Improved Sugarcane Mechanization Technologies

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Lucknow - 226 002 (U.P.)

About the book

This book contains various book chapters on the latest development in sugarcane technologies and their mechanization viz.. tillage machinery, planting and intercropping machines, inter-culturing machines, ratoon initiation machines, water conservation/ management in sugarcane, jaggery manufacturing, custom hiring, impact analysis of sugarcane machines etc. The basic and generalized chapters on the latest sugarcane production technologies, sugarcane varietal development and insects & pests management of sugarcane has also been included. The mechanization of various operations of sugarcane cultivation has been discussed in details. The book will serve as a useful resource to many, especially sugarcane research and development workers and students, entrepreneur and farmers.

भाकृअनुप
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ISO 9001:2015

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Citation : Singh, Sukhbir, Singh, A.K. and Pathak, A.D. (Eds.) 2020. Improved Sugarcane Mechanization Technologies. ICAR-Indian Institute of Sugarcane Research, Lucknow, India. 177 p.

Year of Publication : January 2020

ISBN : 978-93-5396-574-7

Published by : Director
ICAR-Indian Institute of Sugarcane Research
Lucknow-226 002

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Printed by : 33 Nehru Road, Sadar Cantt., Lucknow 522 - 2481164

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AGRICULTURAL SCIENTISTS RECRUITMENT BOARD
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FOREWORD

Sugarcane (*Saccharum* spp. hybrids) occupies a strong position as an agro-industrial crop of the country. It has a significant role in national economy and provides raw material to sugar and over 25 other industries producing alcohol, paper, chemical and cattle feed. With 5 million hectare of area, sugarcane occupies about 2.57% of total cropped area, contributes nearly 10% of gross value of the agricultural GDP in the country and provides livelihood to around 6 million cane growers. Due to its versatile uses in different industries, the demand is increasing for the increased production and its sustainability in the country.

In view of the facts that mechanization of sugarcane crop culture would solve the ever increasing problems of scarcity of labour, cost of cultivation, drudgery and timely completion of cultural operations, commendable work have been done at ICAR-Indian Institute of Sugarcane Research, Lucknow since its inception to develop useful sugarcane machines and implements to perform different cultural operations in time for improving the cane productivity per unit time, area and energy. The developed post-harvest technology for manufacturing of value added jaggery and other products also finds a good place in the recent time. These useful implement/machines/technologies needed to be popularized by creating awareness among different stake holders. The book on, *"Improved sugarcane mechanization technologies"* provides information about latest development in sugarcane cultivation technologies and their mechanization and will be very useful for the researchers, teachers, students, farmers and entrepreneurs working on sugarcane and allied crops.

I appreciate the efforts done by the editors for collecting, editing and publishing this book in the present format. I hope this publication will be very useful to all the concerned.

(K.K. Singh)

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PREFACE

Mechanization of agriculture is an essential input in modern agriculture. It enhances productivity by performing farm operations timely, reduces human drudgery and cost of cultivation. Efficient machinery helps in increasing productivity by about 30% besides, enabling the farmers to raise a second crop, making the agriculture attractive. Raising more crops with high productivity is a path for meeting the future food requirement of the population. Development and introduction of high capacity, precision, reliable and energy efficient equipment is the need for judicious use of inputs. Mechanization imparts capacity to the farmers to carry out farm operations with ease and freedom from drudgery, making the farming agreeable vocation for educated youth as well.

Considering the importance and the necessity of mechanizing sugarcane cultivation in the country, the book on "Improved Sugarcane Mechanization Technologies" has been compiled and edited. The book contains various book chapters on the latest development in sugarcane technologies and their mechanization *viz.,* improved tillage machinery, planting and intercropping machines, interculturing machines, ratoon initiation machines, water conservation/ management in sugarcane, jaggery manufacturing, custom hiring, impact analysis of sugarcane machines *etc*.

We are grateful to all the authors for their efforts in contributing the articles for the book. We also express our gratitude to the Director, ICAR-Indian Institute of Sugarcane Research, Lucknow for his encouragement, guidance and support and providing fund for publication of the book. Thanks are due to Sh. Brahm Prakash, CTO for helping in various ways. The book would be useful to many, especially sugarcane research and development workers and students, entrepreneur and farmers. We express our sincere thanks to all the contributors for their co-operations.

Editors

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Sugarcane Mechanization Research at IISR

A.D. Pathak
Director, ICAR-Indian Institute of Sugarcane Research, Lucknow

The Indian Central Sugarcane Committee (ICSC) was formed by a resolution of the Government of India to co-ordinate research efforts in sugarcane and it began functioning from November 29, 1944. In 1947-48, the Indian Central Sugarcane Committee decided to establish a full-fledged Research Institute on sugarcane in Uttar Pradesh. Thus, came up the Indian Institute of Sugarcane Research (IISR) at Lucknow on February 16, 1952 for conducting research on fundamental and applied aspects of sugarcane culture as well as to co-ordinate the work done on this crop in different states of India. The Government of India took over the Institute from the Indian Central Sugarcane Committee on January 1, 1954. On April 1, 1969, it was transferred to the Indian Council of Agricultural Research (ICAR), New Delhi. Since its inception, the Institute has been working towards the upliftment of cane agriculture in India, in terms of quality, productivity, management practices and various policy issues. The Institute has a unique advantage of carrying out research work on equipment and machinery used in sugarcane cultivation as the Institute has full-fledged Division of Agricultural Engineering, which the many other crop Institutes are not having. The Division of Agricultural Engineering at Indian Institute of Sugarcane Research came into being since its inception in 1952 with an objective to develop suitable equipment and technology for sugarcane crop, sugarbeet farming, soil and water conservation, instruments, *gur* manufacturing and storage. It also catered operational and maintenance support to the Institute.

Sugarcane Mechanization Efforts at IISR

Sugarcane cultivation requires various operations like land preparation, planting, irrigation, inter-culture, earthing up, plant protection, harvesting including de-trashing and de-topping, and ratoon management. Most of the cultural operations are labour intensive; hence, there is an urgent need to switch over to mechanize the crop cultivation to increase overall production and profitability. Use of suitable implements can play an important role in increasing production and productivity of sugarcane on sustainable basis. Mechanization of sugarcane farming aims at timeliness of operation, reduced cost of unit operations, reduced human drudgery and increasing productivity of other critical inputs such as labour, fertilizer and agricultural chemicals.

Initially up to 1980, the focus was on the R&D of animal drawn equipment but gradually the share of bullock power in the total farm power availability goes down and the work on tractor drawn semi-automatic equipments and then automatic equipment was started. Prototypes developed since its inception, specifically of cane based mechanization, have been abridged. Many prototypes developed earlier have lost their utility on the advent of their improved versions.

Bullock-drawn and Manual Operated Tools and Implements

The work on bullock drawn implements was taken up in late fifties by development of multipurpose implement used as mould board, as a furrower/ridger and as a cultivator and then a prototype for opening furrows was developed. A manual sett cutting machine was developed using a sharp shearing plate with a 1.5 m long lever connected with a crank and a fly wheel. For planting sugarcane, first an attempt was made in 1958 to develop a bullock drawn planter for fertilizer dispensing and soil covering unit. Then a bullock drawn semi-automatic sugarcane planter and tillage-cum-potato planter was developed. Bullock drawn sprayer was developed with larger covering capacity, having 40 l fluid tank and capacity of 2.5 to 3 ha/day. Animal drawn weeder mulcher was developed to remove weeds from the inter row spaces in sugarcane. A manual harvesting tool and cane stripper were developed to reduce human drudgery.

Tractor Operated Implements

Some of the machines developed at IISR, Lucknow are used for sugarcane cultivation for different field operations are enumerated below operation wise :

Seedbed preparation

Field preparation with tractor operated culti-harrow have been found quiet effective with less energy consumption as this implements can perform three operations *viz.* cultivating, harrowing and planking in a single pass, thus, thereby saving in time and fuel as compared to conventional practices.

Seed treatment through heat therapy

In order to control the disease, seed cane is treated at a temperature of 54^0C for about 2½ hours at a humidity level of about 95-99% or at 50^0C for a period of about 2 hours in case of moist hot air and hot water treatment plants, respectively. Moist hot air treatment (MHAT) unit was developed by IISR useful in treatment of seed cane and saves crop from seed borne diseases like RSD, Red rot, Leaf scald disease, GSD, Smut *etc*. This unit is being commercially manufactured.

Planting operations

IISR, Lucknow has developed various models of sugarcane cutter planters *viz.,* ridger type, trench planter, paired row planter, deep furrow planter *etc.,* as per the agronomic practices followed time to time. Different variants are either tractor PTO or ground wheel driven.

Work on development of tractor drawn mounted type three row attachments for planting sugarcane was started at IISR, Lucknow in 1957. This unit was modified to two row semi-automatic planter. The work on development of sugarcane cutter planter was started at IISR, Lucknow to accommodate all components related to planting in a single unit. Prototype of tractor drawn PTO operated 2-rows sugarcane cutter planter with four discs was developed. Then a ridger type furrower was used and ridger type cutter planter was developed, tested and demonstrated at farmers' field.

Paired row sugarcane cutter planter was developed to facilitate paired row planting of sugarcane. Ring pit method is another method of cane cultivation. A tractor operated double bottom pit digger was developed for mechanizing ring pit planting of sugarcane. IISR Multipurpose sugarcane planter was also developed which not only worked as three row planter but also used for interculturing and earthing-up in cane field. IISR deep furrow sugarcane cutter planter was developed for mechanizing planting of sugarcane in deep furrows adds advantage over logging of cane, germination, ratooning and yield. IISR trench planter was developed for mechanizing trench planting of sugarcane.

Machine for companion cropping with sugarcane

Mustard seeding attachment (2 rows) with tractor drawn sugarcane planter for companion cropping was developed at IISR, Lucknow. IISR sugarcane planter-cum-seeder was developed for flat planting of sugarcane and drilling 2-3 lines of companion crop seeds in between two rows of sugarcane. For intercropping of wheat with sugarcane, a tractor operated raised bed seeder was developed to make three furrows and three raised beds and drill three rows of wheat and pulse seeds at each bed. Another machine known as IISR RBS (raised bed seeder) cane planter was developed to perform planting of two rows of sugarcane in furrows and sowing of two rows of seeds of companion crop on the raised beds simultaneously in a single pass of the tractor. New prototypes of IISR tractor operated deep furrow sugarcane planter-cum-multicrop raised bed seeder, sugarcane-cum-potato planter and trench planter-cum-seeder were also developed and field tested.

Weeding and interculture

The feasibility of using walking type garden tractor to control the weeds mechanically was started in 1956 at IISR farm. Then a high clearance tool bar and an eleven tine tiller with 35 hp tractor was used for inter-row weeding. During eighties, the Institute had developed engine operated self-propelled weeder for sugarcane. Two models of IISR tractor operated sugarcane manager were developed. Recently, IISR tractor operated multipurpose interculturing equipment was developed for inter row interculturing and intra-row herbicide spraying attachment.

Harvesting and detrashing

Efforts at IISR, Lucknow for development of whole cane harvester was started during 1980 with the development of a power tiller operated front mounted whole cane harvester to cut a single row of cane. A tractor operated side mounted whole cane harvester for cutting of single row of cane and tractor front mounted sugarcane windrower harvester for harvesting two rows of cane was developed. In 2012, a new prototype of tractor front mounted sugarcane harvester was developed for cutting and windrowing of two rows of cane such that windrowing of one row was in transverse direction while other row windrowed linearly to the direction of travel.

The developed harvesters provided partial solution of sugarcane harvesting and rest of the operations such as detrashing, detopping *etc.,* could be performed manually. The work on development of power operated detrashing machine was started in 1972 at IISR, Lucknow. A prototype of tractor mounted sugarcane detrasher was developed consisting of pair of detrashing rollers. A new prototype of power operated sugarcane detrasher was developed in the Institute for removal of green top as well as dry trash from the harvested sugarcane stalks in 2015.

Plant protection

For control of insects and pests diseases, application of chemicals is done with help of sprayers at the initial stage. In order to spray effectively and efficiently in tall cane crop, a T-shaped wide swath spray boom was designed and developed at IISR, Lucknow during 1977-78.

Earthing up

The earthing up operation has been practiced in sugarcane standing crop to protect the cane from lodging. IISR S.S. Furrower and a new IISR deep furrower can be used for earthing up where row to row spacing is 90 cm. Deep furrower can be used for deep furrow opening.

Ratoon management

A tractor drawn single row stubble shaver was developed for this purpose in 1977 and after multi-location trials, the unit was recommended for commercial release. A two row tractor mounted stubble shaver with attachments was designed and developed in 1984. A ratoon management device (RMD) was designed and developed for stubble shaving, off-barring and deep tilling; placement of manure and bio-fertilizer, application of chemical, vegetative extracts *etc.* liquid form; interculturing and ridge making in 2010. IISR also developed ratoon management device and ratoon manager. For performing ratoon initiation operations like stubble shaving, off-barring and fertilizer application in ratoon field with trash, disc-type ratoon management device was designed and developed.

Post-harvest technology

The concentrated research efforts have been devoted to various aspects of jaggery making, packaging, drying, storage *etc.* A jaggery unit has been established for manufacturing of value added jaggery and other products. The Institute has also developed a 2-pan and 3-pan furnace with better efficiency over the traditional ones. Jaggery is produced in many shapes and sizes. Jaggery moulding frames was developed for producing jaggery in cubes of 1 inch weighing 20-22 g each.

The commendable work on sugarcane mechanization has been done by the Division of Agricultural Engineering. During the last 67 years, much useful and innovative machinery have been developed for mechanization of sugarcane cultivation and post-harvest technology. There is need for mass multiplication and adoption of these useful equipment at farmers' level. IISR has signed memorandum of agreement (MoA) with few manufacturers for manufacturing of these equipment on commercial scale.

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Overview of Sugarcane and Sugar in the World

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Sugar was considered as rare commodity and it was used as medicine rather than as sweetener. From medicine to a luxury, sugar has become a necessity. Globally, it is an integral part of food to provide energy. Carbohydrates such as starch, sugar and polysaccharides are very important in the human diet (Blume, 1985). Sugar is today regarded as a mass consumption item and it also accounts for a large share of the total calorie intake of an average household (Pruthi, 1995). Worldwide per capita sugar consumption reached the equivalent of an energy intake of more than 837 kJ (200 kcal) daily (Hagelberg and Harris, 1976). Presently, the sugarcane crop provides the third highest quantity of human consumed plant calories (152 kcal/capita/day) following rice (533 kcal) and wheat (530 kcal) as reported by Moore and Botha 2014. Consumption of sugar has increased remarkably, faster than the growth of the world's population. Just before world war II, the annual consumption of centrifugal sugar had risen to 24 million tonnes while in 1980, it was about 90 million tonnes, raw value, and during the same period the annual per capita consumption increased from 11 to than 21 kg/year (Blume, 1985). Presently, it has gone up to 186 million tonnes (2019) and annual per capita consumption has risen to the level of 23 kg/year (2013). It is expected that World sugar futures will under pressure in 2018-19 due to less production of sugar and it is estimated to fall 9.0 million tonnes less for 2018-19 in comparison to 2017-18, which increasing the gap between global supply and consumption. As our country is also going to face surplus sugar production during 2018-19, we have to plan strategies to meet the demand of our internal consumption of sugar. In this chapter we have discussed the world sugar production and consumption and world sugar trade in major sugar producing and consuming countries of the world with special emphasis on India. As international sugar trade is of strategic importance to India as it helps in maintain stability in the domestic sugar prices despite the cyclic nature in production. Also, the potential for expanding sugar production in India exists and can be fully exploited, if adjustments were introduced to ensure a market driven relationship between sugar and sugarcane prices (Balasaheb, 2013).

Analysis of sugarcane and sugar in different countries of the world

An attempt to understand the sugar production, consumption and trade in different countries of the world was undertaken in this study. Data of sugarcane and sugar producing countries (2013 and 2015) was analyzed. Sugarcane is cultivated worldwide and 80.14% of sugar is produced from cane only (Table 1). The remaining 19.86% sugar is derived from sugar beet by 23 countries, which is grown mainly in temperate zone in the North. Out of 101 sugarcane producing countries, top ten countries contribute 81.47% in area and 82.85% in production of world. Asian and South American countries dominate in sugarcane production, which account for nearly 85% of cane production in

Table 1. Sugarcane area, production, yield and sugar production in top ten countries of the world (2013/ 2015)

Country	Area (000 ha)	Production (000 tonnes)	Yield (t/ha)	Sugar Production (000 tonnes)
Brazil	9835.17	739267.04	75.17	35800.00
India	5060.00	341200.00	67.43	27250.00
China	1819.00	125536.00	69.01	13300.00
Thailand	1321.60	100096.00	75.74	10200.00
Pakistan	1128.80	63749.90	56.48	4700.00
Mexico	782.80	61182.08	78.16	6508.00
Indonesia	450.00	33700.00	74.89	2500.00
Philippines	435.41	31874.00	73.21	2500.00
Colombia	405.74	34876.33	85.96	2300.00
Argentina	370.00	23700.00	64.05	2050.00
World	26522.73	1877105.11	70.77	171340.00

Data Source : FAO database (Food and Agriculture Organization of United Nations, Rome) and International Sugar Journal, 2015.

world. Brazil and India are two major countries contribute a large share of 56.16% in area and 57.56% in production of the world. Among these top ten countries, Colombia had the highest cane yield (85.96 t/ha and the rest of nine countries had cane yield in between 67 to 80 t/ha. Top ten high cane yield (t/ha) producing countries are Peru (133.72), Ethiopia (119.57), Egypt (115.33), Senegal (114.10), Malawi (107.41), Zambia (102.56), Burkina Faso (102.13), Guatemala (100.69) and United Republic of Tanzania (100.00) and Nicaragua (98.18) but these countries contribute only 2.59% in area and 3.97% in production of the world total of sugarcane, whereas world cane yield is reported as 70.77 t/ha.

Out of 91 sugar producing countries, major ten sugar producing countries from sugarcane are Brazil (25.92%), India (19.73%), China (9.01%), Thailand (7.38%), Mexico (4.71%), Pakistan (3.37%), Australia (3.33%), USA (2.36%), Guatemala (2.02%) and Indonesia (1.81%) which accounts for 85 % of total sugar production from cane. Fifty four per cent of world sugar are produced by Brazil (20.77%), India (15.81%), EU (9.46%) and China (7.72%). Main sugar exporting countries are Brazil (44.23%), Thailand (15.84%), Australia (6.52%) and Guatemala (3.63%), these four countries account for 70.77% of the total export of sugar in world. Out of 127 sugar importing countries, major ten sugar importing countries are China (7.55%), Indonesia (7.55%), EU (6.96%), USA (6.26%), UAE (4.67%), South Korea (3.87%), Malaysia (3.83%), Bangladesh (3.78%), Algeria (3.68%) and Iran (3.18%), which accounts of 51.33% of total import of world. Global sugar consumption has continued to increase from 1,62,438 thousand tonne (2010-11) to 1,76,834 thousand tonnes (2014-15) and will further continue at faster rate in under developed countries of Asia and Africa.

Consumption and trade of sugar in different countries of the world

Top five human domestic sugar consumption countries are India (15.93%), EU (10.91%), China (9.01%), Brazil (6.78%) and USA (6.35%) which accounts nearly 50% of total sugar consumption of the world. Classification of per capita sugar consumption in 110 countries is analysised with five categories as Very High, High, Medium, Low and Very Low. Per capita consumption of sugar is very high (> 45 kg) in nearly 20 countries (Israel, Brazil, Cuba, Malaysia, Switzerland, Barbados, Singapore, Costa Rica, Trinidad & Tobago, Belize, New Zealand, Sudan, Gambia, Mauritania, Swaziland, Australia, Guatemala, Jamaica, Belarus) of the world. Out of 151 countries, 56 countries reported negative trend of per capita consumption of sugar (kg/year) during 2007 to 2013. Most of the countries, which had observed negative trends are from developed and developing countries. During 2007 to 2013, per capita consumption of sugar (kg/year) is increasing at faster rate in under developed countries of Asia and Africa. Top twenty five countries where it showed increasing trends are Rwanda, Sudan, Eritrea, Zimbabwe, Cameroon U.R., Myanmar, Tanzania U.R., Bangladesh, Benin, Gabon, Rep. of Korea, Zambia, Guinea Bissau, Armenia, Lao, P.D.R., Papua N. Guinea, Zaire-Congo, Dem R., Kampuchea, Afghanistan, Thailand, Honduras, Belize, Togo, Albania and Jamaica. These countries may be the suitable destination to export sugar from India as most of these countries are not producing sugar.

