustainable agricultural methods and approaches such as conservation agriculture.

Conservation agriculture, based on three basic principles: a) minimal/no soil disturbance, b) crop diversification, and c) residue retention can be tailored to local and agro-climatic conditions which can generate economic benefits for local communities, use resources more effectively, and focus on improving soil health and nutrition simultaneously while contributing to the country's climate targets and goals.

This bulletin provides a technical overview of the research work carried under Agri-Consortia Research Platform on Conservation Agriculture (CRPCA) in sugarcane cropping system during 2015-2020. Here, sugarcane productivity under different proponents of conservation agriculture i.e. tillage, residue management coupled with planting geometry, irrigation, and nutrient management practices are discussed. Besides, economic analysis of tangible and non-tangible benefits, agronomic recommendations along with engineering based technologies developed specifically for sugarcane residue management are reported. The bulletin also includes highlights of capacity building programmes, relevant publications made and future research area under the research consortium.

We sincerely acknowledge the invaluable guidance and contribution of Dr. P.S. Minhas and Dr. N.P. Singh, Former Directors, ICAR-NIASM for initiating and facilitating research on CA in sugarcane. We sincerely thank scientists; technical staff and farmers associated with the programme and those who extended their supports while conducting research work. Acknowledgements are also due to NRM Division of Indian Council of Agricultural Research, New Delhi for their continuous support and encouragement.

We hope that the information contained in this bulletin will be useful for the researchers, farmers, students and other stakeholders.

Authors

1. Introduction

Conventional resource-intensive practices often cause soil degradation, water scarcity, low profitability and higher greenhouse gas (GHG) emissions thereby unable to the meet demand of sustainable food production for burgeoning population (FAO 2017). This challenge can be effectively addressed by identifying, encouraging and realizing widespread and durable adoption of technologies for sustainable agricultural intensification. Conservation agriculture (CA) is one such approach that helps to improve sustainable agricultural productivity, revenue generation and food security. The Food and Agriculture Organization (FAO) of the United Nations defines CA, as a concept for resource-saving agricultural crop production that aims to achieve profits together with yields and conserve environment. It enhances biological processes (above and below ground); reduce tillage; optimizes use of external inputs (agro-chemicals) to avoid biological disruption (Kumar et al. 2019). Thus CA is considered as an ecosystem approach to agricultural land management based on following three principles and interlinked with each other as given in Fig. 1. These principles are universally applicable to all agricultural land and are incorporated with locally formulated and adapted practices.

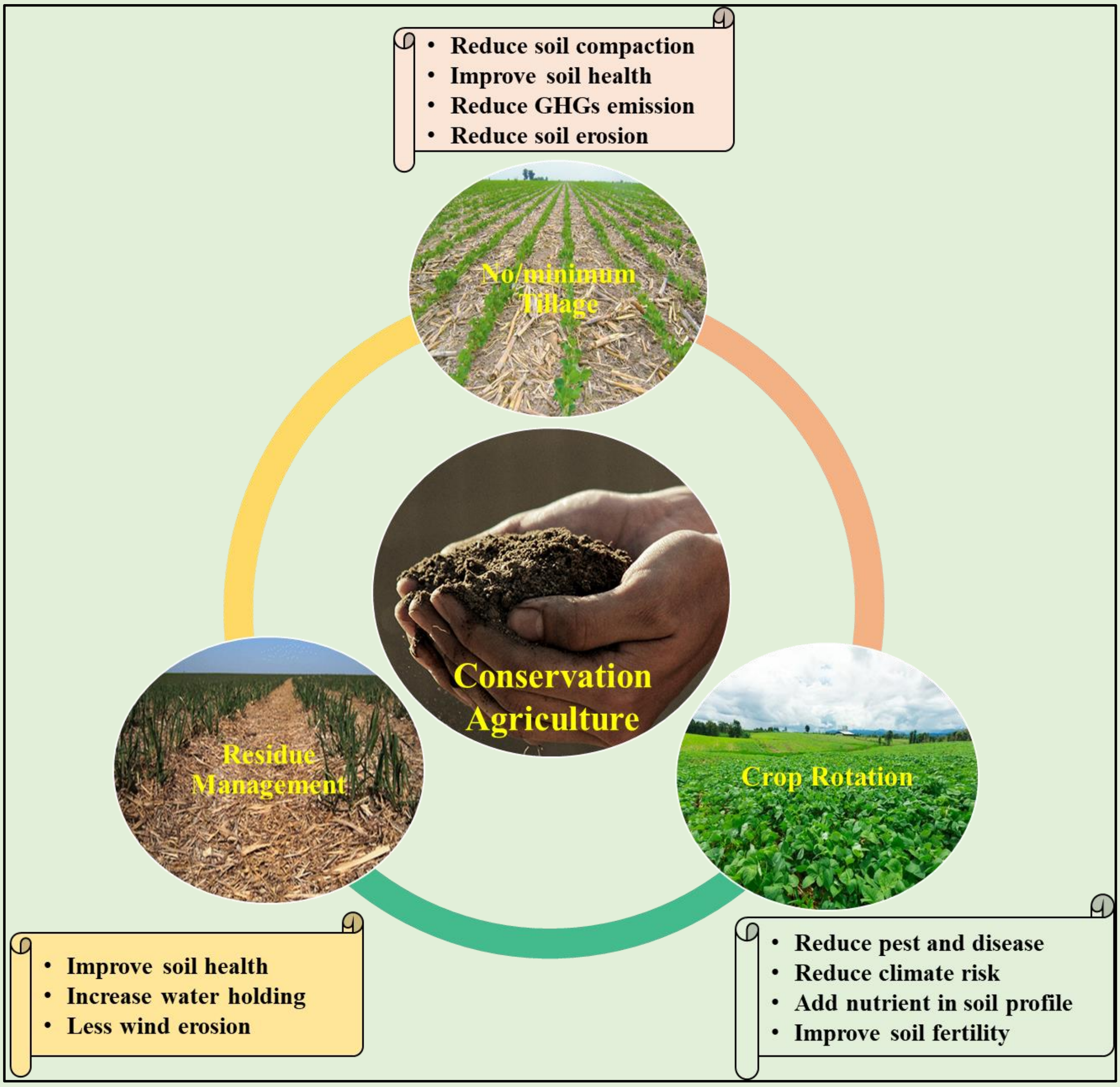


Fig. 1. Basic principles of conservation agriculture.

i. **Minimum soil disturbance through no-tillage or reduced tillage**: Though zero till is ideal, CA can involve controlled tillage where no more than 20-25% of the soil is disturbed.

ii. **Permanent maintenance of soil mulch by retaining crop residues or cover crops on the field:** Over 30% permanent organic soil cover as the minimum is maintained as per CA definitions.

iii. **Diversification of cropping systems through proper crop rotation:** Crop rotation and intercropping are applied to diversify cropping systems with legumes recommended.

Worldwide, CA has been adopted on about 117 million ha or about 8% of the total world crop land (FAO 2017). The maximum adoption are found in South America, North America, and Australia and minimum adoption has been noted in Africa, Central Asia and Europe, but now it is growing to a significant extent (Fig. 2). In India, adoption of CA is increasing, but only slowly, with residue management being a primary concern. The major CA based technologies being adopted is zero tillage in rice-wheat cropping system of the Indo-Gangetic plains (Bhan and Behera 2014). However, it is observed that farmers in those areas do not adhere to continuous no-till as mentioned in the principles, but practice no-tilling in *rabi* wheat season and tilling before sowing rice, thus practicing 'Partial Tillage' a term gaining popularity for estimating the adoption rates of the practice. In rest of the crop production systems, the conventional agriculture-based crop management practices are gradually undergoing a paradigm shift from intensive tillage to reduced tillage operations. In addition to zero tillage, other principles of CA also need to be integrated into the method to further enhance and sustain the agricultural productivity in India.

Fig. 2. Global crop area under conservation agriculture (**Source**: Kassam et al. 2018).

Diverse cropping systems and their interrelation among various factors *viz.*, soil and agro-climatic conditions, availability of resources, market forces, socio-economic conditions of the farmers, demand and supply of agricultural produce are the major features of Indian agriculture. In total, more than 250 cropping systems are being practiced throughout the country, out of which sugarcane based cropping system is a major one and mainly dominant in tropical and subtropical part of the country. Tropical region has about 45% area, contributes 55% of the total sugarcane production, thus sub-tropical region accounts for 55% area, and shares 45% of total production of sugarcane in the country (Shukla et al. 2017).

India is one of the largest producers of sugar next to Brazil. Sugarcane plays a vital role in agricultural and industrial economy of the country. Since last few decades, there is a significant reduction in sugarcane productivity due to continuous mono-cropping system, excess use of inorganic fertilizer, intensive tillage, trash burning, depletion of soil nutrient and microbes level (Bohme et al. 2005; Dengia and Lantinga 2018; Zhao et al. 2018). To overcome these problems, farmers have to understand that agriculture should be not only high yielding but also to be sustainable in the long-term. Therefore, a paradigm shift from conventional agriculture practices (i.e., monoculture, intensive tillage practices, crop residue burning, excess use of water and inorganic fertilizers) is essential for sustainable sugarcane production while conserving the natural resource base.

2. Scope of CA in Sugarcane

2.1. Area, production and productivity of sugarcane in India

India is the second largest producer of sugarcane next to Brazil and accounts about 25% of the world's production. It is grown on around 2.57% of the gross cropped area in sub-tropical and tropical regions (Upreti and Singh 2017). States of sub-tropical and tropical regions contributes about 60% and 40% of country's total area and sugarcane production, respectively. Uttar Pradesh is the largest sugarcane producing state in India, followed by Maharashtra and Karnataka (Fig. 3 and Table 1). These three major states contribute more than 74% both in term of area and production (Fig. 3). Whereas, maximum productivity were reported in Tamil Nadu followed by Karnataka and Maharashtra. As per recent estimates, sugarcane crop covers 51.1 lakh hectare area and gives 400.2 million tons (Mt) production with average productivity of 78.25 t ha^{-1} (Anonymous 2020). However, the low and stagnant productivity of sugarcane over the years is a major challenge for the country's sugar economy. The major factors behind this stagnant productivity of sugarcane are varietal deterioration, biotic and a biotic stresses lower ratoon cane yields, decline in soil productivity, low technology adoption and climatic vagaries. This explores scope for implementation of conservation agricultural practices in existing sugarcane cropping system for efficient utilization and management of basic resource inputs such as land, water, fertilizer and labour.

Table 1. Area, production and productivity of major sugarcane states of India in 2017-18.

State	Area (Lakh ha)	Production (Lakh t)	Productivity (t ha^{-1})
Uttar Pradesh	22.3	1623.4	72.7
Maharashtra	9.0	726.4	80.5
Karnataka	3.7	299.0	80.8
Bihar	2.4	165.1	67.9
Gujarat	1.8	122.3	66.5
Tamil Nadu	1.8	165.6	90.1
Haryana	1.1	87.3	76.6
Others	5.4	361.8	67.4

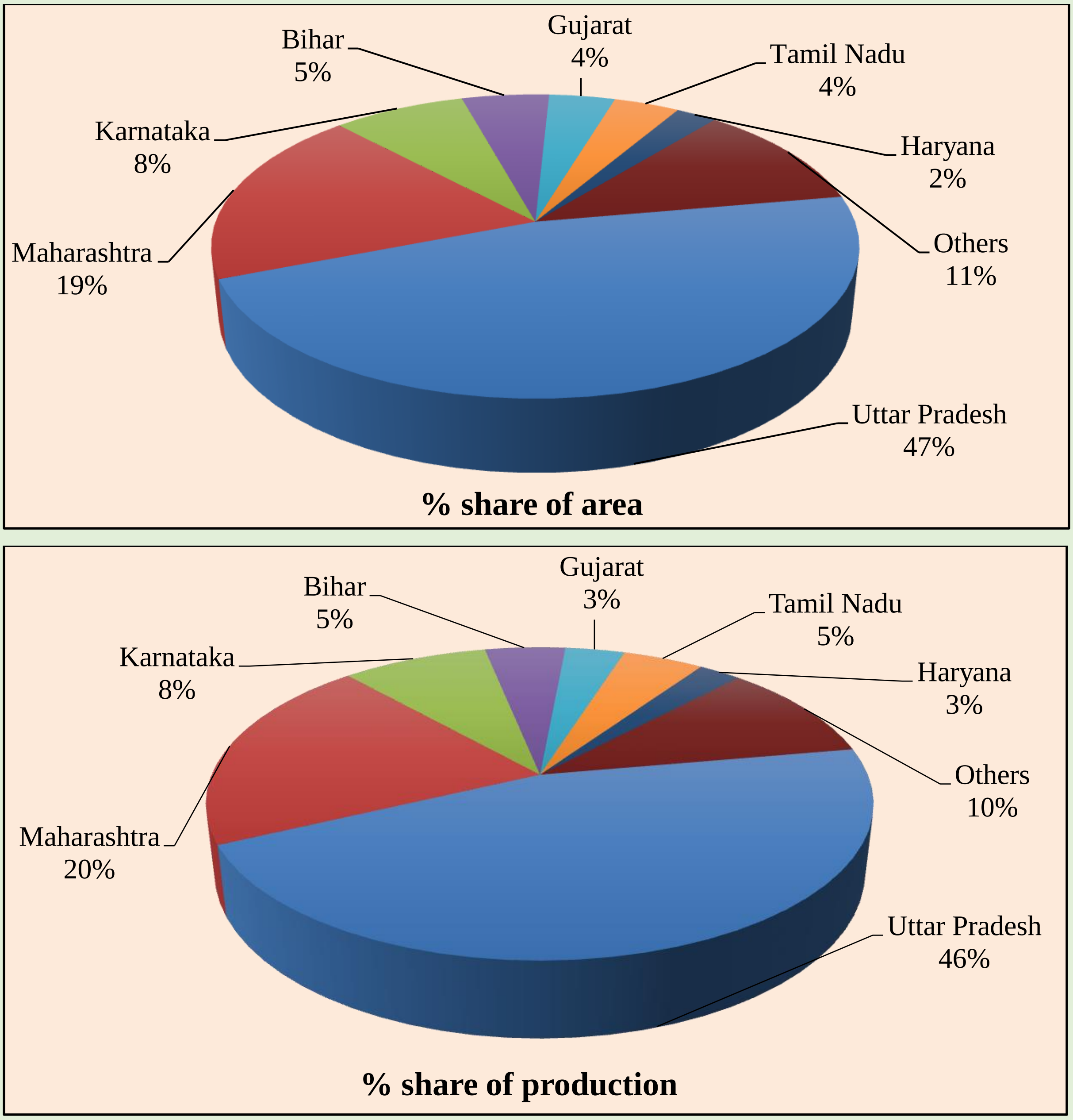


Fig. 3. Share (%) of area and production of major sugarcane growing states in India.

Source: 3rd Advance estimates for sugar season 2017-18, March 2018, Vol. 49, No.7, Issued by Department of Agriculture & Farmers Welfare

2.2. Residue generation

According to the Indian Ministry of New and Renewable Energy (MNRE), India produces on an average 620.4 Mt of crop residue per year (Jain et al. 2014; NPMCR 2019). Among the different crop categories, a cereals, fiber, oil seeds and sugarcane crop generates 361.9, 122.4, 28.7, 107.5 Mt of residues, respectively. Sugarcane alone contributes around 17.3% of the total crop residues. A significant variation in sugarcane trash generation across different states of India signifies the impact of varying cropping pattern, cropping intensity, and productivity of the states. Uttar Pradesh contributed maximum to the generation of sugarcane residue (41.13 Mt year^{-1}) followed by Maharashtra (22.87 Mt year^{-1}) and Tamil Nadu (12.37 Mt year^{-1}). Therefore, trash management is a major challenge in sugarcane and farmers generally go for residue burning as a part of conventional practice. The maximum sugarcane crop residue burning ranged between (4.24-7.73 Mt year^{-1}) was reported in Uttar Pradesh followed by Maharashtra, Karnataka and Tamilnadu (0.83-4.23 Mt year^{-1}), respectively (Fig. 4). However, sugarcane residue-burning releases significant quantity of air pollutants into the atmosphere and causes an adverse effect on above and below ground ecosystem (Bhuvaneshwari et al. 2019; Venkatramanan et al. 2021).

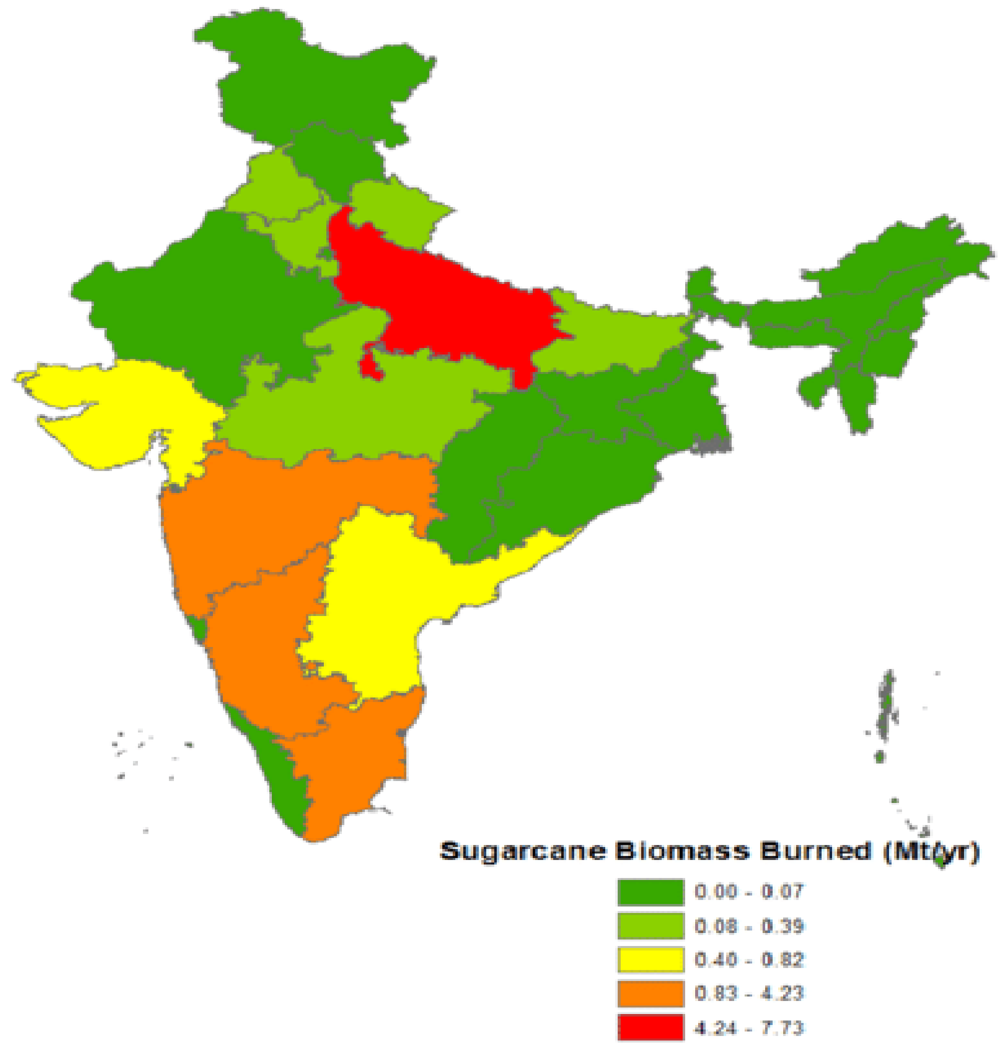


Fig. 4. Sugarcane crop residues burned in various states of India (**Source**: Jain et al. 2014).

2.3. Project objectives

Recently, CA systems are gaining attention worldwide, as an effective option to enhance productivity and profitability in a sustainable way without compromising on resource quality and have potential to address the emerging issues of climate change. CA practices are dependent on resource availability of the location and on the prevalent crops and cropping systems; hence site specific research is essential for the development of CA practices. Further, in order to overcome the productivity and abiotic stresses problems; research on adaptation of conservation technology is on top priority in sugarcane based cropping system. Considering all these aspects, and the need-of-the-hour to introduce and promote CA in existing cropping systems, Indian Council of Agricultural Research (ICAR) formulated a project on “Consortia Research Platform on Conservation Agriculture” in 2015-2016, a part of which was implemented at the ICAR-National Institute of Abiotic Stress management (NIASM), Baramati, Pune, Maharashtra in sugarcane cropping system with the following objectives.

1. Development and validation of location specific CA practices for enhancing productivity, profitability and resource-use efficiency.
2. Quantification of the impact of CA practices on soil health and carbon sequestration.
3. Development of suitable planting systems, micro-irrigation techniques and residue management practices.

Outcomes of this project will be applicable in sugarcane based cropping system to improve soil health, enhancing productivity, profitability and resource-use efficiency in changing climatic scenario.

3. Study location, Soil and Weather Conditions

The experimental site is located at the research farm of ICAR-NIASM (18°09’ 30.62’’N; 74°30’ 03.08’’E; MSL 570 m), Malegaon Khurd, Baramati in Pune district of Maharashtra state, India (Fig. 5). It falls under the agro-ecological region Deccan Plateau, hot and semi-arid climate (AER-6) and agro-climatic zone AZ-95 i.e., scarcity zone of Maharashtra. The long-term average annual rainfall is 560 mm, and distributed erratically mostly from south-west and retreating monsoon. Contribution of southwest monsoon (June-September) and post monsoon (October-December) rainfall is about 70 and 21%, respectively. Because of low rainfall, the soils in the area are shallow and poorly developed from basaltic rocks. Agricultural drought is a common phenomenon in the area. Here, agriculture is largely rainfed except for about one-third of Baramati area along the Nira canal that is irrigated and mainly supports sugarcane cropping system. Thus, fresh water (pH 7.6 and EC 0.22 dS m^{-1}) drawn from the canal is used for irrigating sugarcane crop. The monthly weather conditions during the cropping period of 2015-2020 with respect important parameters are depicted in Fig. 6-8. The average mean monthly, the maximum and minimum temperatures during growing period were 25.4, 32.5 and 18.4°C, respectively. The corresponding values of rainfall and USWB open pan evaporation were 617.1 mm and 2421.4 mm, respectively. The average mean monthly relative humidity, sunshine hours and wind speed were 58.9%, 6.9 h and 7.1 km h^{-1}, respectively. The soil of the experimental field was medium black (sand, silt and clay, 55.2, 8.5, 36.3%, respectively) had pH 8.3; EC 0.23 dS m^{-1}; organic carbon 6.5 g kg^{-1} available N, P and K 170.7, 17.3 and 142 kg ha^{-1}, respectively.

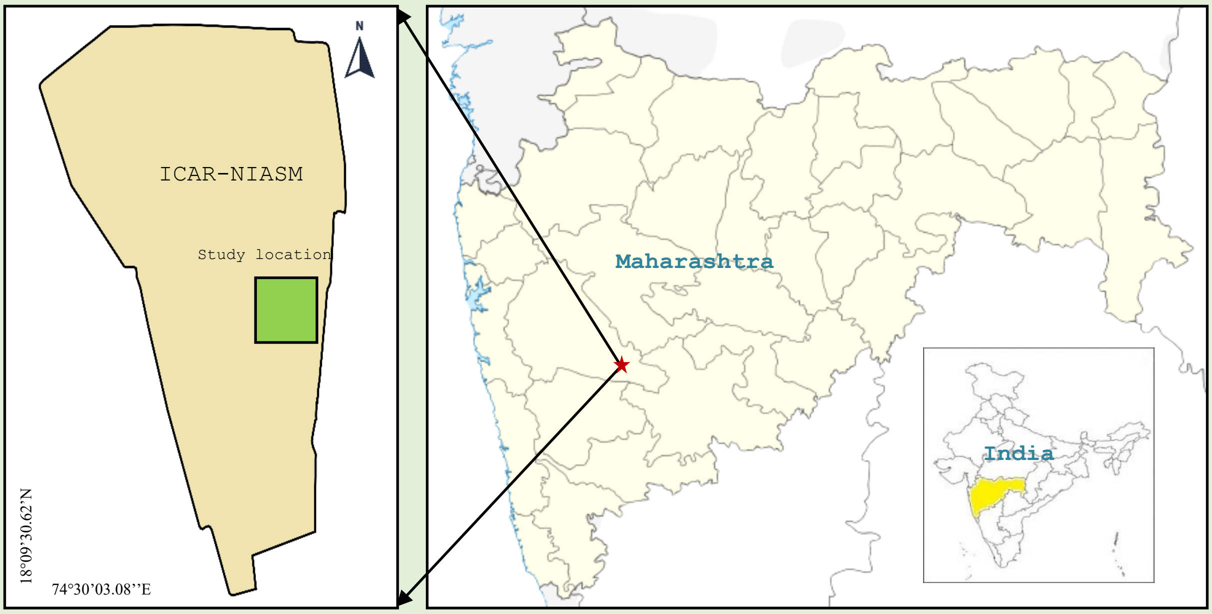


Fig. 5. Location of experimental site at ICAR-NIASM, Baramati.

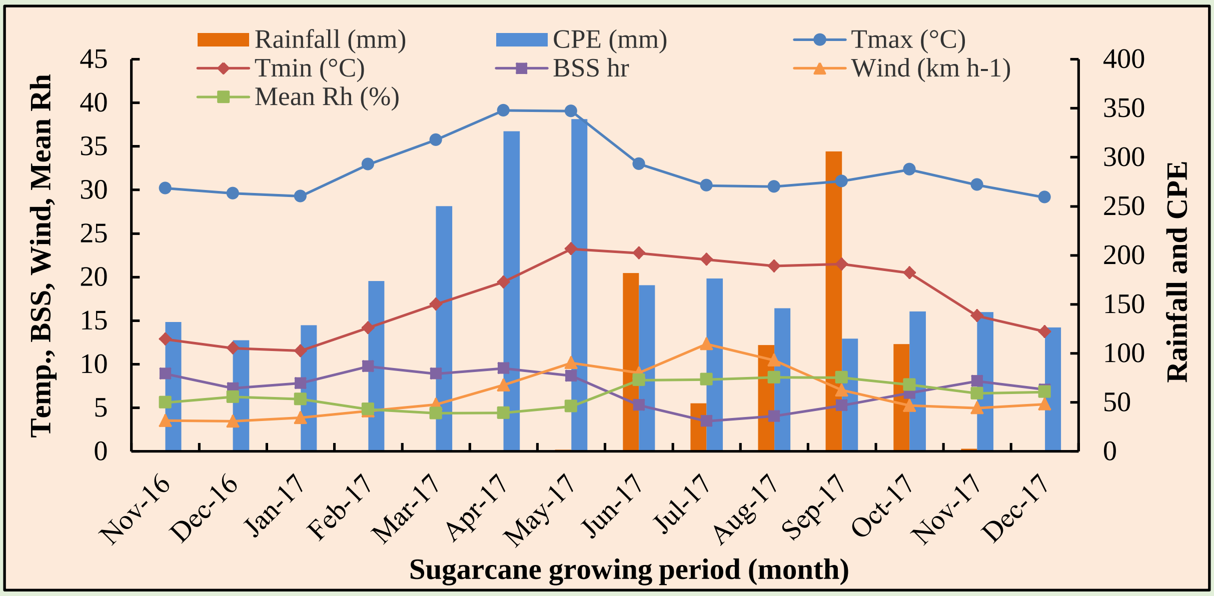


Fig. 6. Weather data during growing period of fresh sugarcane (2016-17).

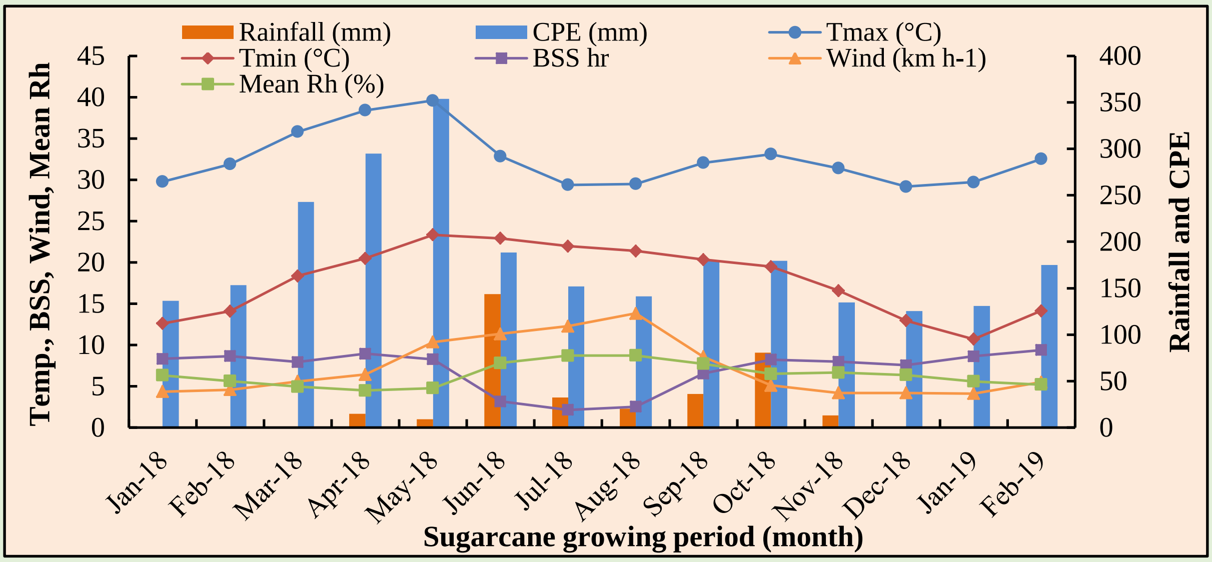


Fig. 7. Weather data during growing period of ratoon sugarcane (2018-19).