After increasing trends of world sugar production from 2010-11 (1,62,438 thousand tonnes) to 2013-14 (1,81,404 thousand tonnes), decline in sugar production was observed in 2018-19 (9 m tonnes from previous year) and will further decline next year as projected by most of the sugar forecasting agencies. Out of 91 sugar producing countries in world, India is the second largest producer of sugarcane (18.18%) and sugar (15.81%) next to Brazil. India is also the largest consumer of sugar (15.93%) of the world and the 7th largest exporter of sugar (2.80%) to 113 countries of the world . The large share of total export (2951 thousand tonnes) was made to Myanmar (27.72%), Sudan (13.05%), Somalia (11.05%), Sri Lanka Dsr (6.26%), United Arab Emirates (4.85%), Tanzania Rep (4.25%), Pakistan (3.66%), Kenya (2.98%), Saudi Arabia (2.33%), Jordan (2.52%), Ethiopia (2.57%), Turkey (1.89%), Djibouti (1.61%), Oman (1.63%), Bangladesh (1.83%) during 2015-16 (April-January). There was significant increase of nearly 51% export of sugar in 2015-16 over 2014-15. Around 35% of sugar produced globally is made available for trade by different importing/exporting countries of the world. Most of the sugar produced by different countries of the world are consumed internally by large producing countries like Brazil (20.77%), India (15.81%), EU-27 (9.46%), China (7.72%) and Thailand (5.92%). These five countries produced 60% of the world total and consumed around 45% of world total. Out of 69 sugar exporting countries of the world, Brazil (44.73%), Thailand (15.84%), Australia (6.52%), Guatemala (3.63%) and Mexico (3.32%) are the major players in export of sugar which account for nearly 75% of the world export.

Current world sugar situation

Based on the average value of production and consumption (2010-11 to 2014-2015) of sugar in different regions of the world, Asia is the largest producer of sugar (33.84%) and also the largest consumer of sugar (41.10%). There is a deficit of 7.27% and require to import sugar to meet the demand of internal consumption. South America is the second largest producer (23.57%) of sugar and consumed only 11.07% of the world and have 12.5% of surplus sugar to export (Table 2). In case of the North and Central America, sugar production and consumption are same of about 11% of the world. Africa contributes only 5.70% of the world production where as it consumes 9.91% of world consumption and require to import 4.21% of world.

Table 2. Sugar production and consumption in different regions of the World (Average value during the period 2010-2011 to 2014-2015)

Regions	Sugar Production (000 tonnes) (1)	Sugar Consumption (000 tonnes) (2)	Difference (000 tonnes) (1) – (2)	Sugar Production (%) over world total (3)	Sugar Consumption (%) over world total (4)	Difference (%) (3) – (4)
EU	17604	19001	-1397	9.05	10.01	-0.96
Europe	28230	31008	-2778	14.51	16.33	-1.82
Africa	11081	18810	-7729	5.70	9.91	-4.21
N. & C. America	21483	20289	1194	11.04	10.68	0.36
South America	45861	21029	24832	23.57	11.07	12.50
Asia	65834	78055	-12221	33.83	41.10	-7.27
Oceania	4481	1708	2773	2.30	0.90	1.40

Data Source : International Sugar Journal, 2015

F.O. Licht (2016) projected that Global sugar production is estimated to fall 7.60% (13.3 million tonnes less for 2015-16 in comparison to 2014-15) which increasing the gap between global supply and consumption. Sugar production is also expected to fall further in 2018-19, as the current dry weather will affect the production and yield in India, Thailand, South Africa, EU and North-East Brazil. According to revised Government estimates, sugar production in India for the current year (2018-19) is expected to be 25.6 million tonnes compared to 28.3 million tonnes produced in 2014-15, a shortfall of 2.7 million tonnes. ISMA estimates that sugar stocks at the end of sugar season 2015-16 will be 7.5 million tonnes compared to 9.1 million tonnes a year back. Sugar analysts opine that lower-than-average rainfall will adversely affect sugarcane production in 2016-17 in major parts of Maharashtra and Karnataka. But this shortage is likely to be well compensated by higher production from UP and Tamil Nadu. UP has increased acreage under Co 0238 variety, which gives a much higher yield and sugar recovery. India’s sugar output risks dropping below consumption for the first time in seven years, threatening to cut exports and boost global prices, particularly if imports are needed for the first time since 2008-09. India’s annual sugar demand is around 26 million tonnes, but B.B. Thombre, President of the Western India Sugar Mills Association, said the country could struggle to produce 24 million tonnes in year 2016-17.

In year 2015-16, sugar production is almost equal to the domestic consumption in our country. The sugar mills opened the current season with a significantly high opening stock of 9.1 million tonnes. Unless and until further export contracts take place, 9.1 million tonnes of opening stocks will get drawn down to around 7.5 million tonnes which is still a significantly high opening balance for 1st October, 2016. A climate management company, Weather Risk Management Services has predicted above normal and well distributed monsoon for India after two successive droughts that will improve prospects for cane planting in 2016-17. Sugar prices have risen substantially since mid-September 2015. India for once is all set to benefit from the world shortage as it is expected to produce sugar equal to it's internal consumption.

Recent growth of sugar in different countries of the world

The annual compound growth rates in top ten sugarcane and sugar producing countries were estimated by fitting exponential type of equation during 2001 to 2013/2015 and results are presented in Table 3. In case of sugarcane area of major ten countries, all the countries recorded positive annual compound growth rate except Colombia. Brazil had the highest compound growth rate of 6.89% per annum. Out of ten countries, six countries recorded compound rate in between 1.5 to 3.0% per annum for cane area. Similar observations were also noted for sugarcane production. As far as cane yield is concern, top three countries, Brazil, India and China, recorded less than 1 % annual compound growth rate. Where as Thailand and Pakistan had highest compound growth rate of 2.70 % and 1.62 5 per annum. Further negative growth rate in cane yield was observed in Indonesia (-1.06), Colombia (-0.69), Mexico (-0.32), Philippines (-0.30) and Argentina (-0.17). Cane production (million tonnes) in these five countries reduced from 29.30 to 29.40 in Indonesia, from 39.85 to 33.22 in Colombia, from 51.65 to 55.78 in Mexico, 31.4 to 32.53 in Philippines and from 24.40 to 27.71 in Argentina over the period 2005 to 2015. Reduction in cane area and production in these five countries may be observed due to decline productivity.

It is revealed from the Table 3 that the quantity of sugar production from sugarcane had a positive annual growth rate for all the countries except Australia and USA among the top ten sugar producing countries from sugarcane. Impressive annual compound growth rate (%) of sugar production from cane were recorded by top six countries, Brazil (5.16), Thailand (5.14), India (3.08), China (4.19), Pakistan (3.45) and Guatemala (3.29). Mexico (1.43) and Indonesia (1.82) also recorded significant growth rate (%). Australia and USA showed negative annual compound growth rate of -1.32% and –0.62% respectively. Out of top ten sugar producing countries from sugar beet, all the countries recorded either negative growth rate or less than 1% except Russia and Belarus. Both the countries showed phenomenal growth of sugar production from sugar beet of around 10% per annum during last fifteen years (2001-2015).

Table 3. Annual compound growth rate (%) of sugarcane and sugar in top ten countries of the world during the period 2001 to 2015

Factors of sugarcane	Annual compound growth rate (%)									
Sugarcane area (2001 – 2013)	Brazil (6.89)	India (1.53)	China (2.98)	Thailand (2.26)	Pakistan (0.45)	Mexico (1.60)	Indonesia (2.13)	Philippines (0.98)	Colombia (-0.28)	Argentina (2.38)
Sugarcane production (2001 – 2013)	Brazil (7.62)	India (2.10)	China (3.77)	Thailand (5.02)	Pakistan (0.06)	Mexico (1.28)	Indonesia (1.05)	Philippines (0.68)	Colombia (-0.97)	Argentina (2.21)
Sugarcane yield (2001 – 2013)	Brazil (0.69)	India (0.56)	China (0.76)	Thailand (2.70)	Pakistan (1.62)	Mexico (-0.32)	Indonesia (-1.06)	Philippines (-0.30)	Colombia (-0.69)	Argentina (-0.17)
Sugar production from sugarcane	Brazil (5.16)	India (3.08)	China (4.19)	Thailand (5.14)	Mexico (1.43)	Pakistan (3.45)	Australia (-1.32)	USA (-0.62)	Guatemal a (3.29)	Indonesia (1.82)
Sugar production from sugar beet	EU-27 (0.05)	USA (0.80)	Russian (9.15)	Turkey (0.46)	Ukraine (-0.27)	Egypt (9.99)	China (-0.37)	Iran (-0.81)	Belarus (10.07)	Japan (-1.18)
Sugar production from cane and beet	Brazil (5.16)	India (3.08)	EU-27 (0.04)	China (3.74)	Thailand (5.14)	USA (0.15)	Mexico (1.43)	Pakistan (3.45)	Australia (-1.32)	Russian (9.15)
Total sugar distribution	India (1.38)	Brazil (4.76)	China (6.24)	EU-27 (0.09)	Thailand (6.82)	USA (1.32)	Indonesia (3.25)	Mexico (1.07)	Russia (-2.88)	Pakistan (2.88)
Sugar human consumption	India (2.68)	EU-27 (0.20)	China (4.32)	Brazil (1.56)	USA (1.50)	Indonesia (4.61)	Russia (-1.33)	Pakistan (1.90)	Mexico (-1.14)	Iran (3.12)
Sugar exports by country	Brazil (7.40)	Thailand (6.28)	Australia (-1.57)	Guatemala (3.40)	Mexico (30.55)	EU-27 (-3.31)	India (8.39)	Cuba (-8.68)	Colombia (-3.75)	South Africa (-3.70)
Sugar imports by country	China (11.23)	Indonesia (8.23)	EU-27 (6.95)	USA (6.95)	UAE (5.50)	South Korea (1.19)	Malaysia (2.70)	Bangladesh (7.77)	Algeria (4.64)	Iran (3.99)

Data Source (2015) : United States Department of Agriculture (http://www.usda.gov) and FAO database (Food and Agriculture Organization of United Nations, Rome)

The highest annual compound growth rate (%) of sugar consumption was estimated in Indonesia (4.61) followed by China (4.32), Iran (3.12), India (2.68), Pakistan (1.90), Brazil (1.56) and USA (1.50). Where as negative growth rate was observed in Russia (-1.33) and Mexico (-1.14) among the top ten sugar consuming countries of the world. Among the top ten sugar exporter countries of the world, the highest annual compound growth rate (%) of sugar export was recorded by Mexico (30.55) followed by Brazil (7.40), India (8.39), Thailand (6.28) and Guatemala (3.40). Whereas highest negative growth rate (%) was observed in Cuba (-8.68) followed by Colombia (-3.75), South Africa (-3.70), EU-27(-3.31) and Australia (-1.57) among the top ten sugar exporting countries of the world.

Among the top ten sugar importing countries of the world, the highest annual compound growth rate (%) of sugar import was observed in China (11.23) followed by Indonesia (8.23), Bangladesh (7.77), EU-27 (6.95), USA (6.95) and UAE (5.50). No negative growth was observed in top ten importing countries of the world. It clearly indicated that the quantity of sugar production have to be increased annually by faster rate as demand is increasing gradually in importing countries of the world. F.O. Licht (2015) reported that a major element of weakness is the general lack of large-scale demand for sugar as many countries have already refilled inventories that were depleted during the deficit phase of the world sugar market (Anon., 2015). It clearly indicated that the quantity of sugar production have to be increased annually by faster rate as demand is increasing gradually in importing countries of the world. If sugar is produced more than our internal consumption, then country can search new destination to export sugar to countries like Indonesia, China, Iran, Bangladesh, UAE and EU-27. As these countries will have more demand of sugar for their internal consumption in near future.

Future of sugarcane and sugar in the world

With a global sugar surplus expected for the marketing year (2017-18), international sugar prices are rather low at the start of the outlook period, reversing the uptrend observed over the last two crop years. Over the medium term, prices are expected to recover due to increased demand in countries where per capita consumption is low compared to the world average. terms, but lower when expressed in real terms. Sugar prices, by 2027, the nominal world price is projected to be USD 392/t (USD 17.8 cts/lb) for raw sugar and USD 472/t (USD 21.4 cts/lb) for white sugar. The white sugar premium is currently low with higher white sugar deliveries from the European Union and increasing refining capacities in Middle Eastern countries and Algeria. The premium is expected to average around USD 79/t over the outlook period. Production of sugarcane, the main sugar crop, is expected to grow by 1.1% p.a., compared to 2.1% p.a. during the last decade.

Growth in world sugar production is expected to slow to 1.5% p.a. over the projection period compared to 2.0% p.a. in the previous decade. Most of the production increases are expected to occur in developing countries which will represent 77% of global sugar production in 2027 (compared to 76% during the base period). Global consumption of sugar is projected to grow at around 1.48% p.a., slightly lower than in the previous decade, to reach 198 MT in 2027.

Table 4. World sugarcane cultivation (2016 and 2018)

Sugarcane producing countries	101
Sugar beet producing countries	23
Sugarcane area	26.77 (million hectare) - 1.7% of arable land of the world
Sugarcane production	1890.66 (million tonne)
Sugarcane yield	70.61 (t/ha)
Sugar production	195.00 (million tonne)
Sugar Production	86% (from cane) 19.86% (from beet)

World sugar outlook for 2018-19

Global production for Marketing Year (MY) 2018-19 is forecast down 9 million tonne to 186 million tonne primarily due to the 8 million tonne drop in Brazil caused by unfavorable weather and more sugarcane being diverted towards ethanol production (Table 5). Global stocks are forecast to rise to a new high of 53 million metric tonne (raw value) as massive stock building in India more than offsets lower stocks in China and the European Union.

Table 5. Importance of sugarcane in national economy (2017-18)

Sugarcane area	5.159 m ha
Sugarcane production	383.892 m tonne
Cane yield	74.42 t/ha
Sugar production	32.95 m tonne
Number of sugar factories	525
Number of sugarcane land holdings	6.26 million (App.)
Sugarcane cultivators / farmers	5.568 million
Sugarcane labors	6.769 million
Total number of sugarcane workers	12.337 million
Working force employed in sugar factories	0.5 million (App.)
Value of sugar (Sugarcane + other product of sugarcane) in GDP	₹ 104.104 thousand crore

Out of 91 sugar producing countries in world, India is the second largest producer of sugarcane (18.18%) and sugar (15.81%) next to Brazil. Around 35% of sugar produced globally is made available for trade by different importing /exporting countries of the world. Most of the sugar produced by different countries of the world are consumed internally by large producing countries like Brazil (20.77%), India (15.81%), EU-27 (9.46%), China (7.72%) and Thailand (5.92%). The quantity of sugar production from sugarcane had a positive annual growth rate for all the countries except Australia and USA among the top ten sugar producing countries from sugarcane during 2001 to 2015. India is also the largest consumer of sugar (15.93%) of the world and the 7th largest exporter of sugar (2.80%) to 113 countries of the world. The large share of total export (2951 thousand tonnes) was made to Myanmar (27.72%), Sudan (13.05%), Somalia (11.05%), Sri Lanka (6.26%), United Arab Emirates (4.85%), Tanzania Rep (4.25%), Pakistan (3.66%), Kenya (2.98%), Saudi Arabia (2.33%), Jordan (2.52%), Ethiopia (2.57%), Turkey (1.89%), Djibouti (1.61%), Oman (1.63%), Bangladesh (1.83%) during 2015-16 (April–January). There was increase of nearly 51% export of sugar in 2015-16 over 2014-15. It clearly indicated that the quantity of sugar production have to be increased annually by faster rate as demand is increasing gradually in importing countries of the world. If sugar is produced more than our internal consumption, then country can search new destination to export sugar to countries like Indonesia, China, Iran, Bangladesh, UAE and EU-27. As these countries will have more demand of sugar for their internal consumption in near future. These countries are also near destination to our country that will reduce the cost of transportation by road or sea route.

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Status of Sugarcane Mechanization in India

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Sugarcane is an important industrial crop of India which plays a crucial role in social and economical upliftment of rural population. It is cultivated in an area of about 5.042 million hectare with an average productivity of 81.5 tonnes/ha (Table 1). The record production of sugarcane is 411 million tonnes in 2017-18. Uttar Pradesh state is largest producer of sugarcane as it contributes 46.21 % of the total area and 43.65% of the total production in the country but have the average yield less than the National average (Table 2). The energy consumption in production of sugarcane is highest as compared to many other crops such as potato, wheat, maize, paddy etc. This crop needs the highest labour as compared to any other crop requiring more than 375 man-days/ha for different operations. Non-availability of man-power at the peak period of farm operations forces the farmers to use modern farm equipment and machines. Use of machinery helps in labour savings, ensures timeliness of operations, reduces drudgery, helps in improving quality of work, reduces cost of operation and ensures effective utilization of resources. In India considerable R & D work for design and development of agricultural implements and machinery for some operations of sugarcane viz. land preparation, planting, interculture and ratoon management have been carried out. However the adoptions of these implements and machinery have not been up to the desired level. The mechanization is limited up to the land preparation, planting and to some extent to intercultural operations. The most laborious and tedious operation of sugarcane agriculture is harvesting including detrashing. Thus, there is a considerable mechanization gap, especially in the area of sugarcane planting, interculture, plant protection, harvesting and ratoon management. Small improved machinery is the need of hour that suits to local conditions as majority of the operational holdings (85%) falls under marginal and small category however, big machines find scope on custom hiring basis.

Table 1. Area, production and yield of sugarcane in India

Year	Area (million ha)	Production (million tonnes)	Yield (tonnes/ha)
2009-10	4.17	292.30	70.0
2010-11	4.88	342.38	70.1
2011-12	5.10	353.76	69.3
2012-13	5.27	354.4	67.1
2013-14	5.34	345.6	64.7
2014-15	5.30	366.8	69.1
2015-16	5.28	336.9	63.7
2016-17	4.94	303.6	61.3
2017-18	5.04	411.0	81.5

Anon.2019. *Indian Sugar, Vol. LXIX (12)*

Therefore it is necessary that concentrated efforts be made for adoption, development and popularization of sugarcane machinery for various cultural operations for mechanizing sugarcane cultivation in the country for increasing production and productivity at reduced cost of operation.

Table 2. Major Sugarcane producing states in India

State	Area (million ha)	% to All India	Production (million tonnes)	% to All India	Yield (tonnes/ha)
Uttar Pradesh	2.33	46.21	179.40	43.65	77.0
Maharashtra	0.915	18.15	99.10	24.11	108.0
Karnataka	0.415	8.23	39.20	9.54	94.5
Bihar	0.300	5.95	18.50	4.50	62.0
Tamil Nadu	0.201	3.98	12.10	2.94	60.0
Gujarat	0.182	3.60	13.10	3.18	72.0
Andhra Pradesh & Telangana	0.177	3.51	11.50	2.80	65.0
Madhya Pradesh & Chhattisgarh	0.140	2.78	10.00	2.43	71.0
Haryana	0.122	2.41	10.10	2.45	83.0
Uttarakhand	0.120	2.38	7.80	1.90	65.0
Punjab	0.105	2.08	8.80	2.14	84.0
Odisha	0.035	0.69	1.40	0.34	40.0
All India	**5.042**	**100.0**	**411.00**	**100.00**	**81.5**

Anon.2019. *Indian Sugar, Vol. LXIX (12)*

Need of farm mechanization

The principal advantage of mechanized agriculture is that it reduces the demand for labour and allows operations to be carried out faster. Mechanization is needed to get over some of the major constraints to enhance productivity and to make farming less arduous and attractive enough to enable educated youth taking willingly agriculture as profession. Mechanization also aims at increasing land labour efficiency by improving the safety and comfort of agricultural labour and to protect the environment by allowing precision operations and increasing the overall income.