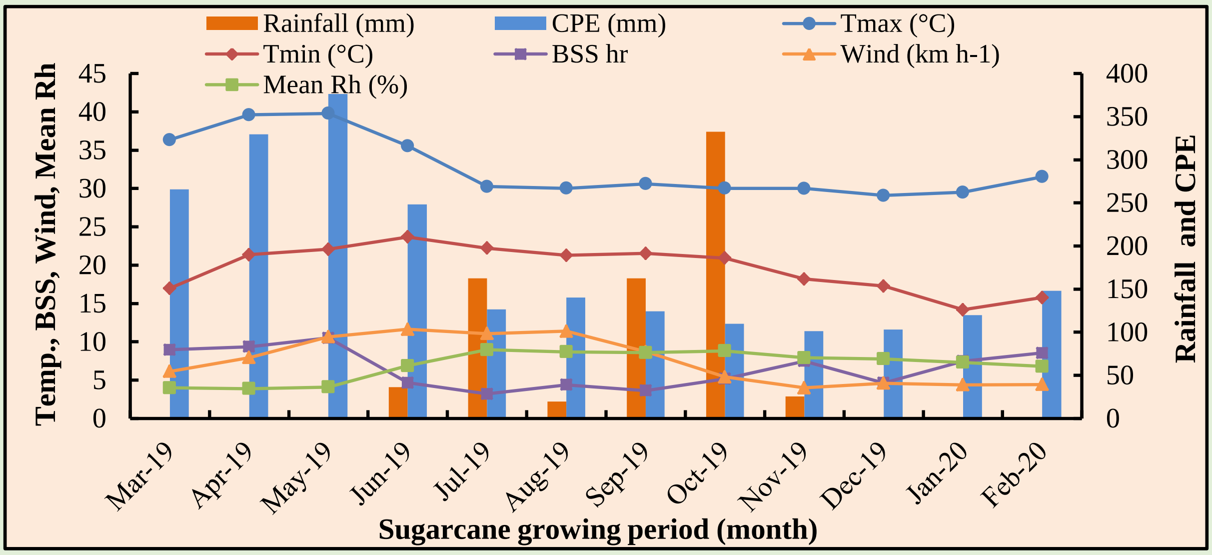


Fig. 8. Weather data during growing period of ratoon sugarcane (2019-20).

4. Experimental Methodology

Two sets of experimental approaches: (1) agronomic measures and (2) engineering interventions were laid for inter-linking three basic principles of CA in sugarcane cropping system, in conjunction with other complementary good agricultural practices of integrated crop and production management. Accordingly, two agronomic field experiments namely (i) optimization of planting geometry, micro-irrigation and residue management practices, and (ii) standardizing tillage system, crop residue and nutrient management practices were simultaneously conducted for improving the resource-use efficiency and productivity of sugarcane based cropping system. Since, sugarcane trash management is major problem in ratoon crop and its' in situ retention can play an important role in replenishing soil quality and reducing environmental pollution. To address this and other issues related to low yields of ratoon sugarcane and intercropping using engineering interventions; three prototypes of multi-purpose (trash chopping, stubble shaving, off-barring, root pruning and fertilizers placement) drill machines were developed for applying CA principles in existing sugarcane system of Deccan Plateau, India. The details of design and development, comparative specifications, important features, benefits and performance evaluation of these prototype drill machines are well explained separately in section 8.

The treatments, statistical design and other details of agronomic experiments are discussed below.

4.1. Optimizing planting geometry, micro-irrigation and residue management practices

Globally water stress is considered to have most significant impact on crop productivity. Sugarcane is a very high water demanding crop, as an average 10,000-12,000 m^3 of water is required to produce 100 t ha^{-1}. Due to changing climatic scenario inadequate supply of water will result in great yield penalty up to 60% (Gentile et al. 2015). Similarly, crop water requirement differed with planting methods and weather conditions. To address these problems, a field experiment was conducted integrating conservation agriculture component with micro-irrigation and sugarcane planting system (*Var.* MS-10001) in split-plot design with three replications. Combination of planting techniques and micro-irrigation were kept as main plot treatments *viz.*, M_1: Parallel planting of each plant in single rows spaced at 150 cm with surface drip irrigation (PSR-150 cm + SDI); M_2: Parallel planting of each plant of paired rows by maintaining spacing of 210 cm between the pairs and 90 cm between the rows with SDI (PPR-210 cm × 90 cm + SDI); M_3: Zigzag planting of each plant of paired rows by maintaining spacing of 225 cm between the pairs and 75 cm between the rows with SDI (ZPR-225 cm × 75 cm + SDI); M_4: ZPR-240 cm ×60 cm + SDI; M_5: ZPR-225 cm × 75 cm + sub surface drip irrigation (SSDI); M_6: ZPR-240 cm × 60 cm + SSDI and M_7: ZPR-210 cm × 90 cm + SDI. Two sub plot treatments of soil surface cover management practices *viz.*, S_1: Residue mulching-covering of soil surface with a live mulch of mungbean (*Var*. BM-2003-2) followed by retention of mungbean residue and trash as mulch and S_2: No (without) residue (trashes were burnt) were accommodated. An absolute control surface irrigation management (Farmer practices, M_8) with trash retention and burning was also maintained to compare the treatment effects (Fig. 9-10).


Installation of sub-surface drip irrigation (SSDI)


Paired row planting + SSDI


Conventional single row planting + SDI


Mung bean as live mulch + SSDI


Zigzag planting


Mung bean as live mulch + SDI

Fig. 9. Integration of the planting geometry, micro-irrigation and live mulch in sugarcane.

Zigzag plantation + Trash mulch + SSDI

Zigzag Plantation + Trash burn + SSDI

Parallel single row + Trash mulch + SDI

Parallel single row + Trash burn + SDI

Parallel paired row + Trash mulch + SDI

Parallel paired row + Trash burn + SDI

Fig. 10. Integration of the planting geometry, micro-irrigation and trash mulch in ratoon sugarcane.

4.2. Standardizing tillage system, crop residue and nutrient management practices

In India, several soil management practices used for sugarcane production, such as excessive tillage, burning of crop residue and excess use of nitrogenous fertilizers, are considered to be contributing towards soil degradation, greenhouse gas emission and nutrient loss. To address these problems, present experiment was planned using variety MS-10001 in split plot design and replicated thrice with following main treatments *viz.*, M_1: Laser land levelling (LLL) + conventional tillage (CT) + 10% of recommended dose of fertilizers (RDF; 300:115:115; N: P: K; kg ha^{-1}) applied as basal and remaining 90% doses of fertilizers applied through fertigation; M_2: LLL + reduced tillage (RT) by excluding deep tillage + 10% of RDF as basal and 90% through fertigation; M_3: LLL + RT + 10% of RDF as basal, 40% through band placement (by SORF) and remaining 50% through fertigation; M_4: Conventional sugarcane management practices i.e. farmers practice. Two soil surface cover management practices *viz.*, S_1: Residue covering of soil surface with a live mulch of mungbean (*Var*. BM-2003-2) followed by retention of mungbean residue and trash as mulch and S_2: without residue were accommodated in sub-plots. A uniformity trial was also conducted with fodder maize after laser land levelling (LLL) and before initiation of experiment. The pictorial view of the various treatments applied in the experimental field has been given in Fig. 11.


Laser land leveling (LLL)


Fodder maize


Sugarcane establishment


Control (without LLL)


Fertigation unit


Mungbean as live mulch


Band placement of fertilizers SORF machine


Recycling of trash as mulch

Fig. 11. Treatment application in experimental field of planting sugarcane.

In ratoon sugarcane crop sub plots again splited in to sub-sub plots i.e. N_1: SORF with placement of 25% of RDF as basal and remaining 75% by fertigation; N_2: SORF with placement of 50% of RDF as basal and remaining 50% by fertigation; N_3: SORF with placement of 75% of RDF as basal and remaining 25% by fertigation/ top dressing (Fig. 12)


Sugarcane trash mulching by chopper


Trash burning


Trash management in experimental plot


Band placement of fertilizers and sowing of intercrop with SORF machine


Sugarcane at tillering stage


Sugarcane at grand growth stage


Manual cane harvesting and transportation


Trash generation for next ratoon mulch

Fig. 12. Treatment application in experimental field of ratoon sugarcane.

5. Results of the Long-term CA Studies

5.1. Interactive effects of planting geometry, micro-irrigation and residue management practices on cane yield, soil health & water productivity

Planting geometry with different micro-irrigation techniques and trash management practices significantly affected cane yield, soil health and water productivity during cropping period (2017-20).

5.1.1. Sugarcane yields

The significant higher cane yields were observed under sub-surface drip irrigation with live/trash mulch in both plant and ratoon cane. Comparing all the treatment combinations, pooled interaction of M_5 (ZPR-225 cm × 75 cm + SSDI) with mulch recorded maximum cane yield (150.3 t ha^{-1}) followed by M_6 (ZPR-240 cm × 60 cm + SSDI) with mulch (142.0 t ha^{-1}) while the farmer practices plot recorded minimum cane yield production i.e., 125.3 t ha^{-1} in trash retention and 106.3 t ha^{-1} in burn (Fig. 13). Covering of soil surface with live mulch of mungbean followed by retention of mungbean residue and trash improved the cane yields on an average by 10.6% as compared to without residue-retained treatment. This indicated that yields of paired row planted sugarcane could be improved significantly with adoption of zigzag planting, micro-irrigation techniques and retaining the trash on soil surface.

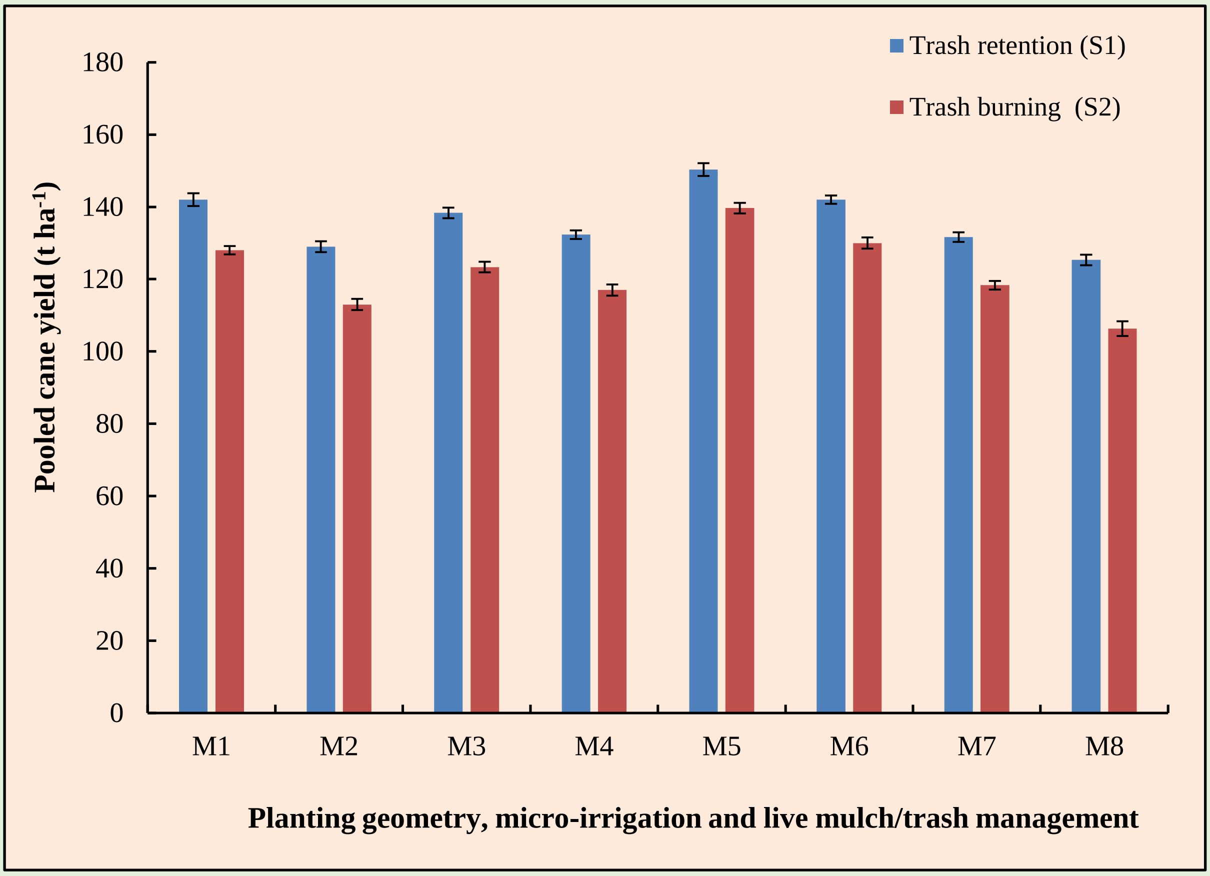


Fig. 13. Effect of planting geometry, micro-irrigation and trash management on pooled cane yield of planted and ratoon sugarcane.

Seed yield of mungbean (3.8-7.9 q ha^{-1}) was an additional production through growing it as intercrop with sugarcane for live mulch and recyclable residue. The mungbean seed yield was recorded maximum with M_1 (PSR-150 cm + SDI), which was 39-84% higher than rest of the treatments.

5.1.2. Water productivity

Water productivity (WP) calculated as the ratio of cane yields to water consumption that includes applied water and rainfall. The results clearly indicated that the subsurface drip irrigation (SSDI) was superior over the conventional flood irrigation and surface drip irrigation (SDI) method. Maximum WP (0.90 Mg ha cm^{-1}) was recorded in M_5S_1 treatment (ZPR-225 cm × 75 cm + SSDI with mulch) followed by 0.80 Mg ha cm^{-1} in M_6S_1 (ZPR-240 cm × 60 cm + SSDI); whereas minimum WP was recorded in farmer practices plots (Fig. 14). WP significantly increased due to the trash management and subsurface irrigation system, which considerably contributed in reducing water loss through evapotranspiration and delivering water directly to the rooting zone. The WP in mulch was 8.86% higher over non-mulch of SSDI, 10% over SDI and 31.03% over SI.

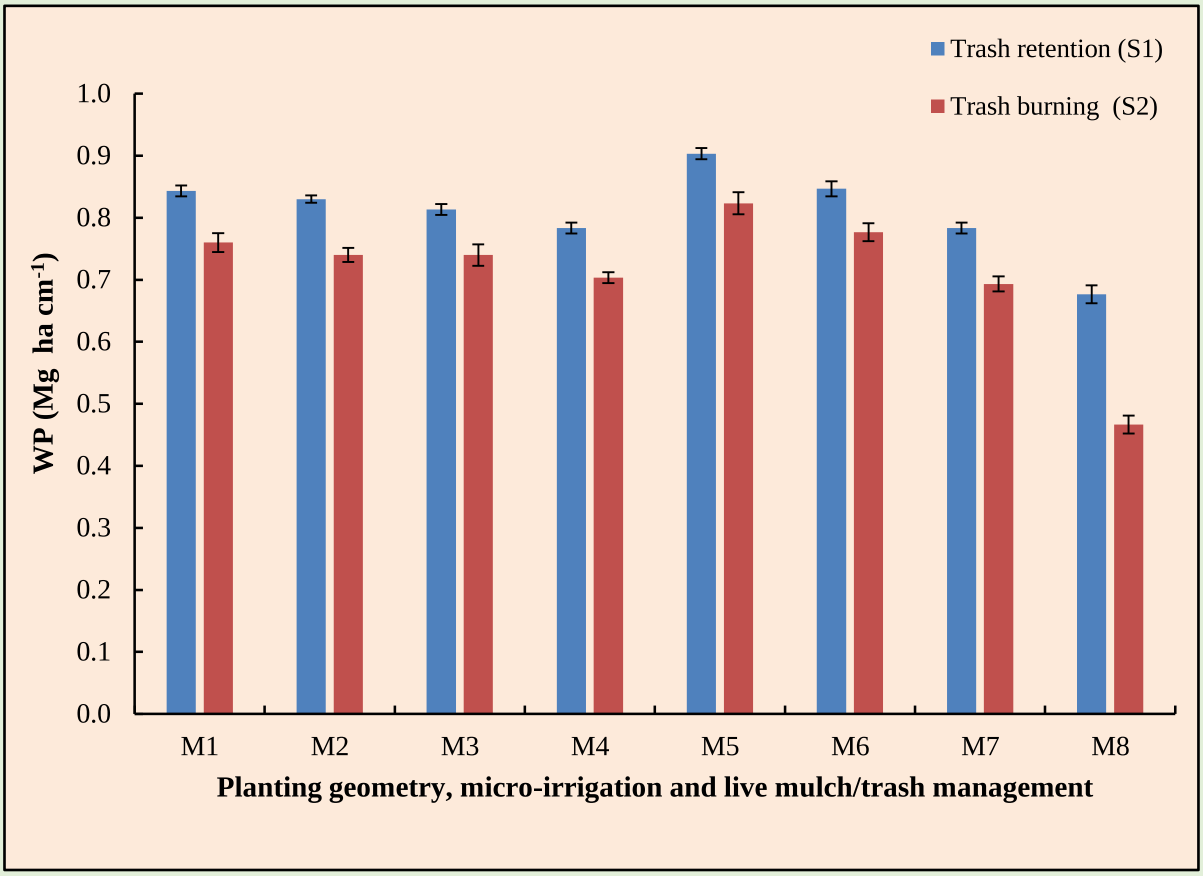
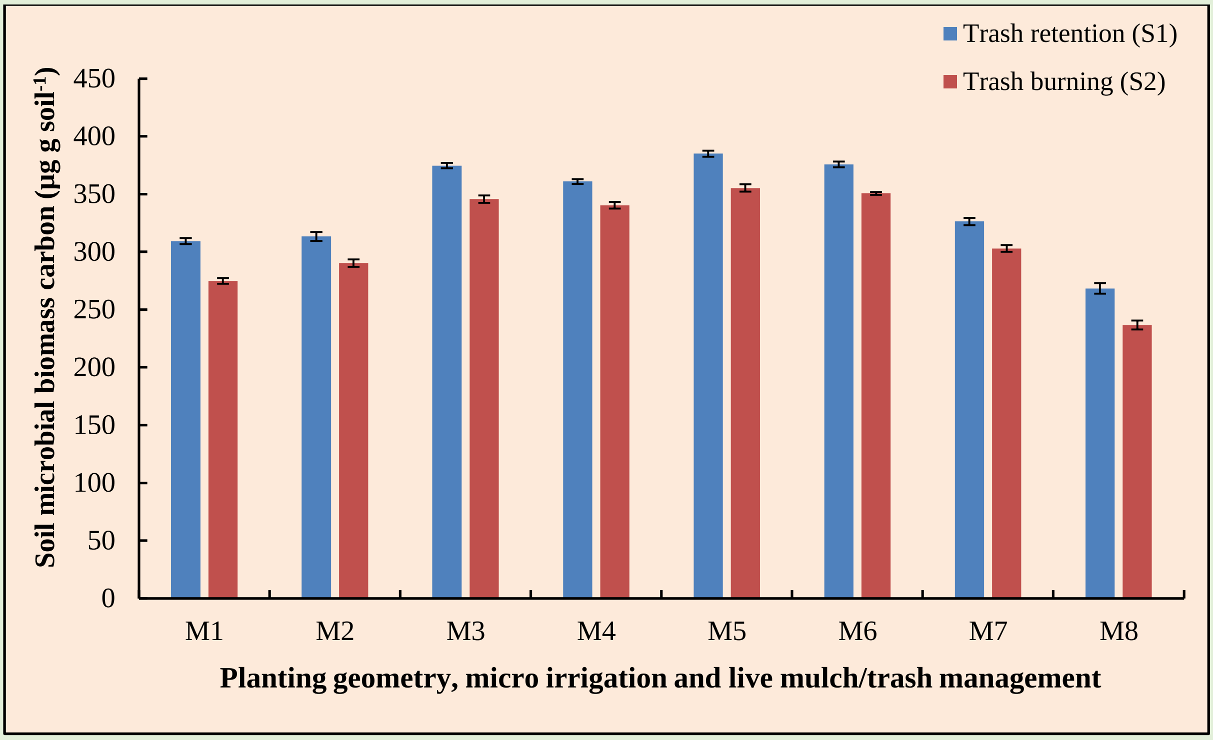


Fig. 14. Effect of planting geometry, micro-irrigation and trash management on WP of planted and ratoon sugarcane.

5.1.3. Soil microbial biomass carbon and dehydrogenase activities

Implementation of the CA practices in sugarcane cropping system favored the accumulation of Soil Microbial Biomass Carbon (SMBC), which could be attributed to the addition of carbon substrates in the soil mainly through the retention of sugarcane trash. Indigenous microbes from the soil thrive on the carbon sources and perform variety of metabolic activities that ultimately leads to the development of humic substances in soil. Plant-root exudates are also known to project molecular signals that could induce assembly of beneficial microbes within the active rhizosphere region. This facilitates mobilization of nutrients and subsequent uptake by the plant, and produce variety of beneficial substances including microbial derivatives of plant growth hormones and additionally these microbes also contribute to biotic and abiotic stress tolerance. Dehydrogenase (DH) enzyme is closely associated with metabolic activities of microorganisms and thus, is a good indicator of soil biological functions. Both the freshly-planted, and ratoon cane crop under CA practices resulted in higher DH activity within the soil, suggesting that the CA practices favorably influence the soil-microorganisms. The treatment M_5S_1 exhibited highest dehydrogenase activity (260 µg TPE g soil^{-1} day^{-1}) and soil biomass carbon (385 µg g soil^{-1}) as compared to the rest of the treatments, which could be attributed to the plating geometry and subsurface drip irrigation technique through higher availability of soil-moisture for optimal microbial activity (Fig. 15).



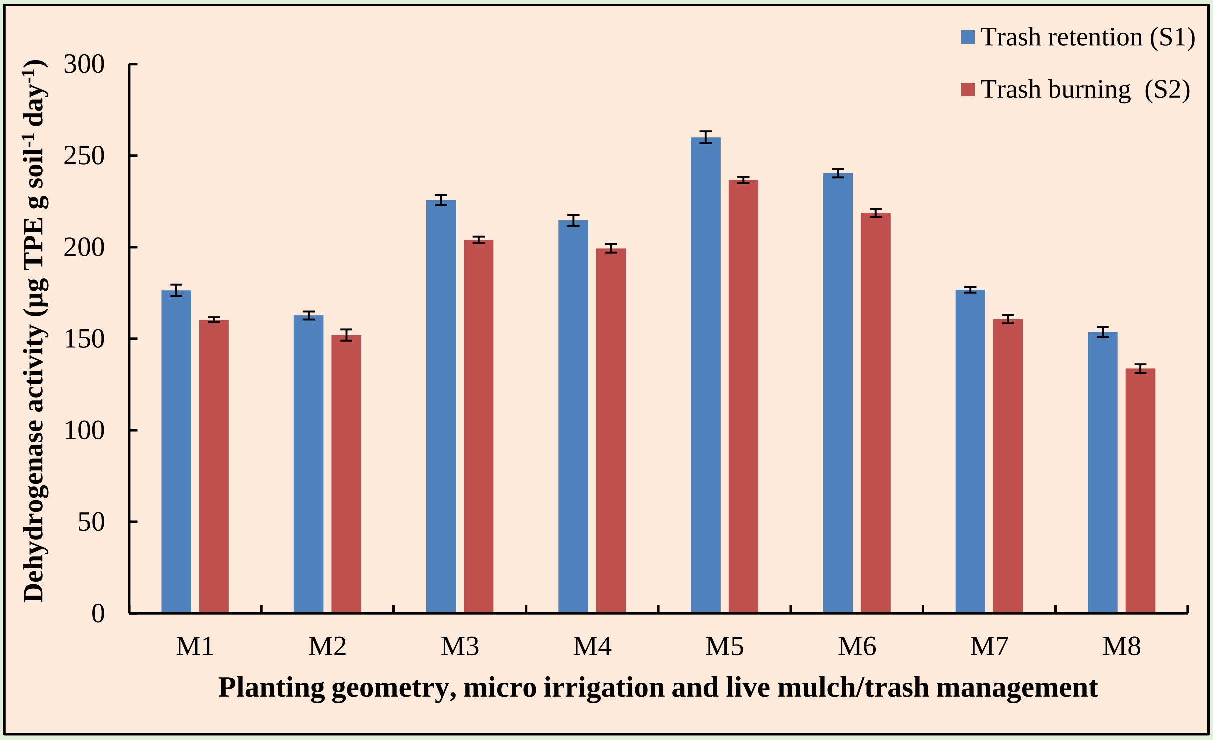


Fig. 15. Effect of planting geometry, micro-irrigation and trash management on microbial biomass carbon and dehydrogenase activities of sugarcane.

5.1.4. Available nitrogen, phosphorus, potassium and organic carbon in soil

Planting geometry and trash management had a significant influence on available nutrient status of soil after harvest of sugarcane. Zigzag paired row (225 cm × 75 cm) planting geometry along with SSDI and trash-retention (M_5S_1) exhibited maximum organic carbon, OC (0.75%), available N (180 kg ha^{-1}), P (18.46 kg ha^{-1}) and K (530 kg ha^{-1}) status of soil after harvest of crop (Fig.16-19). It may be happen due to continuous mulching of crop residue with minimum volatilization losses. The incorporation of crop residue in conjunction with SSDI significantly enhances the sustainability and stability with respect to productivity of sugarcane based cropping system.

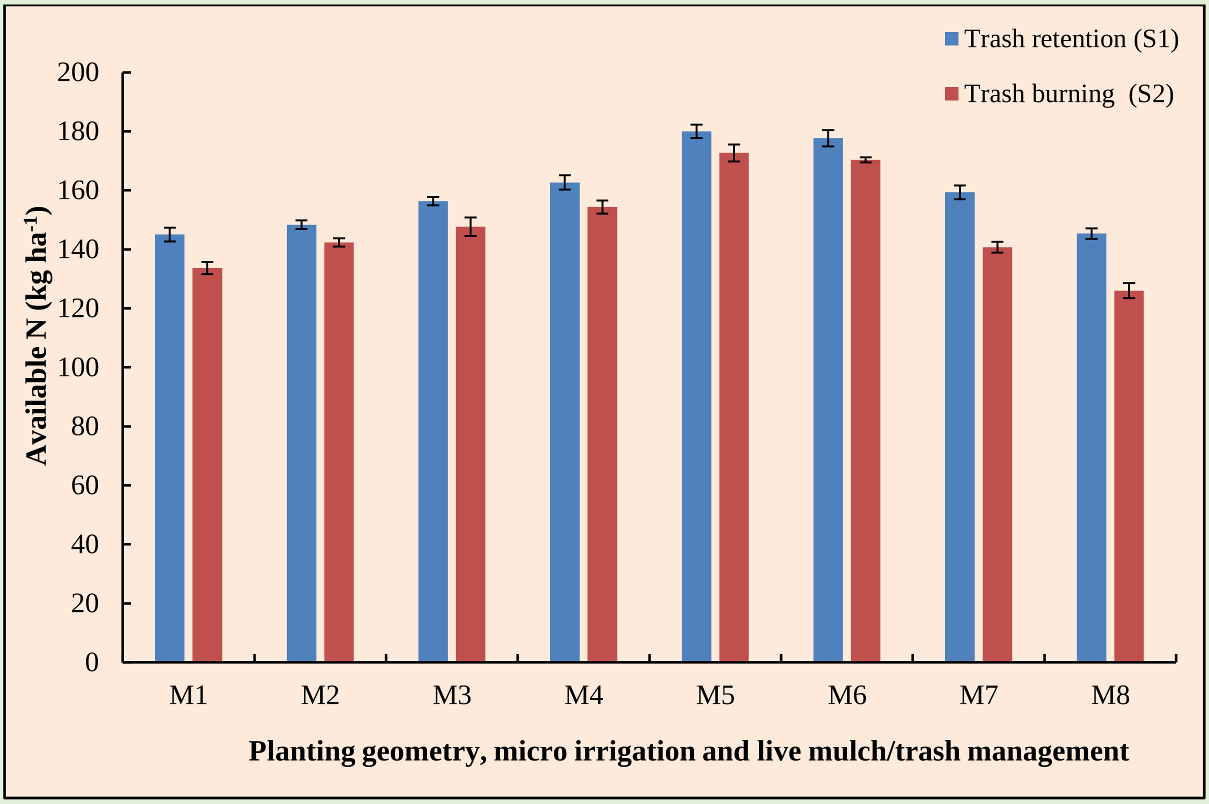


Fig. 16. Effect of planting geometry, micro-irrigation and trash management on available N.

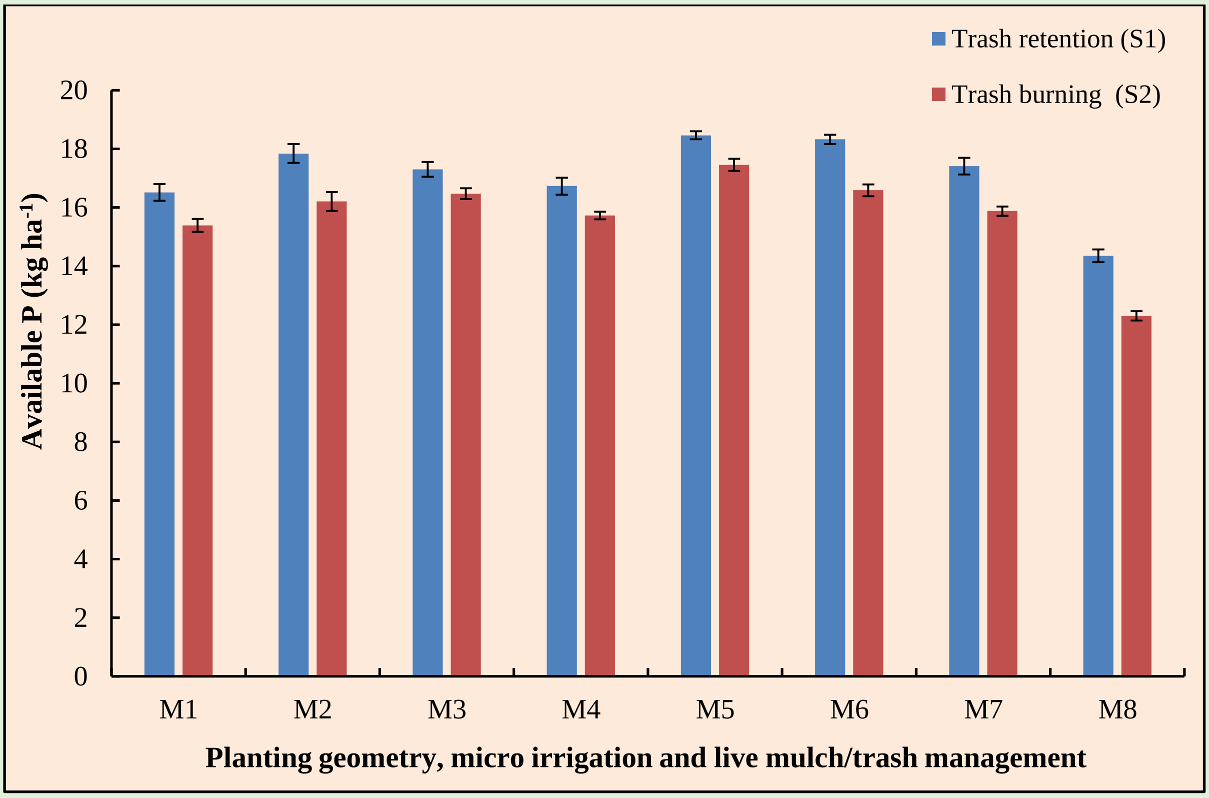


Fig. 17. Effect of planting geometry, micro-irrigation and trash management on available P.