Efficient machinery helps in timely farm operation, input use efficiency, increasing productivity by about 30%. Development and introduction of high capacity, precise, reliable and energy efficient equipment and their judicious use can bring in precision and timeliness in field operations.

Constraints in farm mechanization in India

1. Small and scattered land holdings
2. Majority of farmers are small and marginal
3. Lack of awareness about the latest technology/equipment
4. High cost of equipment and machinery

5. Lack of approach road for the movement of heavier farm equipment to the fields
6. Poor economic conditions of the cultivators
7. Lack of repair, maintenance and replacement facilities in remote rural areas
8. Single operation specific costly machines/equipment

Mechanization of sugarcane cultivation

The cost of sugarcane cultivation accounts about 60-70% of total cost of the sugar production. Sugarcane cultivation requires various operations like seedbed preparation, planting, interculture, earthing up, plant protection, harvesting, transportation and ratoon management. Of the above operations, land preparation is done as in the case of other crops by commonly used tillage implements. Land preparation is done mostly with tractor operated primary and secondary tillage implements viz. mould board plough, cultivator, rotavator. Planting, interculture, earthing up and transportation are in semi mechanized stage. Still, to a large extent, all the operations involved in cane cultivation are performed by conventional energy intensive less efficient tools and equipment (Table 3). Manual harvesting of sugarcane is in vogue. Different types of sugarcane harvesting knives of different sizes, shapes and weights are used for sugarcane harvesting at different places. Sugarcane harvesting is a highly labour intensive operation. About 150 man-days per ha is required for sugarcane harvesting

Table 3. Mechanization status of various operations in sugarcane cultivation

Farm Operation	Equipment/ Method used	Equipment available	Needs R&D/Comments
Seedbed preparation			
Primary tillage	Bullock plough/tractor cultivator	MB Plough, Disc plough, Reversible plough, Sub-soiler	Equipment available
Secondary tillage	Harrow, Rotavator	Power harrow, Rotavator	
Land levelling	Bullock or Tractor operated Patela	Laser Land leveller	
Planting of Cane			
Furrow opening	Bullock/tractor operated ridger	Tractor operated deep furrowers/ trenchers	Different versions of sugarcane cutter planters/trench planters are available. Using these planters, all unit operations of cane planting can be accomplished simultaneously in a single pass.
Sett cutting	Manually by sickle	Power operated sett cutting machine	
Dropping of sett in furrows	Manually by hand		
Fertilizer & insecticides application	Manually by hand/broadcasting		
Covering of sett with soil	Manually by spade/bullock plough/tractor cultivator		

Transplanting			
Bud scooping	Manual bud scooper	Improved Manual/power operated bud scooper	Need modifications/ development
Raising seedlings	Manually	Mechanized system for raising seedling	Need modifications/ development
Transplanting	Manually by spade	Tractor operated transplanter	Need modifications/ development
Deep Fertilizer Placement	Manually	Sub-soiler cum differential rate fertilizer applicator	Need modifications/ development
Weeding & Interculturing			
Interculturing (2 times)	Bullock Desi plough / Cultivator and Tractor cultivator	Sugarcane manager/ multipurpose interculturing equipment / power tiller/power weeders	Equipment available
Hoeing (4 times)	Manually by kudal/spade		
Earthing up Operation	Manually by spade/tractor/ bullock cultivator/ ridger	Tractor operator earthing up equipment	
Spraying			
Spraying herbicide/ fungicide	Knapsack sprayer	Improved power sprayer	Need modifications/ development as per crop requirements for small farms
Harvesting			
Harvesting of cane	Manually with Gandasa/ different types of knives/tools	Big harvester	Need modifications/ development for small land holdings
De-trashing & detopping	Conventional Sickle	Improved manual cane detrasher cum detopper	Need modifications/ development

Table 4. Average man power required per ha for sugarcane cultivation

Operation	Average mandays/ha
Seed bed preparation	30
Planting	35
Weeding and other inter-cultural operations	100
Irrigation	20
Fertilization	10
Harvesting including de-trashing	150
Transportation and loading	30

including de-trashing with the traditional tools. Non-availability of manpower during peak crop season is becoming a major problem in mechanization of sugarcane.

Some of the machines available and are used for sugarcane cultivation for different field operations is enumerated below. Table 4 shows the average man days required per ha for sugarcane cultivation. Harvesting, interculture and planting are the most labour intensive operations.

Seedbed preparation

Sugarcane crop requires well-prepared seedbed. The many farmers are using the animal drawn ploughs and ridgers for the field preparation. But now a day's tractors has replaced animal power to a great extent and are playing key role for farming operation not only in sugarcane but also in all other agricultural operations. The equipment like disc plough, mould board plough, reversible plough, cultivator, duck foot cultivator, disc harrows, leveler, plough, rotovator, ridger, bund and channel former, etc are commonly used in sugarcane cultivation. The seed bed preparation with culti-harrow developed by IISR, Lucknow have been found quiet effective as this implement can perform three operations *viz.* cultivating, harrowing and planking in a single pass thus thereby saving 23-35% time and 17-28% fuel as compared to conventional tillage practice.

Treatment of seed cane

Sugarcane suffers from different types of seed born diseases like red rot, grassy shoot disease, ratoon stunting disease and mosaic etc. In order to control the disease, seed cane is treated at a temperature of 54^0C for about 2½ hours at a humidity level of about 95-99% or at 50^0C for a period of about 2 hrs in case of moist hot air and hot water treatment plants respectively. Moist hot air treatment unit developed by IISR is useful in treatment of seed cane and saves crop from seed borne diseases like RSD, Red rot, Leaf scald disease, GSD, smut *etc*.

Sugarcane sett cutting

Sugarcane is a vegetatively propagated crop. It is planted in the form of cut setts of 2-3 buds. For preparing setts, manually operated hand tools and power operated sett-cutting machines are used. In conventional planting sugarcane sett cutting process is a pre planting practice, while in mechanized system (sugarcane cutter planter) sett cutting is done simultaneously by the planter. This ultimately reduces time, labour and moisture loss in setts of sugarcane seed and helps in higher germination percentage.

Planting

Planting of sugarcane comprises many operations such as opening of furrows, seed setts cutting, placement of setts in the furrows and providing soil cover to setts. Most of the farmers are using manual practice of placing setts in the furrows that are made by tractor drawn or bullock operated ridgers. These methods consume lot of time, energy and also resulted in increased drudgery and cost of operation. Different methods of planting are followed such as flat planting, trench planting, ring pit planting, furrow irrigated raised bed (FIRB) planting, staggered row planting and spaced transplanting. Most of the area in Northern India is flat planted. In the areas where sugarcane lodging takes place, trench planting is followed. Different rows spacing are maintained at different places ranging from 60-70 to 90-150 cm. IISR, Lucknow has developed various models of sugarcane planters viz. semi-automatic, automatic and later cutter planters suited for tractors as well as bullocks. In addition IISR RBS (raised bed seeder) cane planter, paired row sugarcane planter and trench planter are gaining popularity among the farmers. Thus to reduce drudgery and cost of planting and efficient utilization of seed, chemical, fertilizer, use of planters is advocated. For sugarcane production spaced transplanting technique is being followed in some parts of Maharashtra on large scale. Recently trend of single bud sugarcane transplanting for the production of cane requires attention for development of a sugarcane transplanter. Poly bag planting/transplanting and mechanization of tissue culture seed production processes are new emerging areas. However, two row tractor drawn mechanical planter for sugarcane bud chip settlings raised in portray has been developed jointly by ICAR-Sugarcane Breeding Institute and Central Institute of Agricultural Engineering.

Irrigation

Sugarcane is an intensively irrigated crop. However, under deficit water availability conditions, use of sprinklers, drip irrigation system and skip furrow method of irrigation & fertigation are practiced for economical and efficient use of water. Application efficiency is higher in case of drip, sprinkler irrigation than other methods. Skip furrow method of irrigation saves irrigation water by 36.5% and improves water use efficiency by 64%.

Weeding and interculture

Number of interculture operations is required in sugarcane crop to control weeds, moisture conservation, microbial action and creation of better environment for overall growth of the plant. Farmers are using spade, khurpa for weeding manually. Bullock plough and tractor operated cultivators are also used for this purpose. Recently tractor operated three row rotary weeder has been introduced to Indian market for wide spaced crops. The efficient and high capacity equipments like self propelled power weeders, power tillers, mini tractors of various makes and designs are available in the market for weeding and interculture operation. Sugarcane manager and multipurpose interculturing equipment has been developed at IISR, Lucknow for this purpose.

Plant protection

For control of insects and pests diseases, application of chemicals is done with help of sprayers at the initial stage. In order to spray effectively and efficiently, use of wide swath spray boom is advocated. Wide swath spray boom may be operated by foot/hand/engine operated spray pumps. Self-propelled high clearance sprayers, tractor operated aero blast sprayers may also be used in a crop planted in a planned manner.

Earthing up

The S.S. Furrower and deep furrowers developed at IISR can be used for earthing operation in fields where row to row spacing is not more than 90 cm. This equipment is tractor operated and can be used till cane formation height is not more than 40 cm.

Harvesting and de-trashing

Presently harvesting of sugarcane is done manually using different types of knives/tools giving an average output of 0.8 to 1.0 quintal per man-days. Sugarcane harvesting involves base cutting, stripping and de-trashing, de-topping, bundle making of 10-12 stalks, loading and finally transports of sugarcane to the sugar mills. Under the present scenario due to non availability of labour, the harvesting gets delayed affecting the production of sugar. The mechanization efforts in the country have been basically limited to the development of whole stalk harvesters for the partial mechanization of harvesting of sugarcane. IISR has developed tractor front mounted sugarcane windrower whole stalk harvester & it was reported that with this harvester two rows can be cut simultaneously and windrowed at the centre of the rows. Combine chopper harvesters have been imported at few places in Tamil Nadu and Maharashtra. These harvesters are intended to mechanize the whole operation of sugarcane and found acceptability at few places at limited scale.

Large sized harvesters are prevalent used in the countries like Cuba, Brazil, USA, Australia and South Africa. These machines could be economically operated only if the sugarcane is planted in 1.5 m or more row spacing with furrow length of 250 m and above. However, in the eastern countries like Japan, China and Thailand sugarcane harvesting is practiced with medium sized machines where the sugarcane field sizes are more or less similar to that of Indian condition. Power operated detrasher was developed at IISR and PAU, Ludhiana for removal of removal of green top as well as dry trash from the harvester sugarcane.

The main reason for non-popularization of big harvester in India is the row spacing. In north India, the row to row spacing ranges from 60-75 cm while in Central and South India the spacing is around 90-105 cm and some farmers now planting sugarcane at 120 cm spacing. For functioning of big harvester atleast, 120 cm spacing is required. The small size of field, cane purchase system, initial cost, field losses etc. are some other factors limiting the introduction of big sugarcane harvesters especially in northern India.

Ratoon management

The ratoon management involves the process of stubble shaving, off-barring the bunds and stirring and manipulating the soil for better crop establishment. In addition the sugarcane trashes are to be shredded for incorporating with the soil to enrich soil fertility. IISR Ratoon Management Device and Ratoon Manager can perform the ratoon initiations operations very effectively in a single pass. Disc type ratoon management device has also been developed at IISR Lucknow for widely spaced planted crop.

Future mechanization strategies

The mechanization package technology has to be eco-friendly, user friendly, facilitating the strenuous and hazardous farming operations in a safe and comfortable manner, increasing the area and productivity and facilitating custom hiring/ contract farming. Low purchasing power, low literacy and resistance to change from traditional system, inadequate credit facilities and poor risk bearing ability, are some of the socio economic and infrastructure constraints in sugarcane mechanization.

Mechanisation of sugarcane could go a long way not only in enhancing the productivity but also in improving the quality of work of the rural labour. Many technologies for mechanisation of sugarcane cultivation have been developed and they have to be introduced appropriately in the sugarcane mechanization sector together with appropriate policy for successful adoption. Mechanisation technology clubbed with appropriate mechanization strategy would help in achieving the goal of higher productivity in sugarcane.

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Tillage Equipment for Sugarcane Cultivation

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Tillage is a mechanical manipulation of soil to provide favorable condition for crop production. Soil tillage consists of breaking the compact surface of earth to a certain depth and to loosen the soil mass, so as to enable the roots of the crops to penetrate and spread into the soil.

Why Tillage?

- To obtain deep seed bed, suitable for different type of crops
- To add more humus and fertility to soil by covering the vegetation
- To destroy and prevent weeds.
- To aerate the soil for proper growth of crops
- To increase water-absorbing capacity of the soil
- To destroy the insects, pests and their breeding places and
- To reduce the soil erosion

Tillage for sugarcane

Tillage is usually done to improve soil conditions for crop establishment, growth and weed control. The seedbed for sugarcane does not need to be as fine as for small seeded crops due to the way it is propagated (Trouse, 1960). Hence, due to reduced number of tillage operations, the time and energy invested in seedbed formation should be less. Jain and Agrawal (1970) determined that a seedbed consisting of 3.2 to 6.4 mm aggregates resulted in greater germination and increased root growth compared with a finer seedbed. Wood (1985) suggested that yield decline was due to in part to soil structure degradation caused by intensive cultivation.

The soil compaction due to use of heavy tractor and machinery is increasing in the fields that affect the top soil but also the sub-soil. One thumb rule suggests that the compaction would occur upto 20-25 cm depth from axle loads less than 5 t but may exceed to 50 cm depending upon the axle load, soil type and conditions (Thakur, 2010). Sugarcane is a vegetative propagated crop. The plants roots penetrates very deep in search of water and nutrients that may be over 6 m in sugarcane. The compacted soil can reduce crop yield by as much as 50% due to reduced aeration, limited root growth, poor water infiltration and water stagnation. The hard pan, if exist should be disrupted as soon as possible. The top 15-20 cm soil layers can be ploughed with normal soil cultivation operations using M.B. plough and disc plough but deeper pans must be broken with special type of equipment such as chiseler and sub-soiler.

The conventional type of disc harrow and cultivator are being used for tillage operation and generally 10-12 cm maximum depth can be achieved. The problem by using cultivator is that some un-ploughed land has left in between two tynes hence atleast two times we have to plough the field. The sugarcane crop requires deep seed bed preparation for planting as deep planting has several benefits over flat planting of cane such as it avoid lodging of cane, better germination of ratoon etc. The commonly used sequence for field preparation for sugarcane is Ploughing-Harrowing-Cultivating/ rota-tilling /power harrowing-Planking.

Classifications of Tillage

Tillage is divided in two classes: Primary tillage and Secondary tillage

Primary tillage

It constitutes the initial major soil working operation. It is normally designed to reduce soil strength, cover plant materials and rearrange aggregates. The operations performed to open up any cultivable land with a view to prepare a seed bed for growing crops is known as primary tillage. Animal drawn implements mostly include indigenous plough and mould-board plough. Tractor drawn implements include mould-board plough, disc plough, subsoil plough, chisel plough and other similar implements.

Secondary tillage

Tillage operations following primary tillage which are performed to create proper soil tilth for seeding and planting are secondary tillage. These are lighter and finer operations, performed on the soil after primary tillage operations. Secondary tillage consists of conditioning the soil to meet the different tillage objectives of the farm. These operations consume less power per unit area compared to primary tillage operations. Secondary tillage implements may be tractor drawn or bullock drawn implements.

Types of tillage

Minimum Tillage - It is the minimum soil manipulation necessary to meet tillage requirements for crop production.

Strip Tillage - It is a tillage system in which only isolated bands of soil are tilled.

Rotary Tillage -It is the tillage operations employing rotary action to cut, break and mix the soil.

Mulch Tillage -It is the preparations of soil in such a way that plant residues or other mulching materials are specially left on or near the surface.

Combined Tillage -Operations simultaneously utilizing two or more different types of tillage tools or implements to simplify, control or reduce the number of operations over a field are called combined tillage.

Tillage Equipment for Sugarcane

Plough

Ploughing is the primary tillage operations, which are performed to cut, break and invert the soil partially or completely. Ploughing essentially means opening the upper crust of the soil, breaking the clods and making the soil suitable for sowing seeds.

Mould board plough

It is an implement used for primary tillage operation (Fig.1). The main functions of this plough are: 1) cutting the furrow slice 2) lifting the soil 3) turning the furrow slice and 4) pulverising the soil. It is also used for turning green manure crop for decaying under the soil, which adds humus to the soil.

Fig. 1. Commercially available tractor operated mould board plough

The working of the tractor operated plough is controlled by hydraulic system and three-point linkage.

Reversible M.B. plough

It is a mould board plough which turns furrow slice to the right or left side of direction of travel as required (Fig.2). Such ploughs have two sets of opposed bottoms. In such plough, all the furrow can be turned towards the same side of the field by using one bottom for one direction of travel and the other bottom on the return trip. Two sets of bottom so mounted that they can be raised or lowered independently or rotated along an axis. Two way ploughs have advantages that they neither upset the slope of land nor leave dead furrows or back furrows in the middle of the field. The other features of this plough are:

- It helps to even out the soil for better harvest and cultivation.
- It is designed to work in all types of soil for functions such as soil breaking, soil raising and soil inversion.
- The plough has special wear-resistant steel bottoms with points for toughest ploughing jobs.
- It can handle the toughest ploughing job with excellent penetration performance.
- The under-frame clearance is adequate to cope with trashy conditions.
- Easy drawbar adjustment.

Fig. 2. Commercially available three bottom reversible mould board plough

Disc plough

It is used for primary tillage and is especially useful in hard and dry, trashy, stony or stumpy soil where scouring is a major problem (Fig.3). It is a plough, which cuts, turns and in some cases breaks furrow slices by means of separately mounted large steel discs. It is designed to operate as 2, 3 or 4 bottoms. A disc plough is designed with a view of reduce friction by making a rolling plough bottom instead of sliding plough bottom. A disc plough works well in the conditions where mould board plough does not work satisfactorily. The discs of the plough are made of high carbon steel or alloy steel and edges are hardened and sharpened.

Fig. 3. Commercially available tractor operated disc plough

Chisel plough

Chisel ploughs are used to break through and shatter compacted or otherwise impermeable soil layers. Deep tillage shatters compacted sub soil layers and aids in better infiltration and storage of rainwater in the crop root zone. The improved soil structure also results in better development of root system and the yield of crops and their drought tolerance is also improved. The functional component of the unit include reversible share, tyne (chisel), beam, cross shaft and top link connection.

Sub-soiler

The function of the sub-soiler is to penetrate deeper than the conventional cultivation machinery and break up the layers of the soil, which have become compacted due to the movement of heavy machinery or as a result of continuous ploughing at a constant depth. These compacted areas prevent the natural drainage of the soil and also inhibit the passage of air and nutrients through the soil structure. The sub-soiler consists of heavier tyne than the chisel plough to break through impervious layer shattering the sub-soil to a depth of 45 to 75 cm and requires 60 to 100 hp to operate it (Fig.4). The advantages are same as that of chisel plough.

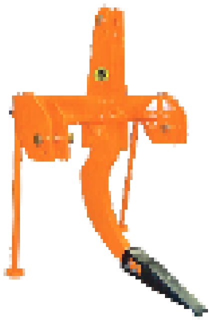

Fig. 4. Commercially available tractor operated sub-soiler

Pant-ICAR subsoiler-cum-differential rate fertilizer applicator

This machine is used for breaking of hard subsoil pan upto 50 cm depth and simultaneously depositing the varying amounts of fertilizers at two different depths (Fig.5). The shallow leading winged tines of the machine place 80% of the recommended dose of fertilizer at 20±5 cm depths whereas the central subsoiling tine places the remaining 20% fertilizers at 40±5 cm depth. It can be operated with a 50 to 75 h.p. tractor depending upon the depths of operation (Mandal and Thakur, 2010).