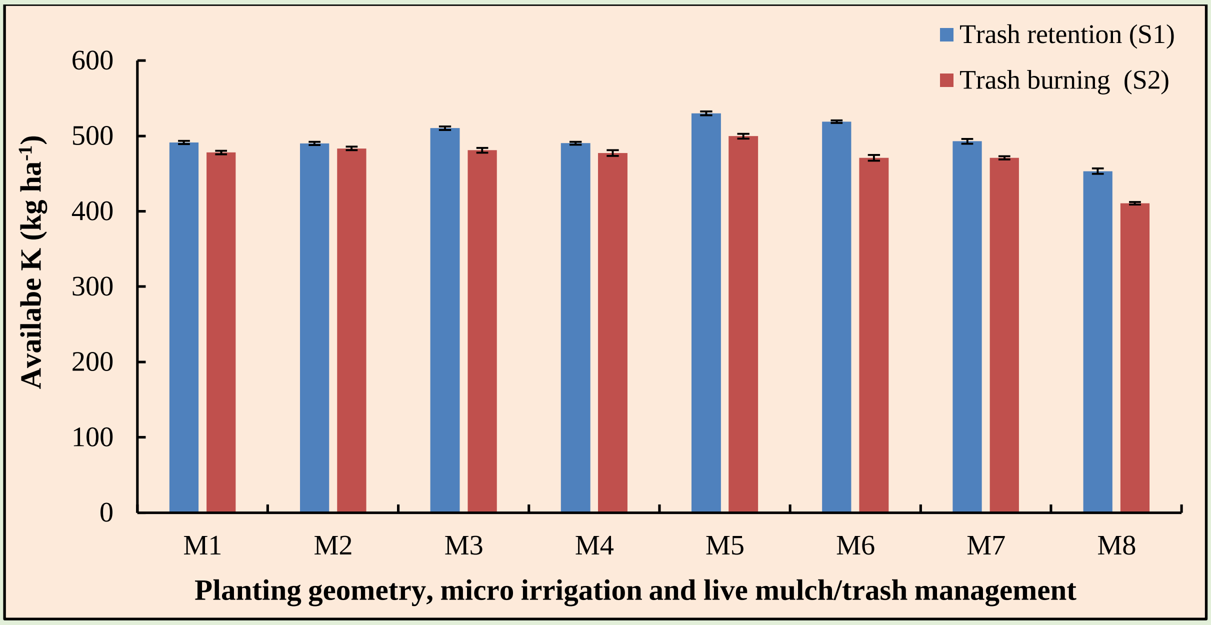


Fig. 18. Effect of planting geometry, micro-irrigation and trash management on available K.

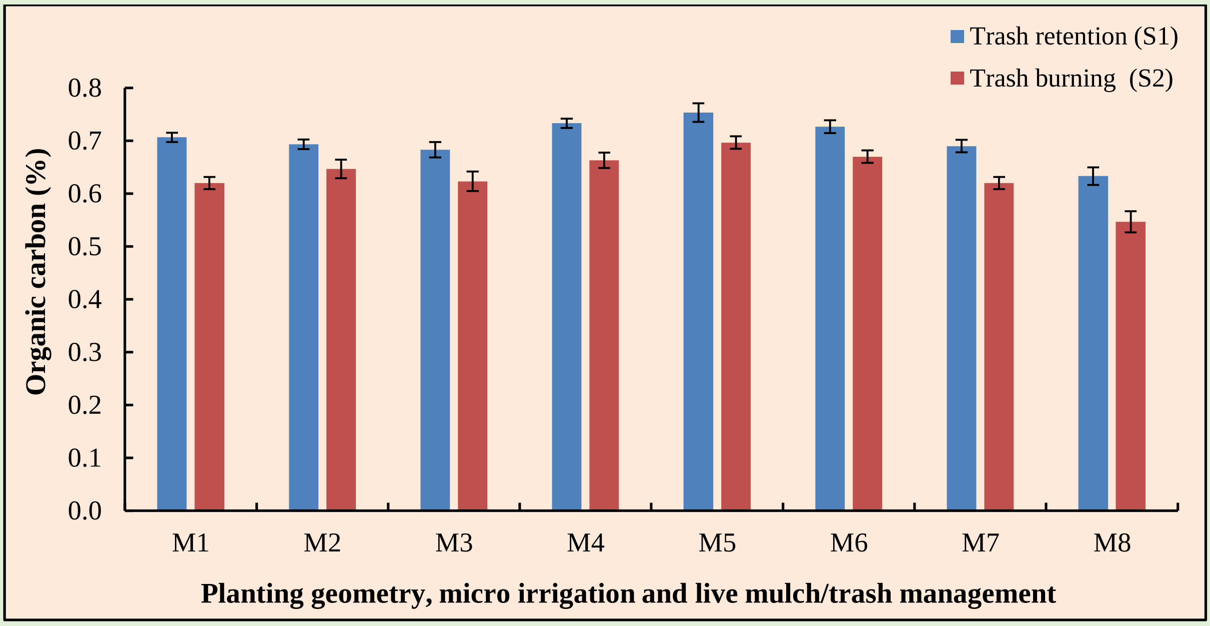


Fig. 19. Effect of planting geometry, micro-irrigation and trash management on available soil organic carbon.

5.2. Sugarcane responses to tillage, crop residue and nutrient management practices

5.2.1. Sugarcane yields

The results of fresh planted sugarcane in 2016-17 revealed that there was no significant difference in cane yields under conventional tillage (157.1 t ha^{-1}, M_1) and reduced tillage practices (162.2 t ha^{-1}, M_2) practices. It indicated that reduced tillage could be adopted without compromising the cane yields. Furthermore, application of 40% of RDF through band placement (through SORF) and 50% of RDF through fertigation (M_3) improved the cane yield (170.0 t ha^{-1}) significantly over the application of 90% RDF through fertigation (Fig. 20-21). The yields improvement with M_3 over M_1, M_2 and conventional sugarcane management practices (M_4) treatments were 5.7, 10.5 and 26.4%, respectively. This might be due to the band placement of 40% of RDF provided the initial boost to the crop growth and remaining 50% applied through drip fertigation helped in sustaining the crop growth during the grand growth stage through synchronized supply of nutrients. In present study, LLL and drip irrigation practices not only saved the irrigation water (48%) but also improved the cane yield upto the tune of 10-15%. The residue management practices also significantly affected cane yield and recorded 5.3-12.7% yield improvement over trash burning.

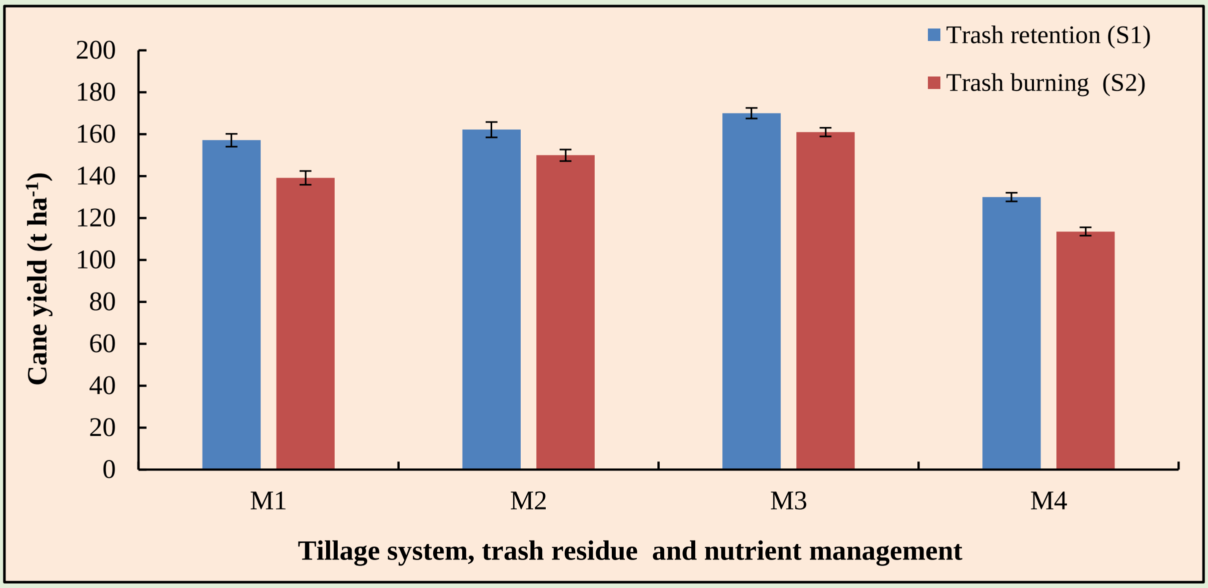


Fig. 20. Effect of tillage, residue and nutrient management practices on fresh cane yields.

M_1: CT + RDF (90% fertigation)

M_2: RT + RDF (90% fertigation)

M_3: RT + RDF(40%SORF + 50% fertigation)

M_4: Conventional management practices

Fig. 21. Effect of tillage, crop residue and nutrient management practices on performance of sugarcane.

The pooled data of 1st and 2nd ratoon sugarcane during 2018-20 are presented in Fig. 22-23. It indicated that individual and interaction effects all treatment combinations were found significant. In ratoon sugarcane, maximum yield (153.5 t ha^{-1}) was recorded in reduced tillage, trash retention with placement of 50% of RDF as basal by using SORF and remaining 50% by fertigation ($M_3S_1N_2$) followed by 75% of RDF as basal by using SORF and remaining 25% by fertigation ($M_3S_1N_3$) (149.8 t ha^{-1}). The application of 50% RDF as basal by using SORF and remaining 50% by fertigation reported 10% yield improvement over 25% RDF as basal by using SORF and remaining 75% by fertigation. Trash residue management improved 13.4 % cane yield over trash burning treatments.

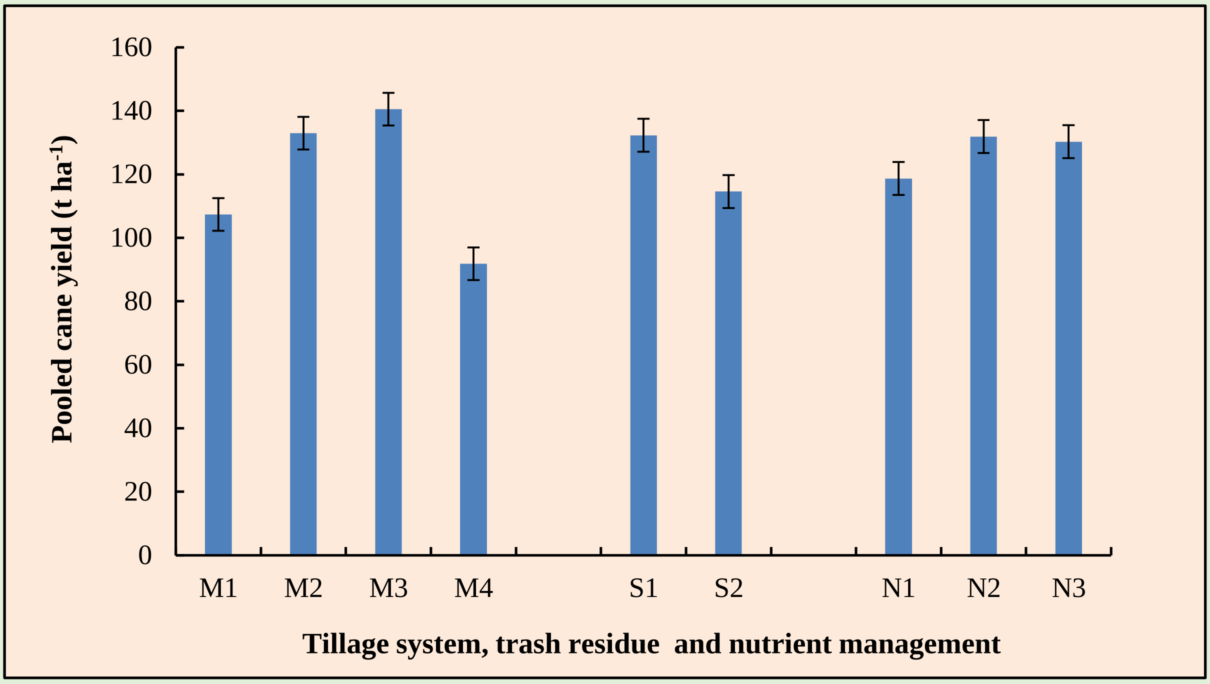


Fig. 22. Individual effect of tillage, residue and nutrient management on ratoon cane yield.