Harrow

Harrow is a secondary tillage implement that cuts the soil to a shallow depth for smoothening and pulverizing the soil as well as to cut the weeds and to mix the materials with the soil. There are several types of harrow used in India such as disc harrow, spike tooth harrow, spring tooth harrow, acme harrow, patela, triangular harrow, bade harrow, guntaka and reciprocating power harrow.

Fig. 5. Pant-ICAR subsoiler-cum-differential rate fertilizer applicator

Disc harrow

It is a harrow, which performs the harrowing operation by means of a set, or a number of sets of rotating slat discs, each set being mounted on a common shaft. Disc harrow is found very suitable for hard ground, full of stalks and grasses. It cuts the lumps of soil, clods and roots. Disc are mounted on one, two or more axles which may be set at a variable angle to the line of motion. As the harrow is pulled ahead, the discs rotate on the ground. Depending upon the disc arrangements, disc harrows are divided into two classes a) Single action and b) Double action

Conventional machinery

- Tractor operated cultivators, disc harrow and ploughs were/are the main equipment for land preparation.
- Tractor operated rotovators have become popular among cane growers for last few years.

Disadvantages of conventional machinery

- Require more time in field preparation.
- Require more energy thereby not cost effective.
- More number of tractor passes, resulting more soil compaction.

Tractor operated culti-harrow

This implement developed at IISR, Lucknow hitched to tractor with three point linkage system (Singh *et al.,* 2012). Three components put together on a tractor mounted type single frame. At front side of the implement, cultivator tynes are mounted. In the middle, two gangs of discs facing each other are mounted. At the rear end of the implement a mild steel

Fig. 6. IISR designed tractor operated culti-harrow

planker is hitched with steel chains. Thus, the implement can perform three operations *viz.* cultivating, harrowing and planking in a single pass (Fig.6). The field capacity is 0.3 ha/h and resulted in better soil preparation & reduced soil compaction. There is saving of diesel up to 4-8 l/ha and time saving of 1.5-2.0 h/ha.

Power harrow

It is a harrow fitted with rigid tynes driven by the power take off in a reciprocating, transverse or rotary motion as the machine moves forward (Fig.7). Power harrow is suitable for the crops which require deeper tillage like sugarcane and tuber crops. It reduces the number of tillage operations reducing number of passes, thus help in reducing compaction of soil. It comes with option of multispeed to adjust speed as per the customer's requirements. Its long and sharp blades can easily plough any land and achieve tillage depth up to 10 inches. Its sturdy structure is welded with high thickness plates which make sure that it operates under toughest conditions. Its Gear Box designed with quality components promises longer life cycle of the implement. It ensures faster operation and completes function in less time reducing fuel consumption and soil compaction.

Fig. 7. Commercially available tractor operated power harrow

Ridger

It is an implement importantly used to form ridges required for sowing row crop seeds and plants in well-tilled soil. It may be animal, power tiller and tractor drawn. The ridger is also used for forming field or channels, earthing up and similar other operations. Ridger is also known as ridging plough and double mould board plough. The ridger generally has 'V' shaped or wedge shaped share fitted to the frog. The nose or tip of share penetrates into the soil and breaks the earth. The mould boards lift, invert and also cast aside the soil, forming deep channels and ridges of the required size. A ridger consists of beam, clevis, frog, handle, mould boards, share and sliding share.

IISR trencher

It is an implement used to form a single trench only having depth and width of 30cm each for planting of sugarcane in paired row geometry (Fig.8). It facilitates the trench planting of sugarcane. The planting of cane by trench method have benefits over flat conventional method. It avoids logging of cane, better germination of ratoon and saving of irrigation water by irrigating furrows only thereby avoids flooding irrigation.

Fig. 8. Tractor operated IISR trencher

IISR deep furrower cum fertilizer applicator

Fig. 9. IISR tractor operated deep furrower cum fertilizer applicator

Furrow opener is an important component as far as sugarcane planting is concerned that influenced the germination and crop stand of sugarcane. Common type of furrow openers used in sugarcane planters are ridger type, slit type and disc type. IISR, Lucknow has developed a three bottom deep furrower cum fertilizer applicator for deep furrow opening and fertilizer application during furrow opening simultaneously (Fig.9). Most of the sugarcane farmers use conventional ridger for furrow opening that having depth of 10-12 cm only whereas the developed IISR deep furrower go up to depth of 22-25 cm that facilitates the deep furrow planting of sugarcane. The deep furrow planting of sugarcane have several benefit over conventional flat planting.

Cultivator

It is an implement for inter cultivation with laterally adjustable tines or discs to work between crop rows. The cultivator stirs the soil, and breaks the clods. The tines fitted on the frame of the cultivator comb the soil deeply in the field. The tines fitted on the frame of the cultivator comb the soil deeply in the field. A cultivator performs functions intermediate between those of plough and the harrow. Destruction of weeds is the primary function of a cultivator. Animal, power tiller and tractor drawn cultivator are available in the market. Animal drawn cultivator may be 3 tine, power tiller having 5 tines and tractor drawn with 7, 9, 11, 13 tines or more depending upon the requirements. Cultivators with spring loaded tines and with rigid tines both are available in the market. The following are a few important functions performed by a cultivator.

1. Interculture the fields. 2. Destroy the weeds in the field. 3. Aerate the soil for proper growth of crops. 4. Conserve moisture by preparing mulch on the surface. 5. To sow seeds when it is provided with sowing attachments. 6. To prevent surface evaporation and encourage rapid infiltration of rain water into the soil.

Fig. 10. Commercially available tractor operated rotavator

Rotavator

It is used for seed bed preparation, weed control, mixing the soil and crop residue and fertilizer and puddling of soil. It is operated by PTO shaft of the tractor attached to the 3 point linkage (Fig.10). The depth can be controlled by linkage and hydraulic system. Rotavator are available in different sizes as per the hp of the tractor. It helps in retaining moisture of the soil and increases soil porosity and aeration which enhances germination and growth of crops. Its specially designed blade rotor reduces load on tractor as well as diesel consumption and avoids tyre slippage

Tractor operated 2-bottom pit digger

For planting sugarcane by ring pit method, two bottom pit digger was developed which makes two holes of 75 cm diameter and depth upto 30 cm at a time (Fig.11). The capacity of digger is 150 holes/h (Singh *et al.,* 2017).

Fig. 11. IISR tractor operated 2-bottom pit digger

Tractor mounted laser land leveler

Precision land leveling saves irrigation water, facilitates field operations and increase crop yield (Chaudhuri *et al.,* 2007). For precision leveling and grading, laser guided land levelers are used (Fig.12). In this system, the hydraulic system is automatically controlled based on the response of the laser system. Laser leveling is to use a laser guidance system to raise and lower the blade of the grading implement automatically (Kumari *et al.,* 2017). Laser land leveling equipment has marked one of the most significant advances in surface irrigation technology. It does not only minimize the cost of leveling but also ensures the desired degree of precision. It helps in improving resource use efficiency under surface irrigation systems by uniform distribution of irrigated water as well as resource conservation without adverse effect of environment.

A laser-controlled land leveling system consists of the following five major components: (i) Drag Scrapper/bucket: The drag bucket can be either 3-point linkage mounted on or pulled by a tractor. This system is preferred as it is easier to connect the tractor's hydraulic system to an external hydraulic by the 3-pointlinkage system. (ii) Laser transmitter: The laser transmitter mounts on a tripod, which allows the laser beam to sweep above the field. (iii) Laser receiver: The laser receiver is a multi-directional receiver that detects the position of the laser reference plane and transmits this signal to the control box. (iv) Control box: The control box accepts and processes signals from the machine mounted receiver. It displays these signals to indicate the drag buckets position relative to the finished grade. (v) Hydraulic system: The hydraulic system of the tractor is used to supply oil to raise and lower the leveling bucket.

Benefits of laser land leveling over conventional land leveling

- Reduction in time and water for irrigation

- Uniform distribution of water
- Less water consumption in land preparation
- Precise level and smoother soil surface
- Uniform moisture environment for crops
- Lesser weeds in the field
- Good germination and growth of crop
- Uniformity in crop maturity
- Reduced seed rate, fertilizers, chemicals and fuel requirements
- Increase productivity up to 50%

Fig. 12. Commercially available tractor operated laser land leveler

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Promising Sugarcane Varieties and their Suitability for Mechanization

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Sugarcane is an important crop in the country, economically, politically and sociologically. It is widely grown in the tropical and subtropical areas of the world. In India, it is the second largest agro-industrial crop next to cotton. Sugarcane is cultivated in around 5.0 million hectares producing 400.1 million tons of sugarcane with the average productivity of over 800 quintals per hectare. In Indiasugarcane cultivated mostly in the subtropical belt across north India from Assam to Punjab with about one half of the total acreage in the state of Uttar Pradesh only. The country produces more than 32 million tons (2017-18 SS year) of sugar through more than 516 sugar mills and nearly 35 million persons are engaged in the production of cane and sugar.

The history of organized sugar industry in the country is hardly a century old dating back to the establishment of first sugar mill at Saran in Bihar in1904. Research on sugarcane to evolve suitable varieties for the Indian conditions began almost simultaneously with the establishment of the Sugarcane Breeding Station, now the Sugarcane Breeding Institute (SBI), at Coimbatore in 1912. In what can be considered a major breakthrough, the first variety Co 205 from the Institute was released for cultivation in 1918 in Punjab, which yielded 50 % more compared to the native varieties. This also marked the beginning of modern day research and development in sugarcane contributing to the phenomenal growth in cane area, productivity and cane and sugar production.

In States like Punjab and Haryana where the use of farm machinery are quite high, the cost of cultivation excluding the cost on family labour and fixed costs is around Rs. 35,000 per acre; approximately 45-48% of the total cost goes to payment on human labour and only 15-16% is spent on machinery rent including transport. Therefore, to increase net returns from sugarcane cultivation there is a need incorporate cost effectiveness in the production system. Taking into consideration the time, precision of field operations, increased input use efficiency and productivity per unit, there is a need to making sugarcane cultivation at least a semi-mechanized one by popularizing machinery like sugarcane cutter planter, inter-culture implements, tractor-mounted-sprayers and harvesters which are available in the country. Although there is no sugarcane breeding programme as such in place which has target for the development sugarcane varieties suited for the mechanized sugarcane agriculture. But now days it is a need that the sugarcane varieties should have traits that make easy to operate different sugarcane machines in the field like planters, interculture machines, power sprayers, harvesters etc.It is the duty of the sugarcane breeders that they should give due emphasis on such traits during the process of selection and evaluation of sugarcane clones.

Role of varieties in sugarcane agriculture

Varieties played a major role in the growth and development of the sugarcane agriculture in the country. A number of landmark varieties which dominated the varietal scene ensuring stability and growth of the sector. Co 205 was followed by prominent varieties like Co 281, Co 285, Co 312, Co 313, Co 527, Co 1148, Co 1158, Co7717, BO 91, CoJ 64, CoS 767, CoSe 92423 in the subtropics, which ruled the varietal scene for long periods with their wide adoptability over large geographical areas cutting across the states. The latest varieties developed by the different Institutes like Co 0238, CoLk 94184 and Co 0118 have performed well across the states in north India and resulted in significant improvement in cane productivity and sugar recovery, particularly in Uttar Pradesh.

Breeding for tropical India was started in 1926 at Sugarcane Breeding Institute, Coimbatore and by 1939 the first wonder cane of tropics Co 419 was released. This variety was predominant in the tropics for several decades and continued to be cultivated till the 1990s. This was followed by varieties like Co 740, CoC 671, CoA 7601, Co 62175, Co 6304 and Co 86032. Co 86032 is perhaps the most popular variety today in the tropical India occupying over 90% area in Tamilnadu and over 50% area in Karnataka and Maharashtra with substantial presence in Andhra Pradesh and Gujarat.

Breeding objectives

The main objectives in sugarcane breeding to develop varieties having high cane yield, high sugar, tolerance to abiotic stresses such as drought, water-logging, frost, salinity etc., disease and pest resistance. Emphasis on improvement of cane yield, sugar content and disease and pest resistance have been given in most of the sugarcane breeding programme.

1. **Breeding for high cane yield:** The cane height, thickness, tillering capacity responsible for number of millable canes (NMCs) of the clones all contributes to the tonnage of cane harvested in unit area. Hence, primary selection is always for growth vigour and for tall, high thickness andweight, canes with high tillering capacity. Yield of cane harvested is also influenced by response to fertilization, resistance to climatic adversities and resistance to disease and insect pests, so these factors must also be considered by the breeders.
2. **Breeding for high commercial cane sugar (CCS):** Juiciness of the stem, sugar content and recovery are also important factors in yield of commercial cane sugar. The canes of the wild *Saccharum spontaneum* are slender and pithy with practically no recovery of sugar, while cane of *Saccharum officinarum* are high in sugar.
3. **Breeding for high sucrose content:** Breeding programmes at India, Barbadose, Louisiana, Australia and Taiwan clearly demonstrated that there is great potential to improve sucrose content through hybridization and selection process. A number of outstanding varieties in which sucrose content has been improved under the intensive breeding programme. Building parental population with very high sucrose content through recurrent selection has given good results in many sugarcane breeding programmes.

4. **Breeding for disease resistance:** The major sugarcane diseases in India are red rot, smut, mosaic, ratoon stunting, rust and root rot. Wilt and grassy shoot also occurs but not much information is available about source of resistance to them. Damage due to red rot is generally more severe in subtropical areasuch as north India than in the tropical climates. The fungus causing red rot may invades any part of the plant but frequently enters through borer injuries and leaf sheath scars. Lesions on leaves or wound on stalk are usually dark or blood red in colour and easily identified. Planting resistant varieties is the primary method to manage the red rot. Breeding for red rot resistance has become one of the important activities in sugarcane improvement owing to the seriousness of the disease. There are two component of red rot resistance namely racespecific and race non-specific. Mosaic is the most widely distributed sugarcane disease and is caused by virus which produces mottling on leaves and reduces the cane yield.

5. **Breeding for insect resistance:** Among the insect pests of sugarcane, shoot borer, internode borer and scale insect are the major insects in tropical areas, whereas top borer, shoot borer and *Pyrilla* in the sub tropics. White grub, white fly, wooly aphids and termite may be damaging sugarcane in isolated areas sporadically. Based on the varying degree, resistance to pest are classified as immunity, high level of resistance, low level of resistance, susceptibility and high susceptibility. Resistance in sugarcane varieties to pest is relative and partial resulted due to non preference, antibiosis, host evasion, escape etc. The pure clones are rated for their resistance while the hybrids are usually rated for their tolerance potential. Since they are exploited for commercial cultivation in large areas. Thus evaluation of genotypes are done for resistance on pest infestation levels in the pure clones and for tolerance in terms of cane yield and sugar output in selection to pest information in the hybrids.

6. **Breeding for quality jaggery and fibre:** Varieties of sugarcane cultivated varies as per the requirement. For chewing purpose, *Saccharum officinarum* type preferred due to its soft nature of fibre. But for the commercial production of white sugar, hybrids having higher sucrose and moderate fibre content are preferred. For jaggery making varieties with high sucrose content and better cleaning are desirable. For ethanol production directly from cane juice, varieties with high total sugars are more suitable. Desirable quality characters in variety for jaggery making are high sucrose, less non sugar component in cane juice, non-flowering, resistance to chlorosis and lodging. Both the quantity and quality alongwith its moisture holding capacity of fibre in a variety is important from the milling quality. The ideal cane for milling in one with moderate fibre content (12-13%) with vascular bundle of high tensile strength. For cogeneration, high fibre variety is desired by sugar mills. At present sugar factories are geared-up to use even high fibre varieties with improvement in milling efficiency. As such several mills are prepared to accept varieties with 16 % fibre or even more.

7. **Breeding for tolerance to abiotic stresses:** Increased yield under stressful environments can be obtained by modifying cultural practices to alleviate the stress or genetically improving

the crop so that it is productive even under the prevailing stresses. Being long duration, sugarcane crop faces different stresses such as drought, water logging, frost, high temperature and salinity at various stages of growth. The drought or water deficit stress is most important for sugarcane crop. Drought in combination with high temperature during summer months is known to influence the cane yield in both subtropical and tropical climates.

The water logging stress reduces cane yield induces early maturity and early flowering and the prolonged water logging deteriorates cane quality. In many parts of Bihar, Assam, Uttar Pradesh, West Bengal, Kerala, coastal area of Andhra Pradesh and Karnataka etc., sugarcane cultivation is affected by water logging. If the water logging is in the early stage of crop growth, it will affect the germination, tillering and cane growth, which may result in crop failure. Generally, the water logging coincides with the grand growth phase to maturity of the crop. The major effect of water logging on sugarcane are high rate of stalk mortality, retarded growth, low cane yield and poor quality. Water logged cane attains higher juice sucrose content early in the season and with recedes in water the juice quality will be poor with low sucrose, high invert sugar, high non-protein nitrogen and total colloids. Water logging tolerant varieties should produce leaf at a faster rate, have quicker growth rate, greater ability to develop adventitious roots and fibrous tissues/intercellular spaces in existing roots and slow and delayed decline in nitrate reductase activity during water stagnation period and resumption of such activity to the normal level on recede of water.

8. **Breeding for wider and local adaptation:** It is known that there are substantial levels of G x E interaction for cane yield and their components. Cane quality is by and large free from G x E interaction, although a variety behaves differently in different environments in a more predictable way. Since a very high level of genetic improvement for cane productivity has been achieved through high yielding varieties with wider adaptation are hard to come by. Greater emphasis is being given to location specific varieties to capitalize on their inherent genetic potential.

Trait based selection of varieties suitable for mechanized sugarcane agriculture

It is a continuous process to develop need based sugarcane varieties started in early part of the 20th century with the establishment of Sugarcane Breeding Institute at Coimbatore. Number of excellent sugarcane varieties have been developed during the period of over hundred years through well-organized sugarcane improvement programme with the objectives like improving the cane yield, resistance to diseases and pests, enhancing sugar content, tolerance to abiotic stresses. Now present day sugarcane agriculture is facing the twin problems of shortage or non-availability of labour and increasing cost of cultivation. Both these problems may be solved to some extent by adoption of various machines specificto different operations in sugarcane agriculture. In this context, there is need to develop sugarcane varieties which have certain features desirable for the sugarcane mechanization.

1. **Erectness of cane:** In sugarcane,there are two types of growth habit i.e. erect and semi-erect. Sugarcane varieties having erect growth habit are more suited for mechanized operations like interculture, spraying, harvesting etc. Therefore, for effective mechanization in sugarcane, varieties having erect cane should be preferably selected.
2. **Erectness of leaf carriage:** Sugarcane varieties differing in the shape and orientation of leaf carriage. Mainly there are three types of orientation of leaf carriage i.e. erect, curved leaf and arched. Sugarcane varieties having erect leaf or curved tip should be preferred for mechanized sugarcane.
3. **Non-lodging cane:** Modern sugarcane varietiesare high yielding ones and having tendency to lodge. It is very difficult to do any operations through machines in the field of lodged canes whether it is harvesting or any other inter culture operations. Hence, it is suggested that those varieties should be selected which have no lodging tendency.
4. **Self detrashing type:** Adherence of leaf sheath to the cane in sugarcane varieties is very important as far as harvesting is concern. Removal of trash from the cane in variety like CoLk 94184 (having strong adherence) is very cumbersome process. The varieties having very weak leaf adherence or self detrashing type should be selected that may help in the adoption of machines.
5. **Absence of zig-zag alignment of internode:** Preferably varieties having straight alignment of internode should be selected. It will help for mechanized sugarcane planting through the various type of sugarcane cutter planters.

Breeding Methodology

Establishment of a parental pool

The parental pool should have a large collection of genotypes as can be assembled to maximize the level of genetic variability available to the breeder and to provide reservoirs of alleles that may prove valuable in the event of crisis breeding. The more advanced breeding programmes which have undergone several generations of variety improvement have generally allocated space to foreign commercial varieties and to various *Saccharum* species and related genera. In India, a National Hybridization Garden has been established at Sugarcane Breeding Institute, Coimbatore.

Pre-breeding strategy

The end product of most breeding programmes around the world is the development of high yielding, disease resistance crop varieties. However, many breeding programmes have as an intermediate step the development of source populations. Source populations generally emphasize specific traits which the breeder believes to be associated with yield potential. Some source populations are developed by incorporating desired genes from unadapted germplasm sources through several cycles of backcrossing onto an adopted commercial genetic background.

Hybridization, seedling raising and evaluation

Synchrony of flowering is a major aspect that decides the choice of parents. With substantial levels of genetic variability available within early, mid and late flowerers, this serves the purpose well. However, in certain cases where there is need to involve parents which do not synchronize, photoperiodic treatment is recorded to. Clones with 0 to 30% pollen fertility (anthers generally do not dehisce when pollen fertility is low) are chosen as females and those with a pollen fertility of 60 and above are chosen as males. Clones in the intermediate range (30-60% pollen fertility) are used either as female or male, if such clones are worthy of use as parents. Self-incompatibility is of frequent occurrence in sugarcane that influences choice of parents.

Sugarcane is a short day plant and is sensitive to photoperiodic simulation and normally flowers during the months of October–December in the Northern Hemisphere (India, North America etc.) and during April–June in the Southern Hemisphere (Australia, South America etc.) Along the equatorial plane, sugarcane flowers all through the year if sufficient growth had been attained. The inflorescence called as tassel, arrow etc. in various countries consists of 40 to 50 thousand spikelet's, which are bisexual and protogynous. But since the inflorescence takes about 7 to 10 days to complete flowering in acropetally succession, there is considerable overlap between the flowerings in different portions of the arrow, which makes selfing a possibility. Clones with less than 20% pollen fertility are generally used as pistil parents. The female arrows are enclosed in pollen proof cloth bags supported by wooden or aluminum cages generally called lanterns. The floral branches of the male inflorescence are collected around 5 A.M. and the anthers are made to dehisce in advance of natural dehiscence by placing them under strong light to provide a higher temperature and a lower humidity to hasten the dehiscence. The dehisced pollen is dusted on the female arrows for 7 to 10 days and the seed maturation period required is about 30 days.

Seed set in sugarcane is generally low, usually in the range of 0-40%. This leads to a great variation in the seedling density in the nursery benches leading to differential vigour of the seedlings, which is inversely proportional to the density of the seedlings per unit area. The sugarcane seed loses viability within 60-90 days of collection, if stored under room temperature. When stored under low temperature (-2^0 C to -8^0 C) in moisture proof polyethylene or laminated aluminum foil pouches with the addition of silica gel or calcium chloride as an insurance against power failure, the seed can be stored up to 10 years or more. The seeds germinate on any suitable medium if the temperature and humidity are above the required minimum levels of 20^0C and 60% RH. The seedlings are generally transplanted to polybags when 30-45 days old and subsequently to the field.

The seedlings are transplanted to the field when around 90 days old with a spacing of around 60 cm within rows and 85 cm between rows. The seedlings are screened for yield and quality components at the age of 10 to 12 months after transplanting, mainly to reject for undesirable traits such as very thin canes, heavy leaf sheath spines, natural incidence of diseases, narrow leaves, damage due to insect pests and other cane characteristics.

Selection methodologies and response to selection

Of the three methods of selection viz., family selection, individual selection and family selection followed by individual selection, the third system has been generally found to give higher realization of selectable types. In the initial stages, when the seedlings are mostly in small unreplicated plots. The extent of the environment component in cane yield and its components is relatively high. Hence selection is generally liberal (25 to 30%) and is based on the measurement of the components of yield rather than on the yield *per se*. Only in subsequent stages when the plot sizes are sufficiently large to reduce error variance, selection is based on actual yield of cane.

Clonal testing procedures

First clonal trial or Pre-final clonal trial

First clonal trial or Pre-final clonal trial is laid out in Augmented RCBD with a plot size of one 6 m row with approximately 300 entries. The entries and standards are screened for the yield and quality components at 10 and 12 months after planting. Since the environmental variation is still high mild selection is made for sucrose % juice and cane yield components. Rejections are made for undesirable traits such as leaf sheath spines, large bud size, splits or growth cracks, tendency to lodge, heavy and early flowering, very thin stalks, natural incidence of diseases such as smut, GSD, heavy incidence of SCMV etc. and insect pests such as top borer etc. Approximately 20% of the entries are selected and multiplied.

Final clonal trial or Pre-zonal trial

Selections from the prefinal clonal trial and selections from various other breeding and genetic experiments are assembled and are evaluated in Pre-zonal varietal trial. The trials are laid out in RCBD or in augmented RCBD depending upon the number of entries. Local commercial standards are used as checks. The plot size is 4 rows of 6 metres with a row spacing of around 0.90 m. The entries are simultaneously screened for the major diseases namely smut and local races of red rot through artificial inoculation, and scored for natural incidence of SCMV, GSD and for infestation of insect pests. The selection intensity at this stage is around 10%.

Zonal Varietal trials

Selections from the PZVT stage are multiplied for one year for entry into ZVT. The entries for ZVT are discussed at the Annual AICRP Workshops and the entries contributed by Sugarcane Breeding Institute, Indian Institute of Sugarcane Research and various State Agricultural Universities are assembled at the concerned zonal centre and redistributed to the testing centre within the zone, which may vary from 5 to 10. The trials are laid out in RCBD with plot sizes of approximately 8 R of 6 m long and the trial is conducted for two plant crops and one ratoon crop. Simultaneously the entries are tested again for the major diseases and insect pests. After the trials are concluded the entries are selected based on their performance across locations and are placed for approval before the State Varietal Release Committees for release within the State and before the Central Varietal Release Committee for release across States.

Normally the above process takes approximately 8 to 12 years from crossing to release and another five years to spread and occupy considerable area due to the low multiplication rate of sugarcane (1:10) and efforts are being made to multiply breeder seed through meristem culture to spread a promising variety in a shorter period.

Recommended sugarcane varieties for different zones of India

Zone	Early	Mid late
Peninsular zone *(Tamil Nadu, Kerala, Karnataka, Maharashtra, Gujarat, M.P.)*	Co 85004 (Prabha), Co 94008 (Shyama), Co 09004	Co 8371 (Bhima), Co 86032 (Nayana), Co 87025 (Kalyani), Co 87044 (Uttara), Co 91010 (Dhanush), CoM 88121 (Krishna), Co 99004 (Damodar), Co 2001-13 (Sulabh), Co 2001-15 (Mangal), Co 06027
East Coast zone *(Andhra Pradesh, Odisha, Coastal part of Tamil Nadu)*	CoC 01061, CoOr 03151	Co 86249 (Bhavani), Co 06030
North central and Eastern zone *(Eastern part of U.P., Bihar, West Bengal, Assam)*	Co 87263 (Sarayu), Co 87268 (Moti), Co 89029 (Gandak), CoSe 95422 (Rasbhari), CoSe 96234 (Rashmi), CoLk 94184 (Birendra), Co 0232 (Kamal) CoSe 01421, CoLk 12207	BO 128 (Pramod), CoSe 92423 (Rajbhog), CoSe 96436 (Jalpari), Co 0233 (Kosi), CoP 06436, CoLk 12209
North west zone *(Central and western parts of U.P., Uttarakhand, Haryana, Punjab, Rajasthan)*	Co 98014 (Karan-1), CoH 92201, Co 0238, Co 0118, Co 0124, Co 0239, CoS 96268 (Mithas), CoS 95255 (Rachna), Co 0237, CoPK 05191, Co 05009, CoLk 11203	CoPant 90223, CoS 91230, (Raseelee), CoS 94270 (Shweta), CoS 96275 (Sweety), CoH 119, CoJ 20193, CoPant 97222, Co 0124, CoH 128, Co 05011, Co 06034 Co 09022, CoLk 09204, CoLk 11206, Co 12029

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Agro-technology of Sugarcane Planting and Intercropping System for Higher Yield and Profit in Sub-tropical India

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Uttar Pradesh is the primary sugarcane producing state of the country and occupies the first place in both sugarcane and sugar production. The state's share in the total area of sugarcane grown in the country is approximately 48%, and it contributes 50% of the total sugarcane production. Sugar mills are the largest industry, as a sector, in 44 districts of the state, and play an important role in the rural economy in these districts. There are 53.37 lakh sugarcane farmers who are registered with the 182 cane and sugar mill cooperative societies, of which 37 lakh farmers supplied 1,111 lakh tonnes of sugarcane in the previous crushing season of 2017-18. Sugarcane crushing was carried out by 119 sugar mills in the crushing season 2017-18 (across India, 528 sugar mills carried out crushing in 2017-18), and the total cane area in the state is 23 lakh hectares. In addition, sugar mills produced 121 lakh tonnes of sugar (by crushing 1,111 lakh tonnes of sugarcane). In the crushing season, 37 lakh sugarcane farmers supplied cane worth ₹ 35,454 crore. Sugarcane productivity in the state is currently 79.19 tonnes per hectare, which is 7% higher than the national average of 72.38 tonnes per hectare. The contribution of Uttar Pradesh to the total sugar production of the country is 38%. In addition to the 119 sugar mills in the state, as well as their subsidiary units, 61 cogeneration units produce about 1,555 MW of power, and there are 32 distillery and ethanol units, whose total production capacity is 2,668 kilolitres per day, and who are cooperating in resolving the state's energy problems and also making the local economy vibrant.

Planting Methods

Sugarcane setts are planted as two or three bud setts in furrows / trenches made at distance varying according to seasons and methods of planting. Distance between furrows vary from 75 cm in spring planting, 90 cm in autumn planting, 60 cm in late planting and 120 cm in trench method of planting.

Flat Planting: The field is prepared in a fine tilth by one or two deep ploughing followed by harrowing and planking. Shallow furrows of 10-15 cm depth at a distance of 90 cm in autumn and 75 cm during spring season are opened. Setts are placed in furrows end to end taking care that one 3-bud sett falls in each running 30 cm length of furrow following either head to head or bud to bud alignment and compacted with heavy wooden plank to conserve soil moisture. Sugarcane cutter planter developed by ICAR-IISR, Lucknow effectively reduces the time and labour required for flat sugarcane planting. Only 05 man days are required by this planter in place of 30-40 man days in manual planting.

Trench Method: In this method, farmers realize high input use efficiency and it provides ample scope for accommodating inter-crops between sugarcane rows. Trenches, 30 cm wide and deep are made with centre to centre distance of 120 cm and sugarcane setts are placed along both the walls of trench (30:90 cm). Singh *et al.,* (2012) reported that this method is suitable for mechanized operations, lesser requirement of labours with enhanced water use efficiency. In this method farmers obtain cane yield of 110 t/ha with cost benefit ratio of 2.15 (Fig. 1).

Fig. 1. Trench method of planting

Furrow irrigated raised bed (FIRB) method

In western part of Uttar Pradesh where 75% of the total acreage under sugarcane is under wheat–sugarcane–ratoon–wheat cropping system, and accordingly sugarcane is planted from April last to end of May and sometimes up to mid of June after harvest of wheat. A drastic reduction (30-50 %) in sugarcane yield is a common feature when sugarcane is planted late (summer) after the harvest of wheat crop. In order to improve sugarcane productivity in wheat-sugarcane sequential system, the overlapping cropping under Furrow Irrigated Raised Bed (FIRB) system with wheat sowing on raised beds and sugarcane planting in furrows has been developed at ICAR-IISR, Lucknow. This is used for growing of sugarcane along with wheat crop. Sowing of wheat is done on top of beds and planting of cane setts in the channels. Due to this, farmers are able to take wheat crop as their routine and take sugarcane crop to be planted in spring season. The crop gets sufficient time for its growth and development and gives good crop yield and quality as compared to summer season/late planting after harvest of wheat. The approximate configuration of furrows irrigated raised bed is adopted mechanically with bed width of 80 cm and sowing of 3 lines of wheat is done on the ridges at 22.5 cm apart. Sugarcane yield enhances by 30% and full yield of wheat as compared to sequential cropping of wheat and sugarcane. In this system sugarcane planting is advanced to 50-60 days which otherwise

Fig. 2. Furrow irrigated raised bed system of sugarcane planting

is done in late April/May in wheat - sugarcane sequential system. Sugarcane planting coincides with irrigation at boot leaf stage in wheat. Irrigation is given in furrows preferably in the evening and sugarcane setts are planted next day and pressed into the soil manually when the soil is in muddy condition (wet planting). The technology has been evaluated in sandy loam soil successfully. In order to chisel the furrow, a wheel hoe has also been designed to loosen the soil before irrigation for better placement of setts. After wheat harvest, the furrows are used for irrigating sugarcane till earthing up operation. To make the technology operationally feasible and cost effective, ICAR-IISR, Lucknow has developed a tractor drawn Raised Bed Maker-cum-Fertilizer Seed Drill. The equipment can be operated by any 35 HP tractors (Fig. 2).

Benefits of the technology

- The first and foremost benefit of overlapping technology under FIRB is that sugarcane is planted at the optimum time *i.e.* in the month of February. Otherwise, which is delayed by nearly 2 months to April end/May in wheat - sugarcane sequential system and thus system produces 35 per cent higher cane yield without reduction in wheat yield.
- The system increases water use efficiency by saving irrigation water as it is applied only in the furrows requiring less volume of water in wheat, which works out to be 20% water saving as compared to flat method. Moreover, no extra irrigation is needed for field preparation (*palewa*) for sugarcane planting. Further, irrigations serve the purpose of both the crops till the harvest of wheat.
- The system serve as alternative weed management technology because minimal weed counts are observed on raised beds and weeds mostly colonize in furrows being moist which could be controlled easily by weeding or directed herbicidal spray.
- The system holds promise to increase input use efficiency. In this system 75-80 Kg seed of wheat is required instead of 100 kg in flat method. The requirement of other inputs like herbicide and insecticide/rodenticide is also minimal.
- Thus the technology reduces production cost and increases margin of profit especially for small and marginal farmers with limited resources.

Cane Node Technology

Concerns

- Huge seed cane quantity (60-80 q/ha) of 3-bud setts cane stalk
- Ranges 22-25% of the total cost of cultivation
- Slow rate of cane buds germination, thus restricts early vigour of cane plants
- Slow multiplication ratio (1:10) of newly released varieties of sugarcane

- Normally 10-15% three-bud setts fail to sprout and thus create 20-25% gaps, and carry forward to subsequent rations, reduces cane yield subsequently
- No uniform plant population, thus low cane yield due to sub-optimal plant stand
- Transportation of seed cane – a cumbersome job, therefore packaging and seed certification difficult.

Methodology of cane node technology

Cane nodes preparation

Cutting of healthy cane nodes having viable buds alongwith root bands, 4-5 cm in length

Treatment of cane nodes

(a) Dipping of cane segments in 0.10-0.75% liquid solution of *carbendazim* for 15 minutes

(b) Preparation of liquid organic formulation made up of cattle dung and cattle urine in a ratio of 1:1 to 1:5

(c) The above solution is diluted 5-10 times with water and stirred for 5-10 minutes to make it a organic slurry

(d) Planting material is immersed in the above slurry for 15 minutes

Preparation of soil mixture

(a) Mixture of field soil and decomposed FYM/SPMC in the ratio of 1:1 to 1:5 maintaining moisture content of 50-70%

(b) Sprinkling of chlorpyriphos (1-10 ml/L of water) on the soil mixture to safeguard against termite

Preparation of nursery

(a) Corner of a field on the planting site

(b) Size should be 5.0 × 0.60 m^2 to cover 1 ha planting material

(c) Layering of 2 cm soil mixture

Placement of cane nodes in nursery

(a) Layering of cane nodes on the nursery bed just like a mat

(b) Then layering of 2 cm soil mixture on the cane nodes

(c) Second layer of cane nodes and covering with 2 cm soil mixture

(d) Covering of nursery bed with dry sugarcane leaves

(e) Sprinkling of water on alternate day basis to maintain 50-60% soil moisture

Incubation period

(a) Primed cane nodes are kept in incubation for 5-6 days

(b) Buds start swelling after 2 days of implantation

(c) Sprouts of 0.2-0.4 cm length emerge on buds after 5-6 days

Field plantation

(a) Sprouted buds planting at 75X30 cm distance

(b) Follow up of normal agronomical practices

Benefits of the technology

- The seed cane quantity requires for this method is 10-11 quintals as against 70-80 quintals /ha in conventional planting, and thus reduces cost of cultivation (Fig. 3)
- Seed cane multiplication ratio: 1:40 as against 1:10 in conventional method of planting
- It lead to quicker germination by planting of sprouted cane nodes in the field
- Uniform plant population that leads to higher yield of cane by way of maximizing initial stand establishment
- An excellent tool for rapid multiplication of newly released varieties of sugarcane
- Easier packaging, transportation and seed certification

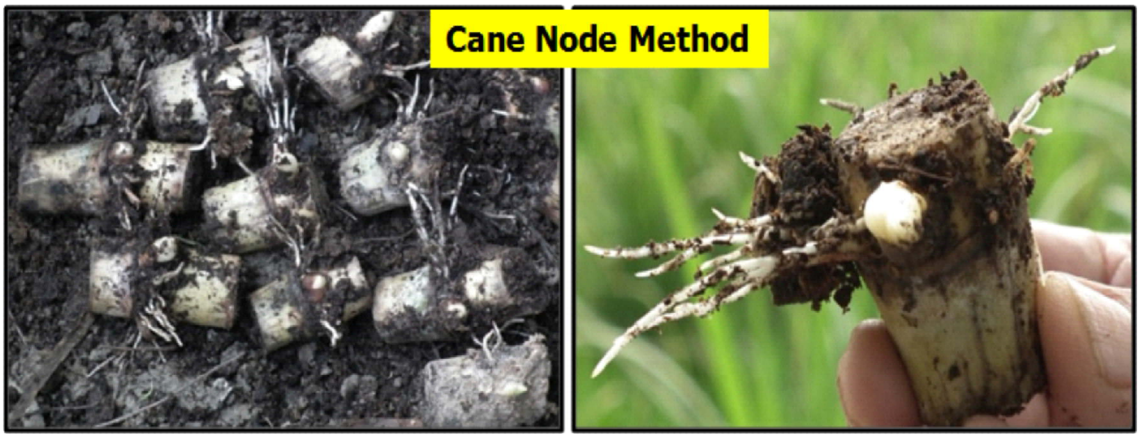

Fig. 3. Cane node method of sugarcane planting

Bud Chip Method

In this method, bud chips are scooped out from freshly harvested healthy sugarcane stalks and soaked in specially formulated plant growth regulator. After fungicide treatment, these are planted in cups/trays filled with mixture of soil, organic matter and sand in ratio of 1:1:1. The seedlings prepared transplanted in fields after 6-7 weeks. The left over cane stalks can be supplied to sugar mills or alternatively for jaggery manufacturing purposes (Jain *et al*., 2011).

Spaced Transplanting Technique (STP)

A new transplanting technique developed at the ICAR- Indian Institute of Sugarcane Research, Lucknow minimizes the input levels and suits farmers with small holdings. Raising settling nursery and transplantation of settings are two basic steps of this method. Before transplanting, leaves must be trimmed and care must be taken during transplanting. This method of planting improves yield by 20-25% in tropics and about 40-50% in sub-tropical regions of India. Besides, there is saving of nearly 4 tonnes in seed cane per ha. The crop stand is characterized by higher stalk population (>1.2 lakh millable canes ha-1), uniform crop stand with higher average cane weight, lower incidence of pests and diseases, late shoot production and reduced lodging. There is an increase in seed multiplication ratio (1:40) over the conventional method (1:10).