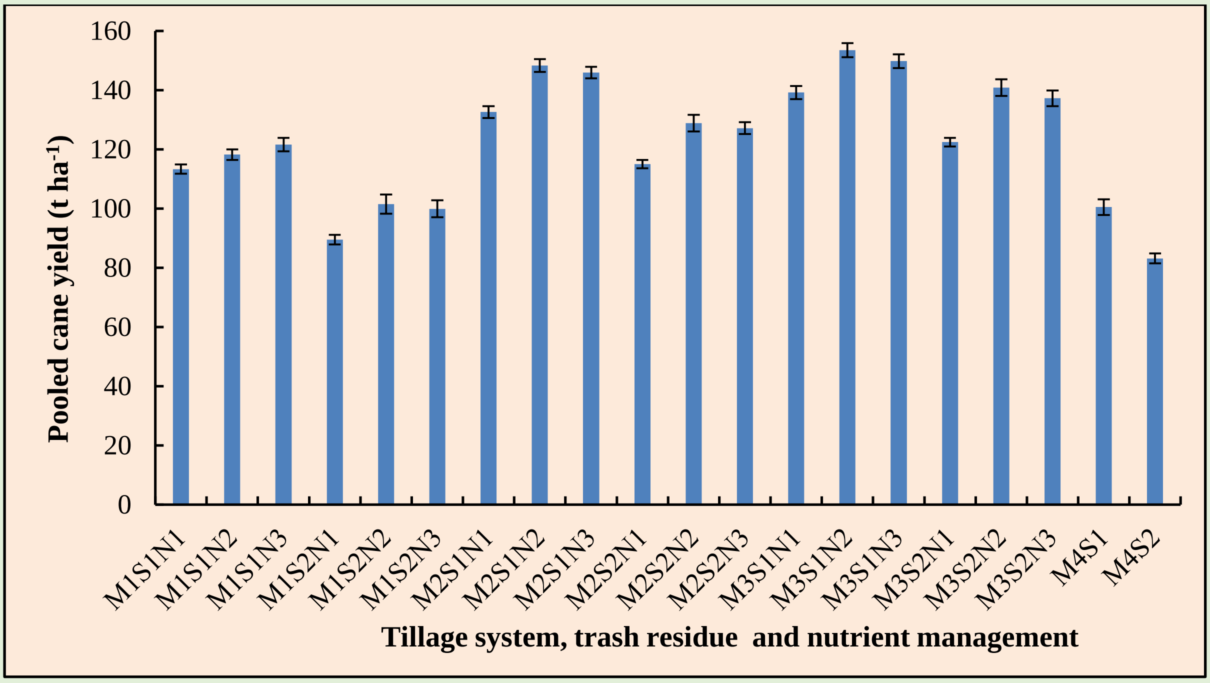


Fig. 23. Interaction effect of tillage, residue and nutrient management on ratoon cane yield.

5.2.2. Available nitrogen, phosphorus, potassium and organic carbon in soil

Nutrient uptake by crop is an indicator of biomass production and available nutrient status of soils. Nutrient management practices had a significant influence on available nutrient status of soil after harvest of sugarcane. In the present study, tillage system, crop residue and nutrient management practices had a significant influence on available nutrient status of soil after harvest of sugarcane (Fig. 24-26). Reduced tillage along with trash-retention and nutrient management ($M_3S_1N_3$) practices exhibited maximum available nitrogen (180.7 kg ha^{-1}), phosphorus (18.6 kg ha^{-1}) and potassium (530.1 kg ha^{-1}) status of soil after harvest of crop.

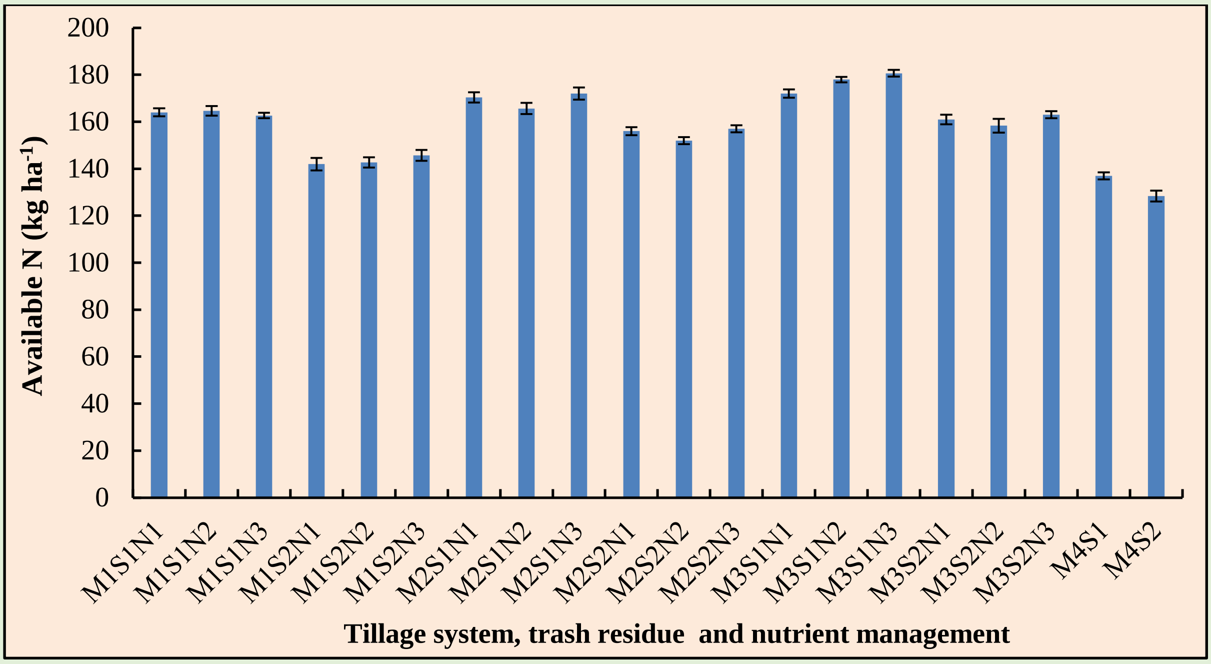


Fig. 24. Effect of tillage, crop residue and nutrient management on available N of soil.

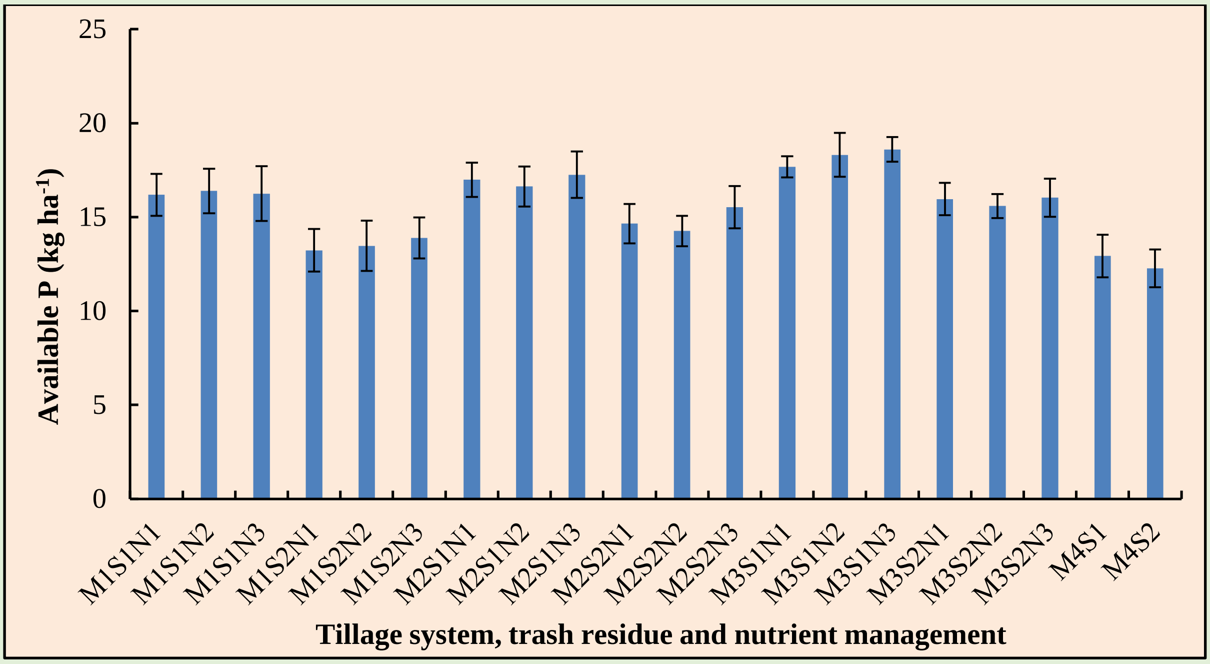


Fig. 25. Effect of tillage, crop residue and nutrient management on available P of soil.

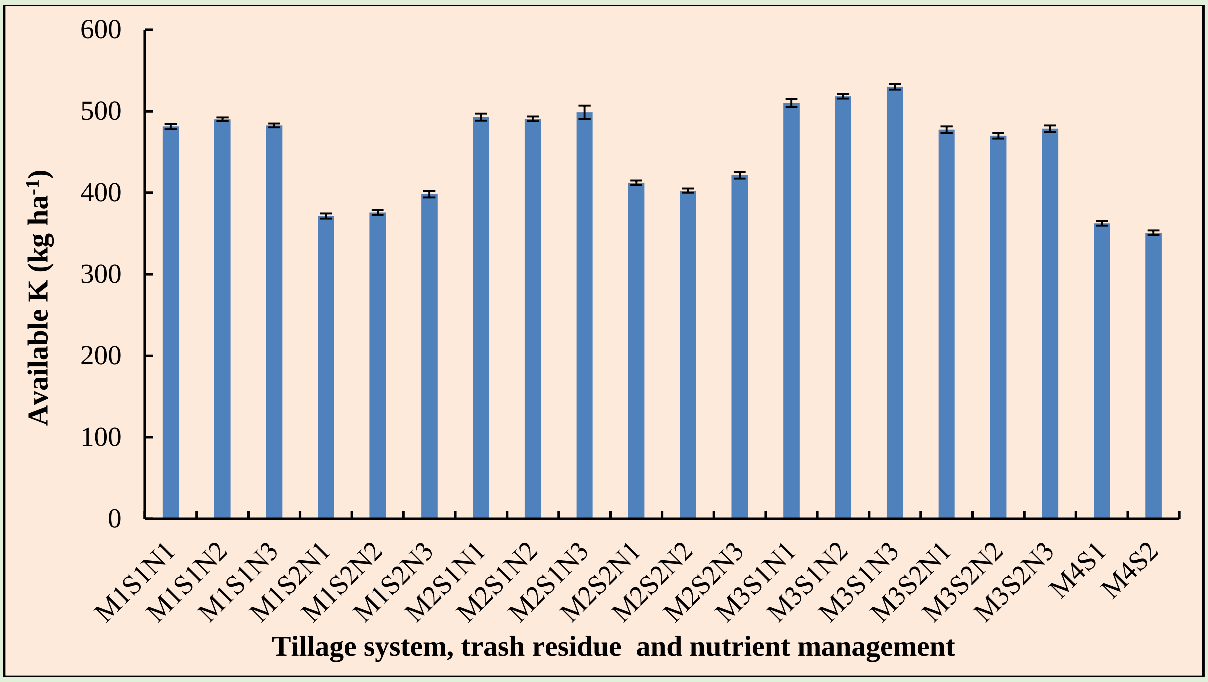


Fig. 26. Effect of tillage, crop residue and nutrient management on available K status of soil.

Soil organic matter is called as reservoir of nutrient for the crop and plays very important role in initiation of all the physical processes, to build the soil structure and texture, which are essential for plant growth and development. In the present study, continuous retention of trash along with reduced tillage enhanced the recalcitrant (non-labile) carbon pools in 0-5 cm depth of soil as compared to conventional tillage. In the conventional tillage treatment non-labile pool are lower as compared to reduced tillage. In $M_3S_1N_3$ treatment 9.7, 7.9 and 4.8 Mg ha^{-1} year^{-1} soil organic carbon storage was reported in 0-5, 5-15 and 15-30 cm soil depth, respectively (Fig. 27).

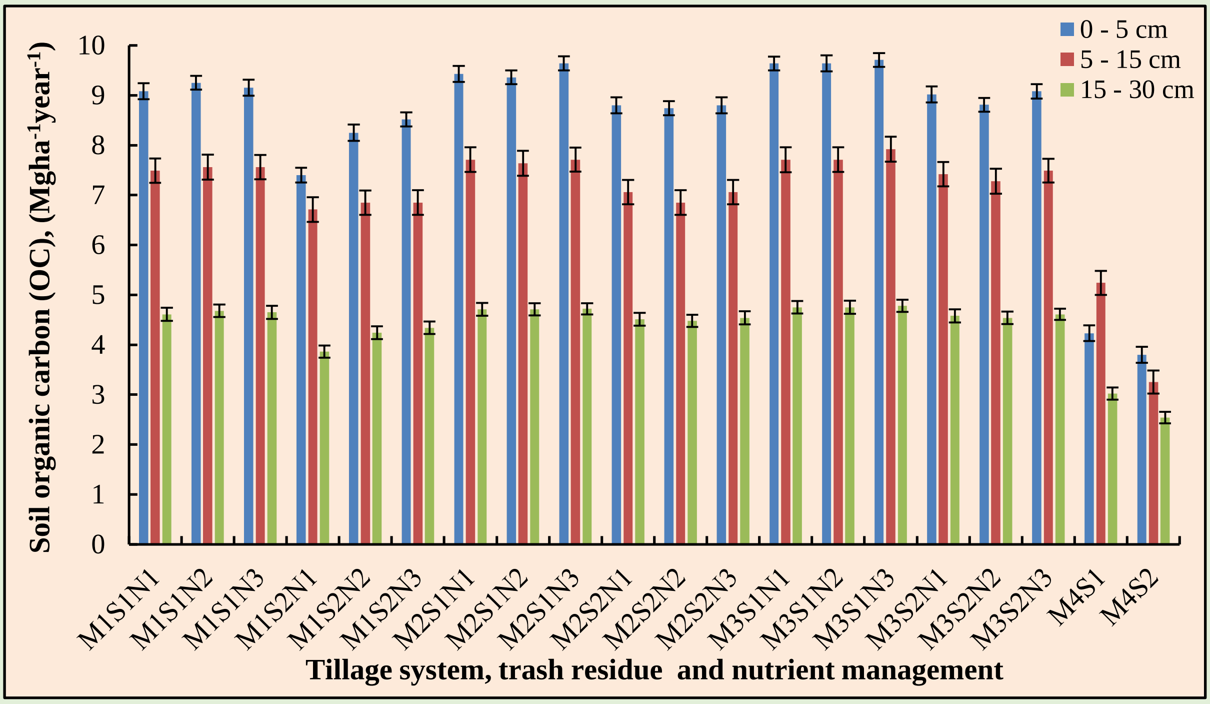


Fig. 27. Effect of tillage, crop residue and nutrient management on OC in different soil depth.

6. Tangible and Non-tangible Benefits of CA in Sugarcane

Conservation agriculture aims to make enhanced use of agricultural resources through the integrated management of available soil, water and biological resources, combined with restricted external inputs. The tangible and non-tangible benefits of the present long term CA investigation are given in Fig. 28. The cost of cultivation significantly reduced in CA as compared to conventional practices and recorded 10.83% and 8.79% saving in fresh and ratoon planted sugarcane, respectively (Table 2). Similarly, CA practices recorded saving in energy input over conventional practices except implement energy input. Because in CA systems, LLL and multipurpose machine were used for fresh and ratoon crop management; whereas in conventional agricultural practices, traditional methods were used and these costs included in other charges in respective inputs. Whereas, crop residue management with drip irrigation system in CA increases nutrient use efficiency by 26.3% in nitrogen, 22.8% in phosphorus, 27.9% in potassium and increases 38.2% organic carbon.

The productivity gain is also deviates in CA as compared to conventional agriculture (Table 3). In conventional agricultural practices, fresh and ratoon planted cane recorded 16.7% and 25.4% yield improvement with saving of 57.4% water and 15.7% electricity consumption. The net returns also increased by 16.5 and 23.5% in freshly and ratoon cane, respectively. The benefit cost (B:C) ratio of fresh and ratoon sugarcane is 2.87 and 2.96 in conservation agriculture, which was higher as compared to conventional agriculture 1.88 and 1.89, respectively.