Ring Pit Method (*Mother Shoot Technology or No Tiller Agronomy*): The method involves a pit specification as 75 cm diameter and 30 cm depth having centre to centre distance of 105 cm. Under this method, about 9, 000 pits are made in one hectare area. The pits are filled to a depth of 15 cm with compost, native soil and mixed well. The healthy setts are placed in a circular fashion leaving 10 cm from the outer boundary of the pits with equal spacing between each setts and are

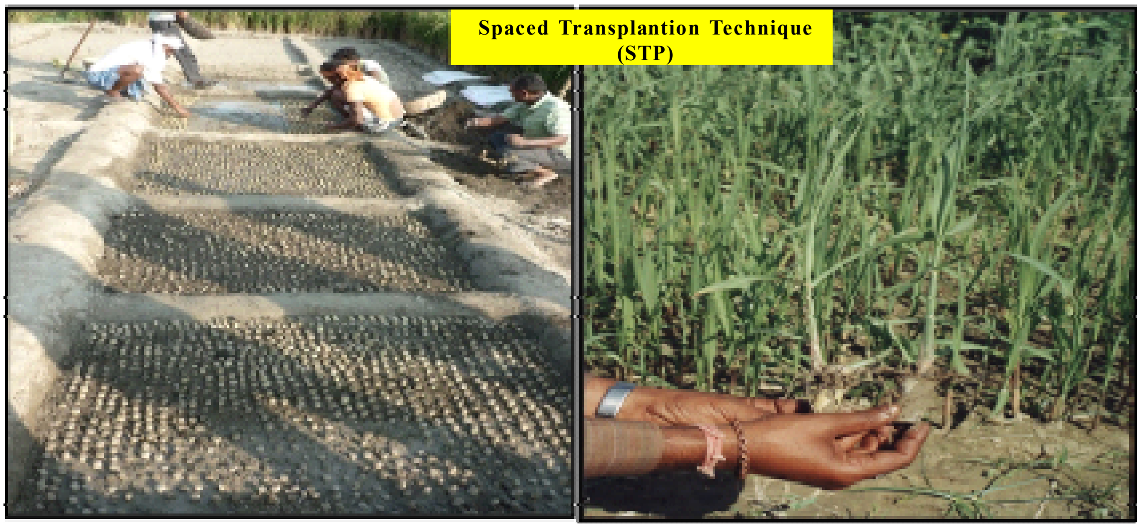

Fig. 4. Spaced transplanting technique (STP)

covered with the soil. After 50 to 60 days of planting, partial earthing up by sliding the soil from the outer boundary of the pits and full earthing up is given by leaving a depression of 2.5 cm from the ground level at 90 to 100 days after planting. This method is suitable for drought prone areas, undulating topography, light textured soils, saline-sodic soils, multi-ratooning and high yielding tall and thick varieties. In this technique framers obtain cane yield of 125 t/ha with benefit: cost ratio of 1.83 (Fig. 4).

Polybag Technology of Sugarcane Planting

Method of raising polybag nursery

Preparation of soil mixture

Field soil, cattle or press mud based compost and sand are taken in equal proportions, mixed thoroughly and sieved through 4 mm sieve, if necessary. The soil mixture is treated with chlorpyriphos 20 EC @ 10 ml/ quintal. The soil mixture then filled in small perforated, polythene bags. The filled in bags are arranged in small plots.

Seed preparation

About 60 Cm long pieces, each containing a healthy undamaged bud, are cut from the freshly harvested sugarcane variety to be used for raising the nursery. The piece should be cut down from upper 2/3rd portion of cane using a sharp cutter, without damaging the buds. An eye-bud cutter, having two blades at a distances of 6 cm can be used for efficient cutting of the pieces. About 23,500 single bud piece are required for raising the nursery to transplant in 1 ha area (Singh *et al.,* 2011). The pieces are soaked in water for 6-8 hrs to maintain the moisture level.

Seed treatment

Fifty liters of water is taken in a plastic tub. To this, 100 g of bavistin (0.2%) is added and mixed thoroughly. This chemical is helpful in preventing the buds from fungal contaminations. In addition, growth regulators viz. Gibberallic acid and Naphthalene acetic acid are also added to the aforesaid solution each @ 50 ppm GA_3 is known to enhance the germination of buds and growth of shoots while NAA promotes the development of roots. The single bud pieces, soaked for 6-8 hrs in water are treated with the aforesaid solution for about 10 min.

Fig. 5. One month old plantlets of sugarcane

Implanting in poly bags

After seed treatment, the pieces are implanted in polythene bags containing the soil mixture. Implanting can be done either keeping the pieces in vertical or horizontal position, however, the buds should face upward in each case. Almost similar results have been obtained regarding germination of buds in both vertically or horizontally implanted pieces. During implanting, the pieces should be introduced deep into the soil mixture, so that the buds remain about 2.5 cm below the surface of soil mixture in the polythene bags. A light irrigation is given to the plots so that the water absorbed by the soil mixture through the perforation reaches up to the soil surface. Cover the nursery with dry leaves of sugarcane to maintain the humidity. After 4-5 days, water should be sprinkled over the nursery, if necessary, to maintain the proper moisture level till germination (Fig.5).

Intercropping in Autumn Planted Sugarcane

Intercropping refers to growing of two or more crops simultaneously on the same piece of land with a definite row-planting pattern to obtain higher productivity per unit area and time. Rapidly increasing population, increased demand for food, limited scope for extension of cultivation to new areas, diversified needs of small farmers for food and cash, etc. have necessitated the adoption of intercropping systems. In long duration crops like sugarcane, intercropping holds much promise. Due to slow establishment of sugarcane during the first 90-120 days, the greatest scope for complementary effect lies in the addition of annual intercrops to the temporal system to improve resource use efficiency in the early crop growth (Singh *et al*., 2008). Intercropping offers an opportunity for profitable utilization of available space. Sugarcane growers take advantage of this and grow various short duration crops like cereals, pulses, vegetables and spices as intercrops to obtain interim return. Small sugarcane growers need not wait until the harvest of the sole crop to obtain financial returns. Intercropping of economically important short duration crops with sugarcane through utilization of the present limited land resources would help to sustain sugarcane cultivation and provide interim return to marginal and small farmers, besides meeting the ever-increasing demand for vegetables and pulses. Great potential exists in India for increasing crop production and productivity through wider use of multiple cropping in cereals, millets, oilseeds, legumes and fibre crops. Legume intercrops in cropping systems enhance soil fertility through the excretion of amino acids into the rhizosphere. The nitrogen fixed by the legume intercrop may be available to the associated sugarcane in the current season itself, as sugarcane remains in the field for over nine months after the harvest of the legumes.

A further possibility of soil fertility improvement is through addition of crop residues, which on decomposition adds to the fertility of the soil. Since considerable addition of nutrient occurs through intercrops, there is a possibility of reducing N application through fertilizer. In general, the optimum row spacing recommended for autumn planted sugarcane is 90 cm which is widely followed in sub-tropical India, although there is a possibility to adopt wider row spacing. Such wider row spacing permits intercropping without adversely affecting the cane yield and thus increases the overall productivity and profitability of the system. Wider row spacing now becomes an important agronomic consideration to adopt mechanization on account of non-availability of labourers in sugarcane cultivation.

In the sub-tropical region, sugarcane is normally planted in autumn (September- October), *i.e.* before the onset of winter or after the cessation of winter. This planting of sugarcane invariably yields 15-20% higher sugarcane as also 0.5 units more sugar recovery than spring planted cane (Singh *et al*., 2001). The cane planted in the autumn season germinates before the onset of winter and remains in the field without much growth until the spring sets in. During this period, the cane does not make much demand for the growth resources. This facilitates raising of any *rabi* crop as intercrop with autumn planted sugarcane. Several studies demonstrated that the total productivity of crops in sugarcane + *rabi* crops intercropping system is substantially higher than the total productivity of sole *rabi* crop in winter followed by sole sugarcane planted in spring season. Dwarf type crops with compact canopy including legumes, oilseeds, cereals, spices and vegetables are suitable as intercrops in autumn planted sugarcane. Potato has been reported to be a promising intercrop in autumn planted sugarcane in sub-tropical India. Therefore, cultivation of short duration spices and vegetables as intercrops in sugarcane can be a successful package as it provides the needed income during the early stages and increases the total productivity without affecting the cane yield in the system. There is a higher demand for vegetables in the market now-a-days since the consumption of vegetables is increasing at faster rate in modern time as these are supplementary items in human diet (Fig. 6).

Recently, Hon'ble Union Minister of Agriculture and Farmers Welfare, Govt. of India while addressing a Seminar on 'Hundred Year of Sugarcane Varieties', said that the Government has set a target of doubling farmers' income by 2022 and is taking various steps to achieve this objective. The Minister stressed that the sugarcane farmers should be encouraged to adopt intercropping to boost their income. To boost income of cane farmers, the Minister called upon the farmers to go for intercropping and grow pulses, oilseeds or vegetables along with sugarcane. Moreover, Progressive farmers in certain areas of Punjab have improved their earning three times what they did earlier after they started inter-cropping their cane with garlic, potato and turmeric. In inter-cropping, cane rows are sown three to four feet apart and this space is used for the other crops. According to estimates of the cane department of Govt. of Punjab, around 40 to 50 per cent of the farmers are already growing autumn cane with suitable intercrops. At a few places, up to 80 per cent farmers have gone for intercropping with autumn planted sugarcane. In autumn planting seed requirement is reduced and yet gives a high yield, besides bringing in an additional income from inter crops. Alongwith vegetables and spices, the under mentioned *rabi* crops can be grown successfully as intercrop with autumn planted sugarcane in Indian sub-tropics for enhanced yields and net returns.

Cereals	**Wheat**
Legumes	Pea, French Bean, Chickpea, Lentil
Oilseeds	Mustard, Toria, Linseed, Sunflower, Sesame
Flowers	Gladiolus, marigold
Medicinal and aromatics	Mentha, Ginger

Spices	Chillies, Onion, Garlic, Coriander, Fennel, Cumin, Fenugreek, Nigella, Turmeric
Vegetables	Potato, Tomato, Carrot, Turnip, Cauliflower, Cabbage, Knoll Kohl, Lettuce, Radish, Lady's Finger, Cucurbits

Fig. 6. Intercropping of winter vegetables with autumn planted sugarcane

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Recent Development in Mechanization of Sugarcane Planting and Intercropping Machines

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Sugarcane is an important industrial crop of India which is cultivated in an area of about 5.3 million hectares. The total annual production of sugarcane and sugar is about 366 and 28 million tonnes, respectively. In the present context of increased cost of sugarcane cultivation and shortage of labour during peak seasons of sugarcane planting operations, ways and means have to be evolved to keep pace with sugar production requirement with the population growth per unit area, time and input. The challenges can be met effectively by way of adopting the appropriate mechanical alternatives not only for increasing the productivity but inculcating cost efficiency and sustainability in sugarcane production system (Singh *et al.,* 2016; Singh, 2017). The farm mechanization in the context of sugarcane cultivation aims at introducing timeliness of operation and reducing human drudgery on one side and improving overall production efficiency on the other. The planting operation of sugarcane is an energy and labour intensive operation. Human drudgery is also involved when the operation is performed manually (Singh *et al.,* 2016). Several methods and techniques of planting sugarcane have received attention of researchers from time to time. These methods include flat method, trench method, furrow method, spaced transplanting technique (STP), cane node method etc. However, flat method of planting is much prevalent among cane growers of North Indian Plains. Planting of sugarcane comprises many unit operations such as opening of furrows, cutting of cane into pieces known as seed setts, placement of setts, fertilizer and insecticide in the furrows and providing soil cover over the setts. Furrows are opened with the help of animal or tractor drawn ridgers. Forty to forty five man-days are required in one hectare to carry out other operations. Since, arranging such a huge number of labour in a day is very difficult, the planting operation prolongs resulting into moisture loss of soil as well as seed setts (Singh *et al.,* 2017). A lot of efforts have been made at ICAR- Indian Institute of Sugarcane Research, Lucknow to mechanize sugarcane planting operations.

Machineries for mechanizing sugarcane planting

Numbers of planting machines have been developed at IISR for mechanizing different methods of sugarcane planting (Singh, 2016). Details of these machines are presented below:

Machineries for mechanizing flat method of sugarcane planting

Various models of sugarcane planters viz. Animal or tractor drawn semi-automatic (billet) planters and later tractor operated sugarcane cutter planters suiting to different agro-climatic and soil conditions have been developed at IISR. Different variants of tractor operated sugarcane cutter planters are either tractor PTO or ground wheel driven. Sett cutting is continuous and uninterrupted in PTO driven planters but proper sett metering is achieved at a particular combination of forward speed and PTO rpm. Sett metering remains same in ground wheel driven planters but precaution is required that ground wheels do not skid and remain in firm contact with soil. Tractor operated planters take four to five hours to cover one hectare. Four to five labourers are needed to operate the planter. There is saving of more than 50 per cent in the cost of planting operation by using sugarcane cutter planter as compared to traditional method.

Machineries for mechanizing furrow method of sugarcane planting

Recently, there is awareness of water shaving in sugarcane cultivation. In north India, it is being recommended to plant the cane in furrow method to save irrigation water. Planting of sugarcane in furrow method needs machine for deep furrow opening. For this purpose tractor operated deep furrower, deep furrower-cum-fertilizer applicator (Fig. 1) and deep furrow sugarcane cutter planter (Fig. 2) have been developed at IISR during last two years. Deep furrow sugarcane cutter planter is a multitasking machine, which performs all the unit operations involved in sugarcane planting including sett cutting, in single pass of the machine (Singh and Singh, 2017). It facilitates planting of sugarcane in deep furrow (20-25 cm) and maintains 5-7 cm loose soil bed underneath the planted seed setts. Planter has been field tested at IISR farm and on-farm trials also also going on at farmers field of western, central and eastern U.P. and Bihar.

Machineries for mechanizing trench method of sugarcane planting

Planting of sugarcane in deep and wide trenches under wide spaced paired row geometry (30:120 cm) has shown promising results on cane yield, water saving, reduced lodging and better ratooning. In order to reap the benefit of trench method of planting tractor operated trencher (Fig. 3) and trench planter (Fig. 4) were developed at IISR. While trencher performs opening of deep and wide furrow for paired row planting of sugarcane manually whereas, trench planter performs all the unit operations involved in cane planting including sett cutting, like earlier developed sugarcane cutter planters, in single pass of the machine.

Machineries for mechanizing ring-pit method of sugarcane planting

The ring pit planting technique is very good from the point of view of increased cane productivity but digging of large number of pits over the entire field was found to be very cumbersome and labour intensive. Therefore, the technique could not be pushed for large scale adoption by the farmers. Efforts were made at IISR to develop tractor drawn pit digger for mechanization of pit digging operation (Sharma and Singh 1989. The developed pit digger was able to dig one pit at a time. There was a problem of excessive vibrations and dynamic instability during the operation. Design refinements were made and modified prototypes of pit digger was developed (Sharma and Singh, 2007; Singh *et al.,* 2017). The equipment dig two pits simultaneously at a time. The developed equipment was tested and evaluated in sandy loam soil at IISR farm. With the help of the equipment approximately 150 pits (75 cm diameter X 30 cm depth) at a spacing of 30 cm were dug per tractor-hour operation. Cost of pit digging operation was saved by 70 per cent by using the pit digger.

Machineries for mechanizing planting of intercrops with sugarcane

Equipment for planting of inter crop with sugarcane has also been developed at IISR. Two types of machineries have been developed for inter cropping on the raised bed with sugarcane (i) raised bed seeder -cum-fertlizer applicator (RBS) (Fig. 5) and (ii) raised bed seeder-cum-sugarcane planter (RBS cane planter). The raised bed seeder is used for making three furrows and sowing of companion crop like wheat on the two raised beds. Sugarcane is planted in the furrows at a later stage manually. With the help of raised bed seeder-cum-sugarcane planter, planting of sugarcane in the furrows and sowing of companion crop like wheat on the raised beds, are accomplished simultaneously in a single pass of the equipment. Recently, sugarcane-cum-automatic potato planter, deep furrow sugarcane cutter planter-cum-multicrop bed seeder (Fig. 6), sugarcane trench planter-cum-multicrop raised bed seeder (Fig.7) have been developed for planting/sowing of intercrop simultaneously with sugarcane. Sugarcane-cum-potato planter (Fig.8) has also been developed for mechanizing planting of sugarcane in furrows and potato on the ridges simultaneously in single pass. These equipments have been performing well during field trials at IISR and other locations.

Strategies for popularization of machineries

Most of the machineries described in the article have been demonstrated at different parts of the country. These have been found effective in saving of time and cost and have potential to make sugarcane cultivation more profitable besides reducing human drudgery. There is a need for concerted efforts by all the stakeholders involved in the pursuit of cost-effective production of sugarcane and sugar for popularization of these machines so that it could reach to the end users. All these useful time, labour and cost saving machineries can be taken to the farmer fields on a large scale in order

Fig. 1. IISR deep furrow opener-cum- fertilizer applicator

Fig. 2. IISR deep furrow sugarcane cutter planter

Fig. 3. IISR trencher

Fig. 4. IISR sugarcane trench planter

Fig. 5. IISR raised bed seeder-cum- fertilizer applicator

Fig. 6. IISR deep furrow sugarcane cutter planter-cum-multicrop raised bed seeder

Fig. 7. IISR sugarcane trench planter-cum-multicrop raised bed seeder

Fig. 8. IISR sugarcane-cum-potato planter

to create awareness among the farmers. Private entrepreneurs could be encouraged to provide these useful equipments to the farmers on custom-hire basis. Machineries should be brought under the umbrella of subsidy for its larger adoption. IISR has signed Memorandum of Agreement (MoA) with the Agricultural Machinery Manufacturers of different part of India to ensure the availability of these machineries commercially. As per need of the local soil and agro techniques these machineries could be modified and adopted for mechanization of sugarcane cultivation for sustainable enhanced sugarcane production.

Numbers of machineries have been developed at IISR for mechanizing different methods of sugarcane planting. Ridger type sugarcane cutter planter, deep furrow sugarcane cutter planter and trench planter are the multitasking machine which performs all the unit operations of sugarcane planting including sett cutting simultaneously in single pass of the machine. These machines have been demonstrated at different places of U.P., Bihar, Maharashtra, Andhra Pradesh, Uttarakhand, Assam, Kerala etc. Use of these machines saves the cost of planting operation by 50 per cent and labour by 90 per cent as compared to conventional method. Low cost machineries like trencher, deep furrower, deep furrower-cum-fertilizer applicator were also developed at IISR to promote trench method or deep furrow method of planting. Trenchers are presently adopted at large scale by the farmers due to its low cost and benefits of yield increase, reduction in cane lodging and better ratooning. Pit digger has also been developed for mechanizing pit digging operation for planting of sugarcane in ring-pit method, which is high yielding technique of cane cultivation. Planting machines were also developed for planting of inter crops with sugarcane to take additional short duration crop without adversely affecting the sugarcane. There is need for popularization of these machineries among the cane growers to address the problem of labour availability and to bring cost efficiency in sugarcane cultivation.

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Potential of Sugarcane Bud Chip Technology and its Mechanization

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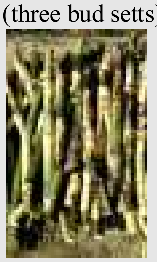
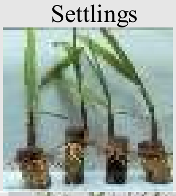
Sugarcane (*Saccharum spp.* hybrid) is commercially planted using seed cane/ setts at the rate of 6-8 tonnes/ha amounting to around 10% of total produce. This large mass of planting material poses a great problem in seed treatment, transport, and storage of seed cane as well as leads to reduced viability of buds resulting in poor bud sprouting. Besides, with the advent of new improved varieties, transportation of their bulk cane seed material and slow multiplication rate (ratio being 1:8 to 1:10) is an important constraint to seed programme. The viable alternative to reduce the mass, quality and quick multiplication of seed is bud chip technique. In this technique, scooped bud chips with a viable bud and root primordial is used as a planting material and raised their nursery

Table 1. Seed requirement for different methods of planting using various types of planting materials

Planting material	Method of planting	Seed requirement (t/ha)	Row spacing (cm)	Seed rate (in thousand/ha)
Setts (three bud setts) 	Flat	6	90	38 - 40
		7.2	75	46 - 48
		9	60	58 - 60
	Paired row trench planting	9	90:30	59 - 60
	Ring pit	15-18	75/90 cm (diameter) and 30 cm deep pit	22 three bud setts/pit 9,000 pits/ha at 75 cm distance
	Furrow Irrigated Raised Bed (*FIRB*)	8	80 cm	44
Settlings 	STP	2	90x60 cm	19 settlings
			75x60 cm	22 settlings
	Bud chip	1	90 cm x 30 cm spacing	30 settlings
			75 cm x 30 cm spacing	40 settlings
	Poly bag raised settlings	1.5- 2	90 x45 cm	25-30 settlings

Modified from Solomon *et al.,* (2013)

under field conditions after soaking in fungicide (Bavistin, 0.1% for 20 min) and growth promoting chemical (Ethrel @ 100 ppm). Within 25 days, settlings are ready for transplanting to raise sugarcane crop. Seed requirement for different methods of planting using various types of planting materials is given in Table 1. Seed cane requirement is comparatively very low, approximately 1.0 t/ha in bud chip method with high rate of bud sprouting (80-90 %) than three bud setts (6-8 t/ha) exhibiting nearly 30 percent bud sprouting. In this technique, seed multiplication rate is very high (bud chip, 1:60) as compared to conventional method (1:10). Bud chip technique saves the precious cane seed material, optimize initial shoot population, ensures higher NMC (number of millable canes) with a uniform crop stand and higher average cane weight. In bud chip technique, the left-over cane could be utilized for crushing since it remains a full cane except for the scooped up bud portions. In addition to this, bud chip transplanting with mechanical planter may save about 40 and 85 percent in cost and labour, respectively over manual planting.

Historical

It was van Dillewijn (1952) who first suggested that a small volume of tissue and a single root primordium adhering to the bud are enough to ensure germination in sugarcane. He has also stated that where growing conditions are favorable, cutting with only one bud did well as seed material. Narasimha Rao and Satyanarayana (1974) who were working on control of red rot in seed cane established that sugarcane can be grown from bud chip raised seedlings instead of setts. The bud chip machine was fabricated by Andhra Sugars and Ramaiah *et al*., (1977) demonstrated the method for commercial planting by carrying out a detailed experiment at Andhra Sugars, Tanuku with three varieties, Co 419, Co 975 and Co 997 under bud chip and conventional three bud setts cultivation. Their analysis brought out the usefulness of the method in saving the seed cane enormously. Gokhale (1977) conducted field experiment and reported that the bud of sugarcane removed with cortical portion, excluding the pith, could be successfully used as seed material for planting sugarcane.

Extensive work has been done using different types of seed cane materials such as single bud settlings, bud chip raised seedlings, 1-3 bud setts for crop establishment then determining the effect of the planting material on growth and yield of sugarcane in India (Reddy *et al*., 1986). It was observed that, due to saving in seed material, the maximum net returns were obtained with bud chips raised settlings. At Mayiladuthurai in Tamil Nadu, Nagendran and Sekar (1988) working at NPKRR Cooperative Sugar Mills reported that ‘bud chip seedlings transplanting technique’ as most suitable for adoption in the wet lands of Cauvery delta. The very good foundation laid earlier at Tanuku Sugars, encouraged Narendranath (1992) for planting sugarcane with bud chip raised seedlings in 500 acres. According to him, one acre nursery was sufficient to produce seedlings for planting 100 acres. Ramamoorthy and Ramanujam (1993) developed simple chemical method for bud encapsulation. Encapsulation of a sugar cane propagule (bud chip) bearing an axillary bud with 2% agar gel slurry maintained viability and hastened the sprouting process to produce a relatively long shoot. Tianco (1995) in Philippines, used 40 days old seedlings raised in polybags and found that yields were 11% higher due to 34% higher single cane weight as compared to normal method of cultivation. At Sugarcane Breeding Institute, Prasad and Sreenivasan (1996) used the bud chip method as a low cost technology for exchange of cane seed material. This facilitated easy carrying and transport of Co canes as bud chips in carton boxes across the country for the regular varietal development programme. The performance of bud chips as seed materials was evaluated at the Bangladesh Sugarcane Research Institute using sugarcane cultivars Isd-16, Isd-18 and Isd-19 (Iqbal *et al.,* 2002). Greater germination was obtained with single bud chips than with the conventional three-bud setts.

Field experiments conducted by Tamilselvan (2006) using different planting methods, revealed that planting seedlings grown on raised bed or polybags for 40 days at 80 x 25 cm spacing could enhance cane productivity. These seedlings produced 63% more early tillers, well-developed stalks with high juice content and cane yield of 108 tonnes ha^{-1} compared to 55 tonnes ha^{-1} with direct planting of chip buds. In year 2009, Biksham Gujja and his Team have established the concept of 'Sustainable Sugarcane Initiative' (SSI) under the WWF-ICRISAT project using bud chip raised settlings for seed saving, drip irrigation for water saving and intercropping for effective land utilization. A study also carried out through front line demonstration using bud chip method of sugarcane cultivation in Angul district of Odisha by Samant (2017). Results obtained indicated 39.7% higher cane yield (129.2 t ha^{-1}), production efficiency (421.8 kg ha^{-1} day^{-1}) and extension gap (36.7 t ha^{-1}) using bud chip technique than conventional method. It produced higher tillers $plant^{-1}$ (17.3) and number of millable canes $clump^{-1}$ (14.2) with 93% survival. The improved practice also recorded the higher gross return of ₹ 271320 ha^{-1}, B:C ratio (3.86) and profitability (₹ 609.6 ha^{-1} day^{-1}) with additional net return of ₹190080 ha^{-1} over local check.

Technology options

In view of manifold benefits of "Bud chip technology", extensive research work has been carried out at the ICAR-Indian Institute of Sugarcane Research, Lucknow to explore the physio-biochemical basis of bud chip viability for long duration storage, its treatment, storability, raising of settlings and their establishment in farmers field. In recent past, several experiments were conducted to maintain the viability of bud chips for long duration storage. In sugarcane agriculture, bud chips can be used in two ways:

1. Bud chip Encapsulation and direct planting
2. Bud chip raised settlings

1. Bud chip encapsulation and direct planting

Bud chip seed material has relatively low food reserves (1.2-1.8 g sugars /bud) compared to conventional 3 bud seed material (6.0-8.0 g sugars/ bud). The food reserves and moisture in the bud chip depletes at a faster rate compared to 2 or 3 bud sett which is reflected in their poor sprouting and early growth. Therefore to maintain moisture and viability of seed material, physical and chemical methods of bud chip encapsulation were performed to raise sugarcane crop by direct planting of bud chip seed material.

a. Chemical method

For chemical method, bud chips were first soaked in sodium alginate (6%) solution, and then in calcium chloride solution (100mM) mixed with fungicide and PGR chemical (ethrel@ 100 ppm) for 10 min. Encapsulated bud chips showed lower rate of moisture loss and early and higher rate of bud germination (90%) under tray culture conditions if stored at low temperature conditions.

b. Physical method

For improving water retention capacity and maintaining shelf life of bud chip seed material, bud chips after fungicide treatment (0.1% Bavistin) were encapsulated using a membrane. By this method, bud chip if stored at room temperature for 8 days, seed moisture was about 65 per cent as compared to control (30 per cent). Similarly, bud germination was comparatively higher (70%) than control (30%) under field conditions.

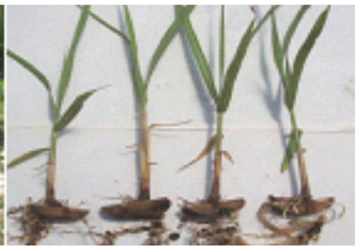
Bud chip raised settlings

Selected freshly harvested sugarcane stalks free from disease /pests (at 10 month's age). Scoop out bud chips with the help of hand operated bud scooping device developed by IISR, Lucknow. Using scooping machine, a labour is able to scoop about 150 buds in an hour and price of machine is Rs 800/-. About 1t/ha cane stalk will be required to raise bud chip settlings for one hectare field. 10 m^2 area will be sufficient to raise settlings for one hectare field. Mechanised bud scooping device is required to enhance the efficiency of scooping and reduce labour cost.

Seed preparation, treatment and raising settlings

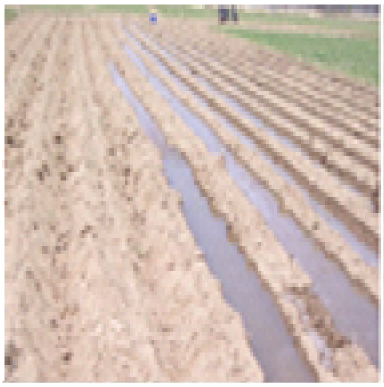
(i) Selected freshly harvested sugarcane stalks free from disease /pests (at 10 month's age) (ii) Scooped out bud chips with the help of hand operated bud scooping device (iii) Soaked bud chips in specially formulated plant growth regulator (ethrel @100 ppm)) solution for 2 hrs (iv) Treated with fungicide, Bavistin (0.1%) for 20 min (v) Kept under fan to dry if it is stored for long distance transport (even for 8-10 days) (vi) Stored in polyethylene bags after fungicide and hormonal treatment at low temperature conditions (10±1^{o}C) (vii) Planted these pretreated bud chips in upright position in plastic cups/trays filled with soil mixture containing soil, organic matter and sand in a ratio of 1:1:1 (viii) Regular watering with a rose can is essential (x). To make this technology more economical, bud chip nursery was raised in mini-plot near experimental field and it is perfect for commercial plantation (Jain *et al.*, 2010 and 2011).





Transplanting of bud chip raised settlings under field conditions

Transplanting of healthy settlings of optimum age ensures better cane yield as growth and tillering proceed normally. In case of sugarcane, about 25-30 days old settlings may be transplanted to realize higher cane yield. Transplanted settlings should be watered after every 15 days for their proper establishment at initial stage. After establishment of settlings, cultural practices similar to conventional method of sugarcane cultivation were followed. To reduce the cost of settlings transplanting, a tractor mounted two row mechanical planter has been developed by Central Institute of Agricultural Engineering-Regional Centre, Coimbatore and Sugarcane Breeding Institute,




Coimbatore. This showed 40 and 85%, saving in cost and labour, respectively over manual bud chip settling planting (Naik *et al.,* 2015).

Transplanting time

For autumn planting, second week of October and last week of February / first week of March for spring planting is optimum time for settling transplantation to ensure good plant vigor and higher tillering in sugarcane crop.

Plant spacing

Healthy settlings were transplanted in well prepared field after 25-30 days with row spacing of 90 x 30 cm (autumn planting), at 75 cm x 30 cm (spring planting) and 60x 30 cm (late planting) in different planting conditions which helps to obtain higher tillering and uniform plant population.

Nutrient management

Similar to conventional system of sugarcane planting, full dose of phosphorus (P) @ 80 kg P_2O_5 ha^{-1}, potassium (K) @ 80 kg K_2O ha^{-1} and 1/3rd of nitrogen (N) of full dose of 150 kg ha^{-1} were applied at the time of planting. Rest 2/3rd of N in the form urea was top dressed in two equal splits before earthing up in the month of May and June.

Weed management

An effective weed management program viz., mechanical or conventional method by laborers called hoeing was performed to manage weed flora in between settlings and rows to trigger early plant vigor and tillering in sugarcane.

Irrigation

In subtropical India, settlings were transplanted in furrow irrigated field. The critical stage of water requirement for sugarcane settlings is initial establishment and tillering phase before monsoon. Therefore, minimum five irrigations before monsoon is required for higher tillering, cane yield and good quality juice.

Harvesting

Crop raised using bud chip settlings was harvested in the month of November for autumn planting and February for spring planting. Delayed harvesting leads to over ripening and reduced sucrose recovery.

Benefits of bud chip technology

- Bud chips raised in cups are less bulky, easily transportable seed material.
- It showed higher bud germination (90%) as against 30-35% in conventional system.
- Nearly 80 per cent (by weight) of the planting material can be saved by using bud chips as it requires about <1.0 tonne seed per hectare while in conventional system of cane cultivation, 6-8 tonnes seed per hectare is needed.
- It showed higher tillering, cane height and cane weight as against setts planting method hence higher cane yield (100t/ha) as compared to conventional method (67 t/ha).
- Higher seed multiplication rate in bud chip (1:60) as compared to conventional method (1:10).

- Bud chip technology is most viable and economical alternative in reducing the cost of sugarcane production. Cost of cultivation further reduced if it is performed by mechnical ways.
- The left-over cane can be utilized for juice/ sugar / jaggery making.



Net benefit using bud chip technology

- Seed cane saving (5 t ha^{-1}),
- Seed Multiplication rate (1: 60)
- Monetary gain: ₹ 12,960 ha^{-1} in terms of seed saving

Using bud chip settlings with application of improved production technology for nursery management, settling transplanting with mechnical transplanter, good cane yield (>100t/ha) can be realized at farmers field and seed multiplication rate can be enhanced to 1:60 from conventional method of 1: 10 (using three bud setts). Farmers can increase their income as well as sugarcane yield using bud chip method of sugarcane planting with good management practices.

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Improved Hand Tools and Equipment for Sugarcane Cultivation

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Sugarcane is an important industrial crop of India which plays a crucial role in social and economical up-liftment of rural population. It is grown in an area of 5.04 million ha producing 411 million tonnes with an average productivity of 81.5 tonnes/ha. Uttar Pradesh state is largest producer of sugarcane as it contributes 46.21 % of the total area and 43.65% of the total production in the country but have the average yield less than the national average. In India, the majority of the farm holdings fall under small and marginal category (86%) and the average size of land holding is about 1.08 ha (Table 1). Table also revealed that number of land holdings having less than 2.0 ha farm size has increased in 2015-16 as compared to 2010-11. The density of agricultural workers per thousand hectares is about 2218. Gender perspective of agricultural workers indicates that about one half of the agricultural labours are women (Table 2). The sugarcane cultivation involves different operations such as seed bed preparation, planting (seed setts cutting, furrow making, placement of seed setts in furrows, fertilizer and chemicals application, soil covering over setts), weeding/ inter-culturing, spraying, harvesting including de-trashing and transportation. Most of these operations are being done manually with conventional tools and equipment which are very time, labour consuming (more than 500 man-days/ha) and involve lot of drudgery which ultimately increases the cost of operation and reduces the net profit to the growers (Singh and Gupta, 2015; Singh *et al.,* 2016). The participation of women farmers are there in carrying out most of these operations such as seed sett cutting, seed

Table 1. Number and size of operational holding by size group

Category of holdings	No. of holdings (000 no.)		Area (000 ha)		Average size of holdings (ha)	
	2010-11	2015-16	2010-11	2015-16	2010-11	2015-16
Marginal (<1 ha)	92826 (67.0)	100251 (68.45)	35908 (22.5)	37923 (24.0)	0.39	0.38
Small (1.0-2.0 ha)	24779 (17.9)	25809 (17.6)	35244 (22.08)	36151 (22.9)	1.42	1.40
Semi-medium (2.0-4.0 ha)	13896 (10.0)	13993 (9.55)	37705 (23.6)	37619 (23.8)	2.71	2.69
Medium (4.0-10.0 ha)	5875 (4.2)	5561 (3.79)	33828 (21.2)	31810 (20.15)	5.76	5.72
Large (10.0 ha & above)	973 (0.7)	838 (0.57)	16907 (10.6)	14314 (9.06)	17.38	17.07
All holdings	**138348 (100.0)**	**146454 (100.0)**	**159592 (100.0)**	**157817 (100.0)**	**1.15**	**1.08**

Anon. 2019. Agriculture Census 2015-16 (Phase I), Agriculture Census Division, Department of Agriculture, Co-operation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India, 2019.

Table 2. Gender perspective of agricultural workers

(in Millions)

Agricultural Workers	Cultivators (Main & Marginal)	Agricultural labour (Main & Marginal)	Male Cultivators (Main & Marginal)	Male Agricultural labour (Main & Marginal)	Female Cultivators (Main & Marginal)	Female Agricultural labour (Main & Marginal)
Total	127.3	106.8	85.4 (67.1)	57.3 (53.6)	41.9 (32.9)	49.4 (46.3)
Rural	124.7	102.4	83.4 (66.9)	54.7 (53.4)	41.2 (33.1)	47.7 (46.6)
Urban	2.6	4.3	1.9 (73.6)	2.6 (60.5)	0.65 (26.0)	1.7 (39.5)

Table 3. Gender participation and labour requirement per hectare in sugarcane cultivation

S.No.	Operations performed	Gender Involvement	Equipment/ method used	Man-h/ ha	Man-days/ ha
1.	**Land preparation**				
a.	Ploughing & harrowing	Male	Bullock plough/tractor cultivator	126	21
b.	Removal of grass	Male & female	Manually by sickle	296	50
2.	**Planting of cane**				
a.	Sett cutting	Male & female	Manually by sickle	90	15
b.	Furrow opening	Male	By bullock plough/ tractor cultivator/ridger	55	9
c.	Dropping of setts	Male & female	Manually	5	1
d.	Dropping of fertilizer	Male & female	Manually	5	1
e.	Dropping of insecticides	Male	Manually	5	1
f.	Closing of furrow	Male	Bullock plough	7	1
g.	Planking	Male	Manually Bullock/Tractor Planker	8	1
3.	**Interculture**				
a.	Hoeing (2 times)	Male	*Desi* plough	100	16
b.	Hoeing (4 times)	Male	*Kudal*	1018	166
c.	Weed picking (2 times)	Male & female	By hand sickle	447	74
4.	**Top Dressing (1 time)**	Male & female	By hand	15	3
5.	**Earthing-up (1 time)**	Male	Spade	667	111
6.	**Stubble Shaving (1 time)**	Male	Spade/*kudal*	144	24
7.	**Harvesting**	Male & Female	*Gandasa*/different types of knives	600	100
			Total	**3588**	**594**

sett placement, weeding, harvesting and de-trashing with traditional tools (Table 3). With the use of traditional tools, work efficiency of the operation reduces and drudgery involved in performing the operations resulted in physical stress on the worker. So, there is need to ergonomically study the various traditional tools used for different operations in sugarcane cultivation critically with design modification and development of improved tools based on the anthropometric data of the user population so that the drudgery involved could be minimized. Many hands tools have been ergonomically designed/modified and developed by different R& D Institutes so that drudgery involved with traditional methods could be minimized with enhanced efficiency.

Improved Manual Tools and Equipment

IISR manual sugarcane bud chipper

Manual sugarcane bud chipper has been developed to remove buds from the sugarcane stalk for raising seedling for transplanting (Fig. 1). The device consists of a platform with a fixed frame supporting spring loaded shaft, a handle and a semi-circular chipping device/blade. Cane stalk is put transversely on the platform manually to cut the eyes by pressing the handle. An output of 1000 buds/h can be achieved with this tool.

Fig. 1. IISR Manual Sugarcane Bud Chipper

IISR cane juice sampler

This sampler is used to draw composite juice samples from standing crop of cane for assessment of maturity of the crop. The sampler consists of an aluminium handle, machined to take a stainless steel needle and glass capsule (Srivastava, 2000). The needle is locked in position on the handle with a grub screw. It has a cutting edge which neatly severe the fibres when pushed into a cane stalk. The juice from the puncture runs down the groove in the middle of the needle and collects in the capsule. A rubber seal provides a leak proof seat for the capsule which is held in position by a cap made of polyethylene.

IISR manual harvesting knife

Manual harvesting knife is used to cut the cane stalks closed to ground surface during harvesting. It consists of chaff cutter knife mounted on an angle of 120^0 with the handle. While working with this tool there is no need to bend for cutting the standing canes. Use of this tool facilitates the cutting of cane closed to the ground surface (Srivastava, 2000).