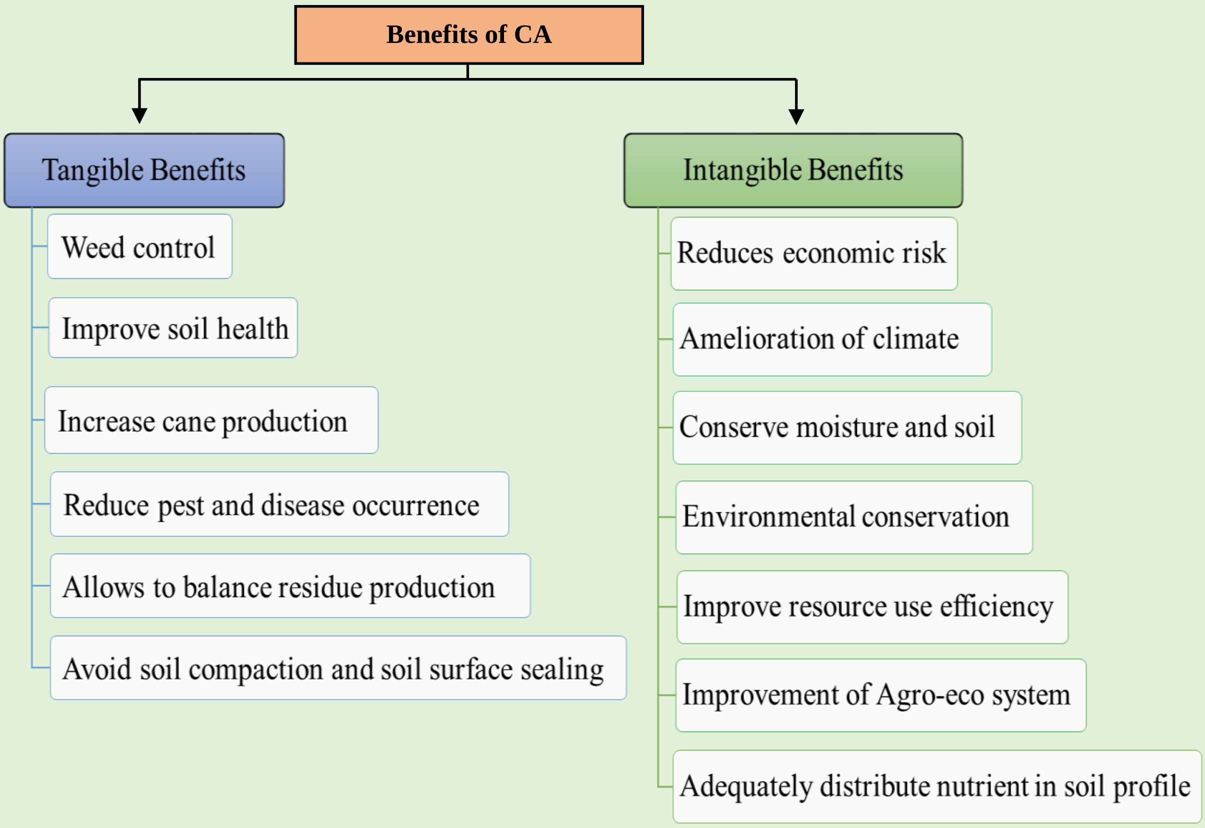


Fig. 28. Tangible and non-tangible benefits of CA practices in sugarcane.

Table 2. Cost of cultivation, energy inputs and nutrient saving in CA over conventional practices in fresh and ratoon sugarcane cropping system.

Cropping System	Cost of cultivation (Rs ha^{-1})		Mean values of energy inputs in fresh and ratoon sugarcane (MJ ha^{-1})								Nutrient saving (kg ha^{-1})			SOC increase (%)
	Fresh	Ratoon	Labour	Machinery	Diesel	Saplings	Irrigation	Herbicide	Pesticide	Implement	N	P	K	
Conventional agriculture	99892.1	86993.4	8911.3	4241.3	50451.3	50907.5	25238.5	2092.5	2730	2530	157	14.0	443	0.42
Conservation agriculture(CA)	89402.1	79608.4	4818.8	33.93.8	35768.8	43890.0	8743.8	1842.5	1135	3078	213	18.1	614	0.68
Saving/ increase over conventional agriculture (%)	10.8	8.8	45.9	20.0	29.1	13.8	65.4	12.0	58.4	-21.7	26.3	22.8	27.9	38.2

Table 3. Productivity gains, input saving and B:C cost ratio of CA over conventional practices in fresh and ratoon sugarcane.

Cropping System	Fresh crop yield (t ha^{-1})	Ratoon crop yield (t ha^{-1})	Water consumption (HP hours)	Electricity consumption (MJha^{-1})	Water use (HP hours)	Electricity efficiency (MJha^{-1})	Net return (Rs ha^{-1}) fresh crop	Net return (Rs ha^{-1}) ratoon crop	B:C fresh crop	B:C ratoon crop
Conventional Agriculture	125.5	109.4	7489	234608.2	48.1	1845.2	188757.9	164626.6	1.88	1.89
Conservation Agriculture	150.6	137.2	3192	197846.3	20.5	1361.5	256977.9	235951.6	2.87	2.96
Gains/increase over conventional agriculture (%)	16.7	25.4	57.4	15.7	57.3	26.2	16.5	23.5	-	-

7. Recommendations from the Long-term CA Studies in Sugarcane System

S. No.	Sowing	Situation	Time of sowing	Varieties	Seed rate	Spacing	Weed management	Nutrient management (kg ha^{-1}) N	P_2O_5	K_2O	Yield
1. Sugarcane (Planting geometry, micro-irrigation and trash management practices)											
1.	Fresh cane with Mung bean as live mulch	Sub-surface irrigation	Pre-seasonal Nov-Jan	Sugarcane MS-10001	11,400 sapling ha^{-1}	Zigzag paired row (225 cm × 75 cm) + SSDI	Four cycles of manual weeding	300*	115*	115*	Cane 159 t ha^{-1}
				Mung bean BM-2003-2	6 kg ha^{-1}						Mung bean 4-5 q ha^{-1}
2.	1st Ratoon +Crop residue retention/ live mulch	Sub-surface irrigation	Jan-Feb	Sugarcane MS-10001	11,400 sapling ha^{-1}	Zigzag paired row (225 cm × 75 cm) + SSDI	Three cycles of manual weeding	250*	115*	115*	Cane 149 t ha^{-1}
				Mung bean BM-2003-2	6 kg ha^{-1}						Mung bean 3-4 q ha^{-1}
3.	2nd Ratoon + Crop residue retention/ live mulch	Sub-surface irrigation	Feb-March	Sugarcane MS-10001	11,400 sapling ha^{-1}	Zigzag paired row (225 cm × 75 cm) + SSDI	Three cycles of manual weeding	250*	115*	115 *	Cane 143 t ha^{-1}
				Mung bean BM-2003-2	6 kg ha^{-1}						Mung bean 3-4 q ha^{-1}
2. Sugarcane (Tillage System, crop residue and nutrients management)											
4.	Planting Cane with Mung bean as live mulch	LLL + RT + 10 % of RDF as basal , 40 % through band placement and 50 % through fertigation	Pre-seasonal Nov - Dec	Sugarcane MS-10001	16,200 sapling ha^{-1}	150 cm × 45 cm + SDI	Four cycles of manual weeding	300 #	115 #	115 #	Cane 170 ha^{-1}
				Mung bean BM-2003-2	8 kg ha^{-1}						Mung bean 4.5-6 q ha^{-1}
5.	1st Ratoon + Crop residue retention/ live mulch	LLL + RT + SORF with fertilizer placement	Jan- Feb	Sugarcane MS-10001	16,200 sapling ha^{-1}	150 cm × 45 cm + SDI	Three cycles of manual weeding	250#	115#	115#	Cane 155 t ha^{-1}
				Mung bean BM-2003-2	8 kg ha^{-1}						Mung bean 4-5 q ha^{-1}
6.	2nd Ratoon + Crop residue retention/ live mulch	LLL + RT + SORF with fertilizer placement	March-Feb	Sugarcane MS-10001	16,200 sapling ha^{-1}	150 cm × 45 cm + SDI	Three cycles of manual weeding	250 #	115#	115#	Cane 152 t ha^{-1}
				Mung bean BM-2003-2	8 kg ha^{-1}						Mung bean 4-5 q ha^{-1}

***indicates** N, P_2O_5 and K_2O applied as 10% basal dose, 90% through fertigation in 13 splits

#indicates N, P_2O_5 and K_2O applied by multipurpose machine with placement of 25% of RDF as basal and remaining 75% by fertigation

8. Engineering Interventions for Conserving Resources in Sugarcane System

8.1. Multipurpose drill machine: Prototype details and field testing

Ratoon sugarcane crop is grown on half of the sugarcane area in India. Here, management of high load (10-15 t ha^{-1}) and tough nature of loose trash generated after harvest is major challenge for implementing CA practices. It also hinders most of field operations and thereby prevents intercropping in ratoon crop. Hence, trash burning is common practice followed by most of the farmers (Fig. 29), which results in loss of organic carbon, plant nutrients, soil biota besides the environmental pollution and health hazards due to release of soot particles, smoke and green-house gases (Hemwong et al. 2009). This also reduced ratoon cane yields by 25-30% than the fresh crop. There is lack of machinery in trash-retained fields for proper placement of fertilizers thereby poor acquisition and utilization of nutrients by the older roots and higher mortality of tillers. To address these issues, three different prototypes of multipurpose drill machines were developed with close collaboration with ICAR-IISR, Lucknow and private entrepreneurs (Fig. 30). All these prototypes are tractor (35-65 hp) operated and mounted with PTO-driven three-point hitch linkages. In addition to drilling of fertilizers and seeds (0.05-0.20 m soil depth depending on height of raised beds), the machines were found suitable to perform various other operations *viz.*, trash chopping, stubble shaving, covering of trash with loose soil, off-barring and root pruning in a single go for sugarcane ratoon crop. In brief, all prototypes consisting three main components: (i) power transmission unit, (ii) central horizontal rotating disc attachment with fixed peripheral blades for stubble shaving and (iii) two vertical discs/shovels for off-barring along with root pruning cum fertilizer placement mechanisms. The spacing between two high carbon steel root pruners mounted to the main frame is adjustable depending on the row spacing used for planting sugarcane. Adjustable vertical off-bar discs/shovels cut the raised bed (0.10-0.20 m soil depth) from outer sides and spread the lifted soil over the chopped trash. This also acts as root pruners for pruning of older roots. Fertiliser/seeds can be placed simultaneously through fertiliser box using fluted role-star wheel metering drill mechanism depending upon adjusted fertiliser rate below the surface.

Fig. 29. On-farm trash burning after sugarcane harvest- a common practice.

Before field trials with specified drill machine, it was calibrated for seed cum fertilizer applications. Then the disc/shovel type off bar/root pruning/ cutting mechanism was tested at field conditions (Fig. 31). Finally, it was evaluated for its performance in terms of growth and productivity of ratoon sugarcane under farmers' field conditions where comparisons were made with the usual practice of burning trash or its simple chopping and retention over the soil surface. The specification details and field testing results of most recently developed multifunctional ratoon manger drill machine (MRMD) i.e. prototype-III were compared with SORF machine (Prototype III) upgraded by ICAR-NIASM from basic ratoon management device (ICAR-IISR, Lucknow), as given in Table 4.

Prototype I: Trash chopper, offbar, root pruner cum fertilizer/ seed drill(ICAR-NIASM)

Prototype II: SORF machine- a upgraded version of ratoon management device

Prototype III: Multifunctional Ratoon Manager Drill (MRMD)

Fig. 30. Different prototypes of multipurpose drill machines for ratoon sugarcane.

Fertilizer cum seed calibration

Field testing of root pruner & cutting mechanism

Fig. 31. Calibration and field testing of multipurpose drill machines.

Table 4. Details of specification and field test results of different prototypes.

Details	Prototype II (Upgraded SORF, ICAR-NIASM)	Prototype III (MRMD, ICAR-NIASM)
Soil type	Best suited for alluvial soil	All (alluvial, black, murrum and stony etc.)
Power	55-65 hp	35-40 hp
Weight	390 kg	193 kg
Compactness	Comparatively less	High
Trash blockage problem	Resolved upto 90%	Completely resolved
Operations	Four operations (stubble shaving, off bar/ root pruning , fertiliser application	Five operation (stubble shaving, off bar/ root pruning, fertiliser application, sowing of intercrop (chickpea, maize etc.)
Field capacity	0.28 ha h^{-1}	0. 57 ha h^{-1}

8.2. Important features of the multipurpose SORF and MRMD machines

The SORF/MRMD machines are suitable to perform four-five major operations in a single run under ratoon sugarcane.

a. Stubble shaving: Un-even stubbles which are left in the field after manual harvesting of sugarcane are cut very sharply at a uniform height close to soil surface with a stubble shaver.

b. Off-baring: Adjustable vertical off-baring disc of SORF/shovels of MRMD cut the raised bed partially from outer sides and spread the cut soil over the chopped trash to accelerate its decomposition.

c. Root pruning: The side older roots of ratoon sugarcane are pruned to stimulate in fresh root growth. The slush of newly developed roots promotes the uptake of water and nutrients for boosting initial growth of ratoon sugarcane.

d. Placement of fertilizers: A fertilizer attachment is utilized for band placement of fertilizer in ratoon sugarcane while retaining the trash at the surface.

e. Sowing of intercrop (additional in MRMD): A seed drill attachment is utilized for sowing of intercrop in ratoon sugarcane while retaining the trash at the surface.

8.3. Performance evaluation of the multipurpose machines in ratoon sugarcane

The performance of multipurpose drill machines was evaluated with more than 40 field trials during 2015-2020; however results of initial 10 on-farm trials on black soils varying in texture (clay 27-44% and fertility (Org. C 4.4-9.3 g kg^{-1}) were presented. While evaluating the performance of this machine at farmers' fields, the following four treatments were imposed in randomized complete block design at each site, T_1: Burning of left over trash and broadcasting of basal fertilizer doses (farmer's practice); T_2: Chopping and surface retention of trash and thereafter broadcasting of basal fertiliser doses; T_3: Chopping and surface retention of trash and use of multi-purpose machine for stubble shaving, off-barring, root pruning and drilling of basal doses of fertilizers and T_4: Same as T_3 but increasing the basal N to double the recommended. Table 5 shows the improvement in cane yields average 16 and

11% over the trash burning (farmer's practice) and chopping followed by recommended practices of fertilizer application (0.45, 0.45 and 0.10 N as basal, at earthing-up and onset of monsoon rains, respectively) while the nitrogen uptake efficiency (NUE) improved by 9.9%. Band placement of double the dose of N as basal rather than the recommended two splits as basal and at earthing-up further boosted the initial growth and improved the cane yields and NUE by 22 and 11% over farmer's practice (Table 6).

Table 5. Effect of trash and nitrogen management on yield attributes of ratoon sugarcane.

Treatment	Millable cane ('000 ha^{-1})	Internodes per cane(nos.)	Internode length (cm)	Juice yield (ml $cane^{-1}$)	Cane yield (t ha^{-1})
T_1	132.0	16.9	10.5	420.3	124.1
T_2	141.3	17.6	10.9	444.5	130.4
T_3	157.8	19.4	11.8	485.5	144.3
T_4	167.3	19.9	12.0	513.8	149.7
LSD(p=0.05)	20.3	2.0	1.1	50.8	13.4

Table 6. Effect of trash and N management on uptake, apparent balance and nitrogen uptake efficiency (NUE) in sugarcane ratoon crop.

Treatment	Fertilizer -N (kg ha^{-1})	Total (stem, dry leaves and green leaves) N uptake (kg ha^{-1})	App. N Balance (kg ha^{-1})	NUE (%)
T_1	275	169.7	129.0	36.2
T_2	275	118.7	106.1	39.0
T_3	275	216.4	57.5	46.1
T_4	275	221.0	54.5	47.1
LSD(p=0.05)		22.7	23.2	4.8

Overall, it can be concluded that stubble shaving, off-barring, pruning of older roots and fertiliser placement, especially, double the basal N with the multi-purpose machine substantially improved the N-use efficiency and productivity of sugarcane ratoon crop under surface-retained trash conditions (Fig. 32). This certainly can help in boosting income of the sugarcane growers in addition to improving soil health, conserving water and environmental protection. Long-term monitoring would be required to quantify the latter benefits.

Ratoon cane growth in multipurpose machine

Ratoon cane growth under farmers practics

Fig. 32. Ratoon cane performance under multipurpose machine over conventional practices.

8.4. Benefits of the technology

a. Timely completion of ratoon management operations with highest field capacity (0.60 ha h^{-1}) using 35 hp tractor at 3.2 km h^{-1} operational speed.

b. Ratoon cane yield improved by 10-38%.

c. Healthier and more numbers of malleable canes and least tiller mortality rate.

d. Saving of 6-21% irrigation water and 20-25% fertilisers for ratoon sugarcane.

e. Band placement of fertilisers and sowing of intercrop like chickpea and maize is possible even surface retention of the trash conditions.

f. Significant improvement in nitrogen use efficiency up to 13% and environment friendly since reduction in ammonia volatilization losses and N_2O emission.

g. Net profit increased up to Rs.50000 ha^{-1} and cost ratio increased up to 12.6%.

h. Improved root growth helps in mitigating the adverse effects of short-term water stress.

8.5. Potential applicability, demonstration and cost of the technology

With the use of multipurpose machine, ratoon cane yield improved by 10-38%, while net profit of farmers improved by Rs. 27000 to 50000 ha^{-1}. Keeping in mind around 2.5 million ha area under ratoon crop, it is estimated that approximately Rs. 6.75-12.50 thousand crore/annum could be earned as an additional net profit by the farmers. Net profit increased up to Rs. 50,000.00 per hectare. This machine can perform the ratoon management operations along with sowing of intercrop viz., chickpea and summer maize etc. under surface trash retained field condition thereby enhances productivity and trash burning which creates environmental pollution could be avoided (Fig. 33). In situ retention of trash in the field sequestered the carbon and improved the soil health in long run. Considering the benefits of the machine, it was imperative to reach the technology, more than 250 on-farm experiments, demonstrations and exhibition programs were conducted for farmers, sugarcane industries and entrepreneurs during 2015-2020 (Fig. 34). The technology not only benefited the sugarcane growers but also the machinery manufacturers and sugar industries. The maximum cost of machine is INR. one lakh with all accessories.

Sowing of chickpea using multipurpose machine

Intercropping of summer maize using multipurpose machine

Fig. 33. Sowing and intercropping of chickpea and summer maize using multipurpose machine in ratoon sugarcane.

Fig. 34. Demonstration of multipurpose machine and on-farm experiments.

This is one of the revolutionary developments for ratoon sugarcane which enhanced the input-use efficiency, crop productivity and profitability of the sugarcane growers, in addition to reducing the environmental pollution by avoiding the trash burning and reduced emissions of GHGs. Further, with improved soil health and carbon sequestration through residue retention, it has potential to address the adverse effects of climate change in long run.

9. Salient Findings

1. The planting geometry ZPR-225 cm × 75 cm + SSDI resulted in higher 5.5% and 16.6% cane yields as compared to PSR (150 cm) + SDI and PSR (150 cm) + surface irrigation (SI) methods, respectively.
2. The synergies of micro-irrigation and mulching (trash/ live mulch) enhanced the cane yield by around 10-23%.
3. Laser Land Leveler (LLL)+ Reduced tillage (RT) + application of 40% RDF as band placement in standing crop and remaining 50% RDF through fertigation improved the cane yields by 5, 10 and 26% over LLL+ conventional tillage (CT) + 90% fertigation, LLL+RT+90% fertigation and farmer practices, respectively.
4. Soil health parameters N, P, K and organic carbon improved significantly under trash retained over trash burning practices.
5. Surface retention of trash improved the soil organic carbon (SOC) content by 7.1-16.2 % over trash burnt treatments.
6. Developed multi-purpose machines for stubble shaving, off-barring, root pruning, intercropping and band placement of fertilizers under soil-surface retained trash/residue condition: provided new avenues for successful implementation of CA in sugarcane based cropping system.
7. In-situ retention of chopped trash along with adoption of SORF techniques of ratoon management improved the soil microbial biomass carbon and dehydrogenase activity by 5.72 – 11.80 % and 6.55 – 13.01 % over conventional trash burnt treatments.

10. Capacity Building (Farmers, SMS, Students, Industry)

Following capacity building programmes were conducted during year 2015-20 (Fig. 35).

1. Organized two days’ workshop on “Challenges and Opportunities in Sugarcane Cultivation under Changing Climatic Scenario”, held during July 10-11, 2017, at ICAR-NIASM, Baramati, Pune, Maharashtra. More than 350 progressive farmers from Maharashtra were participated.
2. Organized model training on “Climate Smart Agriculture for Enhancing Crop and Water Productivity under Abiotic Stress Conditions", held during Dec 16-23, 2017 at ICAR-NIASM, Baramati, Pune, Maharashtra. More than 20 extension functionaries of state development departments/KVK/ICAR/ SAUs from India were participated.
3. Organized one day awareness workshop cum training program on “Scope and Prospects of Organic Farming in Sugarcane Cultivation”, held on June 26, 2018 at ICAR-NIASM, Baramati, Pune, Maharashtra. More than 150 progressive farmers were participated.
4. Organized one-day workshop on “Climate Smart Technology for Cultivation of Sugarcane”, held on July 27, 2019 at ICAR-NIASM, Baramati, Pune, Maharashtra. More than 320 progressive farmers were participated.

5. Organized collaborative training on “Climate Smart Agriculture and Abiotic Stress Management Technologies for Enhancing Farmers Income” held during December 16-20, 2019 at ICAR-NIASM, Baramati, Pune, Maharashtra. Total 26 extension functionaries of state development departments/KVK/ICAR/ SAUS from India were participated.

6. Organized model training course on “Climate Change & Abiotic Stress Management Strategies for Enhancing Crop Productivity & Farmers Income” held during January 4-11, 2020, at ICAR-NIASM, Baramati, Pune, Maharashtra. Total 23 extension functionaries of state development departments/KVK/ICAR/ SAUS from India were participated.

7. Conducted more than 250 field trials/frontline demonstrations of SORF/MRMD machines to the farmers, sugarcane industries and entrepreneurs during 2015-2020 at ICAR-NIASM, exhibition and foundation day programs etc. More than 1500 farmers, students, entrepreneurs were benefited.

Fig. 35. Workshop and trainings for farmers and extension functionaries.

11. Future Research in Assessing CA Impacts on Sugarcane Cropping System

Objectives		Activities
1. To quantify the impact of conservation agriculture on GHGs emission in sugarcane-based cropping system	i.	To assess GHG emission from sugarcane systems with conventional and conservation agriculture practices.
	ii.	Assessing water, carbon, nitrogen and energy footprints of conventional and conservation agriculture-based sugarcane systems.
2. To improve the water productivity through restructured planting technique, sub-surface drip irrigation systems and CA practices	iii.	To optimize the planting geometry and sub-surface drip irrigations for improving water productivity under CA practices.
	iv.	To assess the effect of conventional and conservation tillage system on soil compaction and infiltration rate.
	v.	To assess the impacts of conventional and conservation tillage system on yield, quality and water productivity.
3. To develop intercropping systems for sustainable soil and environmental health through conservation agriculture	vi.	To standardize intercropping in fresh and ratoon sugarcane cropping systems.
	vii.	To evaluate total system productivity, profitability and soil health in sugarcane-based cropping systems.
4. To develop suitable machine and microbial technology for sugarcane trash decomposition and nutrient management	viii.	To develop machines for detrashing in standing sugarcane crop.
	ix.	To refine the multifunctional ratoon manager, seed cum fertilizer drill in sugarcane cropping system.
	x.	Assessing efficacy of microbial biopolymers and growth promoting chemicals for managing water stress in sugarcane cropping system.
	xi.	To analyze available micronutrients and enzyme activity in soil under different tillage system, crop residues and nutrient management practices.

12. Publications

12.1. Research paper

1. Choudhary RL, Wakchaure GC, Minhas PS and Singh AK (2017) Response of ratoon sugarcane to stubble shaving, off-barring, root pruning and band placement of basal fertilisers with a multi-purpose drill machine. Sugar Tech 19(1), 33-40. DOI 10.1007/s12355-016-0438-x.

12.2. Books/book chapter/bulletin/proceedings published

1. Singh NP, Choudhary RL, Singh Y, Rane J, Krishnani KK, Wakchaure GC, Nangare DD, Singh AK, Meena KK and Kumar M (2017) Proceedings of Workshop on Challenges and Opportunities in Sugarcane Cultivation under Changing Climatic Scenario (July, 10-11 2017). Publication No. 17. ICAR-National Institute of Abiotic Stress Management, Baramati, Pune, India, pp. 28.

2. Choudhary RL, Kumar M, Wakchaure GC, Singh Y, Krishnani KK and Singh NP (2017) Conservation agriculture in sugarcane cropping systems: challenges and opportunities. In: Recent Advances in Abiotic Stress Management for Climate Smart Agriculture. (Singh NP, Bal SK, Singh Y. Eds.). Training Manual, ICAR-National Institute of Abiotic Stress Management, Baramati, Pune, India. pp. 77–87.

3. Choudhary RL, Kumar M, Kumar S, Ram H and Kumari A (2017) Potential of conservation agriculture in drought stress management in crop plants. In: Climate Change and Sustainable Agriculture. (Kumar PS, Kanwat M, Meena PD, Kumar V, Alone RA, Eds.). New India Publishing Agency, New Delhi, pp. 103–142.

4. Choudhary RL, Kumar M, Singh Y, Meena KK, Krishnani KK and Singh NP (2018) Conservation agriculture in sugarcane based cropping systems: the beginning. In: Advanced Training on Detection, Identification and Application of Microbially Derived Biomolecule for Alleviation of Salinity Stress in Crop Plants. (Meena KK et al., Eds.). Training Manual, ICAR-National Institute of Abiotic Stress Management, Baramati, Pune, India. pp. 158-169.

5. Choudhary RL, Wakchaure GC, Kumar M, Singh Y, Krishnani KK and Singh NP (2017) Conservation agriculture in sugarcane cropping system: a way towards climate smart production system. In: Climate Smart Agriculture for Enhancing Crop and Water Productivity under Abiotic Stress Conditions. (Wakchaure et al., Eds.). Training Manual, ICAR-National Institute of Abiotic Stress Management, Baramati, Pune, India. pp. 1–7.

6. Wakchaure GC (2020) Sugarcane ratoon management machinery for climate resilient agriculture. In: Wakchaure et al.; Climate change and abiotic stress management strategies for enhancing crop productivity and farmers income. ICAR-National Institute of Abiotic Stress Management, Baramati, Pune, India. pp. 134-137.

7. Meena KK, Choudhary RL, Wakchaure GC, Kumar M and Singh Y (2020) Planting methods for enhancing yield and water productivity of sugarcane crop through conservation agriculture. In: Wakchaure et al. Climate change and abiotic stress management strategies for enhancing crop productivity and farmers income. ICAR-National Institute of Abiotic Stress Management, Baramati, Pune, India. pp. 91-98.

12.3. General/popular article/technical folder

1. चौधरी आर एल, मिन्हास पी एस, वाकचौरे, जी सी, कुमार एम और मीणा के के (2015) गन्ने में संरक्षण खेती: वैश्विक जलवायु परिवर्तन के दौर में अपनाने की आवश्यकता, अवसर एंव चुनौतियाँ। *किसान खेती* 2(1): 43–48।

2. Choudhary RL, Singh AK, Wakchaure GC, Minhas PS, Meena KK, Singh NP (2017) SORF: A Multi-purpose Machine for Ratoon Sugarcane. Technical Folder No. 11, Consortia Research Platform on Conservation Agriculture, ICAR-National Institute of Abiotic Stress Management, Malegaon, Baramati- 413 115, Pune, Maharashtra, India.

3. चौधरी आर एल, सिंह ए के,वाकचौरे जी सी, मिन्हास पी एस, कृष्णानी के के,पटेल डी पी और सिंह एन पी (2017) सोर्फ;पेड़ी गन्ने के लिए एक बहुउद्देशीय मशीन तकनीकी फोल्डर संख्या 12; संरक्षण कृषि अनुसंधान मंच, भाकृअनुप- राष्ट्रीय अजैविक स्ट्रैस प्रबंधन संस्थान, मालेगांव, बारामती, पुणे-413115, महाराष्ट्र, भारत ।

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5. चौधरी आर एल, सिंह ए के, वाकचौरे जी सी, महेश कुमार, काले पी ए, कृष्णानी के के और सिंह एन पी (2018) गन्ने से अधिक मुनाफे के लिए बहुउद्देशीय मशीन । खेती, दोगुनी कृषक आय विशेषांक 59-57 ।

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12.4. Extended summaries/abstracts

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2. Choudhary RL, Minhas PS, Pondkule RG, Kale PA, Wakchaure GC, Kumar M, Saha S and Singh NP (2016) Root growth and cane yield of ratoon sugarcane under the combined effect of stubble shaving, off-barring, root pruning and placement of basal dose of fertilisers with surface retention of trash. In: Extended Summaries, 4th International Agronomy Congress on Agronomy for Sustainable Management of Natural Resources, Environment, Energy and Livelihood Security to Achieve Zero Hunger Challenge, 22-26 November, 2016, New Delhi, India. Vol 3, pp. 209-210.

3. Choudhary RL, Kale PA, Pondkule RG, Kumar M, Wakchaure GC, Meena KK, Krishnani KK and Singh NP (2017) Innovation and scope in summer mungbean cultivation for sustainable diversification of sugarcane cropping system in peninsular India. In: Souvenir & Abstracts, National symposium on Advances in Agriculture through Sustainable Technologies and Holistic Approaches, 15-17 February, 2017, Panjim, Goa. pp. 62.

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