IISR manual cane detrasher

Fig. 2. IISR Manual detrasher

Manual detrasher is used to remove dry trash from standing as well as harvested cane crop (Fig. 2). It has three fingers (20-30 cm long) mounted at an angle of 15-20^0 with the handle (Srivastava, 2000). While working in the standing crop long handle is removed. With the help of this tool 13 persons can cover 1 ha of field in a day.

IISR manual sugarcane detrasher cum detopper

Fig. 3. IISR Sugarcane detrasher cum detopper

For detrashing and detopping, IISR Lucknow has developed a hand tool which does the job of stripping of dry leaves and cutting the green top satisfactorily (Fig. 3). It consists of a pair tongs, the jaws of which close to form a square and extend beyond the square to form a "V" in front (Srivastava, 2000). One of the two limbs is bent down and provided with a wooden handle. A light tension spring holds the jaws closed. A knife is welded on the stem of the detrasher for detopping the cane after harvest. The cane is gripped between the jaws of the tool and drawn downward in one or two sweeps. The stripper removes the dry/green leaves by separating them and pushing them away from cane stalk. The green top is then cut with a knife provided for this purpose on the stem of the stripper.

OUAT sugarcane detrasher

The sugarcane detrasher developed at OUAT Bhubaneswar has similar configurations to that of the IISR model (Kathirvel *et al.,* 2010). The knife is absent in this model. The sugarcane stem is held between the two jaws and the detrasher is forced vertically for detrashing the dry leaves from the sugarcane.

TNAU sugarcane detrasher

This is the tool for detrashing the green/dry leaves from the standing crop of the sugarcane (Kathirvel *et al.,* 2010). It consists of two curved knives welded to two ends of the U shaped stem. The stem is attached to a hollow metal pipe. An adjustable oval shaped loop is provided to increase or decrease the gap between two knives depending on the diameter of sugarcane stalk. The knives are inserted between the internodes at the top and pulled vertically down for removing the dry and unwanted leaves.

IISR manual cane node/bud chip/sett cutting machine (3 in 1)

A manual machine was developed for doing three operations separately viz. cutting cane node, bud chip scooping and seed sett cutting of sugarcane as seed material required for sugarcane planting by various methods (Fig. 4). The machine has a handle, high carbon steel blade, a scoop and platform to fix the machine. One person can easily operate by holding cane in one hand and pressing handle with other hand for the required operation.

Fig. 4. IISR manual cane node/bud chip/sett cutting machine

IISR sugarcane manual stripper-cum-detopper (new models)

The weight of earlier designed model of manual stripper cum detopper was slightly heavy to use for a longer duration. So, three new models of sugarcane stripper cum detopper were designed and developed (Fig. 5). The technical specifications of models are given in Table 4. The testing of these tools have been carried out at Institute farm. Two individuals male and female were selected for operating these tools that have the experience of sugarcane harvesting for more than five years. After harvesting of cane, data of cane stripping and de-topping with all tools was taken for 20 minutes continuous work by the operator (Table 5).

Table 4. Technical specifications of the sugarcane stripper cum detopper

Parameters	Model I	Model II	Model III
Weight, g	408	398	225
Material of blade	High carbon steel	High carbon steel	High carbon steel
Thickness of blade, mm	3.0	2.0	2.0
Thickness of cutting edge, mm	0.5	0.5	0.5
Dia. of hand grip, mm	35	30	30
Cutting length of the blade, mm	110	95	85
Material of handle	Wood	Wood	PVC
Overall dimensions (LxB), mm	370x60	350x75	310x55

Model I **Model II** **Model II**

Fig. 5. Developed sugarcane stripper cum de-topper

Table 5. Test results of sugarcane stripper cum de-topper (Variety: CoPK 5191)

Parameters	Model I		Model II		Model III	
	Male	Female	Male	Female	Male	Female
Time, min	20	20	20	20	20	20
No. of cane stripped & de-topped	107	65	86	66	116	99
Weight of the clean cane, kg	48	29	38	31	50	45
Green top weight, kg	10.5	7	7.5	9	15	10
Dry trash, kg	5.8	4.2	4.3	5.4	9.1	5.5

Manual multi crop planter for sowing intercrop in sugarcane

A single row manual multicrop planter was designed and developed for sowing intercrops in sugarcane (Fig. 6). PVC rotor with vertical grooves on periphery was used for metering the seed. There is a provision to change the rotors as per the crops to be sown. The drive to the seed metering shaft was from ground wheel through chain and sprocket. Two persons were used to operate the machine. Testing of the machine was carried out for sowing of black gram, lady finger, wheat and mustard as intercrop in sugarcane. The effective field capacity of the machine was 0.07 ha/h and 0.10 ha/h in wheat and mustard, respectively. The crop stand was observed good (Fig.7).

Fig. 6. Manual multicrop planter for sowing intercrop in sugarcane

Fig. 7. Intercropping of wheat and mustard in sugarcane with manual multicrop planter

Manual weed cleaner for weed management

A manual light weight weed cleaner was developed based on the principle of wiping (or brushing) for weed control in between crop rows by using non-selective herbicides i.e. glyphosate (roundup) to the targets (weeds) by direct contact without damaging the crops (Fig. 8). The herbicide solution is supplied to an absorbent surface i.e. spongy roller in weed cleaner. The weed cleaner was calibrated for herbicide dose and volume of water. Testing of weed cleaner was carried out at Institute farm. Weed cleaner was tested at the farm in sugarcane field planted at 75 cm row spacing. One person is required to operated the cleaner. The capacity of the cleaner was 0.04 ha/h at operating speed of 2.0 km/h. The discharge rate was observed 470 l/ha

Fig. 8. Manual light weight weed cleaner and field condition after operation

Solar powered manual sprayer

A solar powered manual sprayer was developed for spraying herbicide/fungicide in different crops (Fig. 9). The technical specification of the sprayer has been given in Table 6. The height of the spraying can be adjusted from 300 mm to 1000 mm. Preliminary testing of this sprayer has been carried out at Institute farm for spraying pre-emergence herbicide in sugarcane.

The effective field capacity of the sprayer was observed 0.52 ha/h with field efficiency 80% at average speed of 1.8 km/h (Table 7). The sprayer takes about 71% less time as compared to knapsack sprayer to cover one hectare area.

Fig. 9. Solar powered manual sprayer

Table 6. Technical specifications of the solar powered manual sprayer

Overall dimensions (L x W x H), mm	1830 x 2930 x 1550
Minimum base height, mm	300
Maximum height, mm	1000
Type and No. of nozzles	Flat fan nozzles and 7
Nos. of wheels and dia., mm	3 and 670
Nos. of battery and pump used	2 each
Battery voltage and capacity	12 V and 8Ah
Pump voltage, press. and flow rate	12V, 5.09 kgf/cm^2 and 3.1 l/min
Pipe length, dia. and capacity	1900 mm, 200 mm and 65 litre
Power of solar panel used	20 W

Table 7. Performance results of sprayer during preliminary testing

Effective width, mm	3600
Average speed of operation, km/h	1.8
Average force required to pull the sprayer, kgf	18
Average discharge of nozzle, ml/minute	614
Average discharge of all nozzles, l/minute	4.3
Effective field capacity, ha/h	0.52
Time to cover 1 ha area, h/ha	1.92
Field efficiency, %	80
Battery backup after fully charging (self charging by solar also during operation)	> 6 h

The improved manual tools and equipment enhances the capacity and efficiency of the operation with less time, cost and drudgery as compared to conventional practices. So, these manual tools need to be popularized for wide adoption among the farmers.

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Mechanization of Sugarcane Interculturing and Earthing up Operation

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Weed infestation in sugarcane is very fast and the extent of crop loss due to the weed varies from the 10% to the total crop failure (Srivastava, 2000). Sugarcane requires number of intercultural operations for weed control, moisture conservation, microbial action and creation of better environment for overall growth of the plant. Delayed weeding leads to strong competition for light, water and soil nutrients between weeds and young seedlings. The purpose of weeding and interculture operation is to provide best conditions for crop to establish and grow vigorously. Weeds in sugarcane fields can be controlled through mechanical and chemical methods. Mechanical method is preferred to chemical method because weedicides are not only expensive but some of the weedicides are also injurious to crops and human beings. Mechanical methods also contribute towards maintaining the soil physical conditions thus improve plant growth and successfully check the loss in cane yield. Manual weeding, digging by spade, inter-cultivation by bullock and tractor drawn cultivators are the common practices being followed. Manual weeding is most effective but very costly with low efficiency. Manual or mechanical hoeing at 30, 60 and 90 days after sowing/planting has been found effective to minimise the yield loss.

Earthing-up in sugarcane is an important operation and mostly performed manually with spade or tractor operated ridger. Initially earthing-up must be light to give less suppressing effect on tiller production. Experiment has shown increased cane yield after earthing-up operation at Lucknow. Ridger or furrower is an implement which cuts and turns the soil in two opposite directions simultaneously for forming ridges. Tractor drawn ridger (3 bottom) is most commonly used implement in sugarcane cultivation for furrow opening and then earthing up operations.

Fig. 1. Conventional cultivator and ridger used in sugarcane cultivation

Keeping in view the above points, various R&D Institutes have developed different interculturing and earthing-up equipment as described below:

Tractor/ Animal drawn cultivator

Cultivator is an implement used for inter cultivation with laterally adjustable tines to work between crop rows. For actual cutting the soil, different types of shovels and sweeps are used. Most of the farmers are using this implement for interculturing in between crop rows and for seed bed preparation also. This implement is commercially available with spring loaded and rigid tines having 7, 9, 11, 13 tines or more depending upon the requirements. The animal drawn cultivators are having 3 and 5 tines.

Tractor-mounted multipurpose implement for sugarcane

The multipurpose implement for sugarcane was developed by Singh and Pandey (2004) at IISR, Lucknow. There are two versions of this equipment. The first model is a three-row sugarcane planter mode. The equipment can be used as (i) 9-tyne cultivator (ii) for intercultural operation, and (iii) earthing-up operations with minor adjustments. It can also be used as seed drill and paddy puddler with minor attachments. The second model is basically a two-row sugarcane planter. For land preparation the equipment can be used as tractor-operated 9-tyne cultivator. For interculture it can be used for intercultural operation in sugarcane field. The field capacity in interculture mode is 0.72 ha/h. Three inter-row spaces are intercultured in a single pass. For earthing-up, three-rows of cane can be covered by this equipment with a field capacity of 0.66 ha/h.

IISR multipurpose tool frame with attachments

This tractor operated multipurpose tool frame with attachments was developed at ICAR-Indian Institute of Sugarcane Research, Lucknow for furrow opening, interculturing, herbicide spraying and fertilizer application in sugarcane (Fig. 2 and 3). For interculturing in sugarcane crop with 3 row interculturing equipment, six tines with shovel and three small full sweeps in between each pair of shovel tines was provided. The total inter-row spacing covered during interculturing with mechanical tools is 450 mm and intra-row width covered for herbicide application is 300 mm. There is a provision for height adjustment of interculturing tine in the range of 500 to 650 mm as per the crop and field conditions. During combined interculturing,

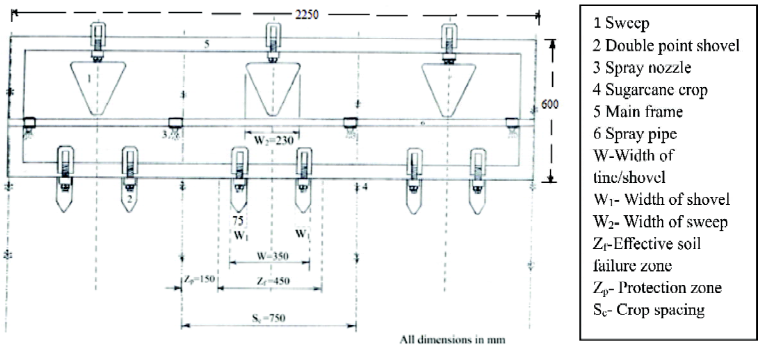

Fig. 2. Schematic diagram of designed multipurpose tool frame with interculture-cum-herbicide spraying and fertilizer application attachment

herbicide spraying and fertilizer application operation, effective field capacity was 0.54 ha/h with field efficiency 81.3%. The weeding efficiency was 83%, depth of interculturing 100 mm and herbicide application rate 265 l/ha.

Fig. 3. IISR multipurpose tool frame with interculturing attachments

The cost of combined operation of inter-row interculture, intra-row weeding through herbicide spraying and fertilizer application with the developed equipment was reduced 58% as compared to conventional practice of using tractor operated cultivator for inter-row and manual hoeing for intra-row weeding and manual broadcasting of fertilizer. The corresponding labour saving was more than 90%. The equipment can also be used for earthing up operation in sugarcane using IISR deep furrowers as an attachment (Fig. 4) with the tool frame. The earthing-up can be performed upto height of 65 cm of plant or till the formation of cane in the plant.

Fig. 4. IISR multipurpose tool frame with earthing up attachment

IISR sugarcane manager

This machine is used for interculturing and fertilizer application in standing crop near root zone of sugarcane. This machine is used for inter-culturing and earthing-up operations in sugarcane (Fig. 5). There is a provision for attachment of furrower for opening of furrows during planting.

Fig. 5. IISR sugarcane manager in operation

Tractor mounted 3-row rotary weeder

Tractor mounted rotary weeder was designed and developed at TNAU, Coimbatore and PAU, Ludhiana (Fig. 6). It consists of a main frame, gearbox, three rotary weeding blade assemblies, a shaft for transmission of power from gearbox to rotary assemblies and a set of sprockets and chains. A standard 3-point hitch arrangement has been provided to mount the frame to tractor. Power from tractor PTO is transmitted to main square shaft through gearbox mounted on main frame and a set of sprockets and chain. It facilitates adjustment of row-to-row spacing from 675 to 1165 mm. The field capacity of machine is 0.24 ha/h with weeding efficiency of 83-87%. The machine saves 54% labour and 74% cost of operation as compared to traditional method.

Fig. 6. Tractor mounted 3-row rotary weeder in the field

Fertilizer band placement cum earthing up machine

The tractor operated (26 kW and above) fertilizer band placement cum earthing up machine has been designed and developed at GBPUA & T, Pantnagar (Fig. 7). The machine is suitable for simultaneous placement of fertilizer, earthing up and cutting of weeds in crops such as maize, sugarcane, potato *etc.* having more than 0.50 m row to row spacing. The urea fertilizer application rate ranges from 60 to 250 kg/ha. It helps in top dressing of fertilizer at 50 to 100 mm from the plant. The field capacity of machine is 0.56 ha/h with 82.4% field efficiency. There is considerable saving in fertilizer, time and labour over traditional method.

Fig. 7. Fertilizer band placement-cum-earthing up machine

Self propelled rotary weeder/ power tillers

Self propelled rotary weeders have been developed at different Institutes and now commercially available. It is used for interculturing in between crop rows. Many firms are manufacturing these small weeders (Fig. 8). They had either petrol or diesel engine. The working width of weeders is about 45-50 cm and depth of operation 8-10 cm. The field capacity of this machine is the range of 0.10-0.14 ha/day. This machine saves lot of labour and drudgery as compared to traditional system of manual weeding.

Power tiller is also a multipurpose machine used for rota-tilling in between sugarcane crop rows. Mostly available power tillers in market have 10-15 h.p. diesel engine. The working width is normally 60 cm and field capacity of 0.06 ha/h, fuel consumption of about 1.0 l/h. Mini tractors of various makes and designs are available in the market for weeding and interculturing operation.

Fig. 8. Commercially available power tiller and mini tractor

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Micro-irrigation System for Water Management in Sugarcane

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The fresh water for direct consumption on the earth is only three per cent. Out of this fresh water, only 13 per cent is accessible (0.4% of total). The rest of the fresh water is locked up in glaciers and snow cover. With only 4 per cent of the world's fresh water resources India supports more than 16 per cent of the world's population on 2.3 per cent of the world's land. Not only per capita land availability but also per capita water availability is decreasing day by day. Other sectors *viz*. Industry, domestic, energy etc. are competing with agricultural sector due to increase in population. All the sectors are to grow within the available water resources. The National Water Policy, 2002 document very categorically states that water is a prime natural resource, a basic human need and a precious national asset. It further states that it is one of the most crucial elements in developmental planning. Agriculture sector in India has been and is likely to remain the major user of water but the share of water allocated to irrigation is likely to decrease by 10 to 15 per cent in the next two decades. As a consequence of this we have to produce more per unit amount of water applied, and for this, an integrated approach to water management is to be adopted.

Sugarcane utilizes more irrigation resources (6.46%) than land resources (2.55%) of the country. This imbalance in utilization of land and irrigation resources calls for efficient use of irrigation water. In India sugarcane is cultivated from 8^0 N to 30^0 N latitude, covering a large variation in climate. This climatic variation is mainly responsible for variation in water requirement of the crop which varies from 1400 mm to 1800 mm per year in sub-topical India and 2000 to 2400 mm per year in tropical India. Ratoon crop of sugarcane requires still 25-30 per cent more water to complete one crop cycle. Peak water use of 7.5–8.5 mm/day is observed during the grand growth period. If this much amount of water requirement is met out through surface irrigation methods, a huge amount of water goes waste in the form of surface runoff, deep percolation and evaporation from soil surface. To overcome this problem, micro-irrigation techniques are now being used to mitigate water scarce situation in the water scarce sugarcane growing areas of the country in a big way. Selection of irrigation method depends on the topography of field, size and shape of field, soil hydraulic properties, its quality and texture, irrigation water quality, labour availability, availability of electrical/diesel power etc. Depending upon these factors, most suited irrigation method can be selected based on the Table 1.

What is micro-irrigation?

Micro irrigation is the frequent application of small quantities of water on, above or below the soil surface, by surface drip, subsurface drip, micro sprayers or micro sprinklers. Water is applied as discrete or continuous drops, tiny streams or miniature sprays through emitters or applicators

Table 1. Factors influencing the selection of irrigation system

Factor	Furrow irrigation	Portable sprinkler	Solid set sprinkler	Center pivot	Moving lateral	SDI	Rain gun
Low AWC soil	-	0	0	+	+	+	-
Heavy clay soils	+	0	0	-	0	-	-
Saline soils	+	-	0	+	+	+	0
Erodible soils	-	0	0	0	0	+	-
Steep topography	-	0	0	-	-	0	-
Undulating topography	-	0	0	0	-	+	0
High sediment water	+	0	0	0	0	-	0
Saline water	+	-	0	+	+	+	0
Odd shaped fields	0	0	+	-	-	+	0
Ease of management	+	+	+	+	-	-	+
Automation potential	-	-	+	+	-	+	-
High winds	+	-	0	-	0	+	-
Labour shortages	-	-	+	+	0	+	+
High electricity costs	+	-	-	+	+	+	-

Negative (-) indicates factor has a negative influence on selection of the system.
Positive (+) indicates that factor has a positive influence on selection of the system.
No Effect (0) indicates that the factor should not significantly influence system selection.

placed along a water delivery line near the plant. Micro irrigation is characterized by low flow rate; long duration irrigation; frequent irrigation; water applied near or into the plants root zone; and low pressure delivery systems.

Micro-irrigation system components

Different components (Fig. 1) used in a typical micro-irrigation system may be classified as under:

1. Head control unit

Pump

Air valve

Vacuum gauge

Pressure gauge

Filtration unit (Gravel/Hydro cyclone/Disc/Screen)

Fertigation unit

Throttle valve

Water meter

Other fittings and accessories

2. Water carrier system

PVC pipeline for main

PVC pipeline for sub-main

Control valve

Flush valve

3. Water distribution system

Lateral pipe and drippers

Spagetthi (for connecting emitter to lateral)

Barbed connecter

Grommet

Nipple

Start connector

End cap

The selection of the appropriate components depends on crop condition (row to row and plant to plant spacing), environmental demand for water, water quality, and availability of labour.

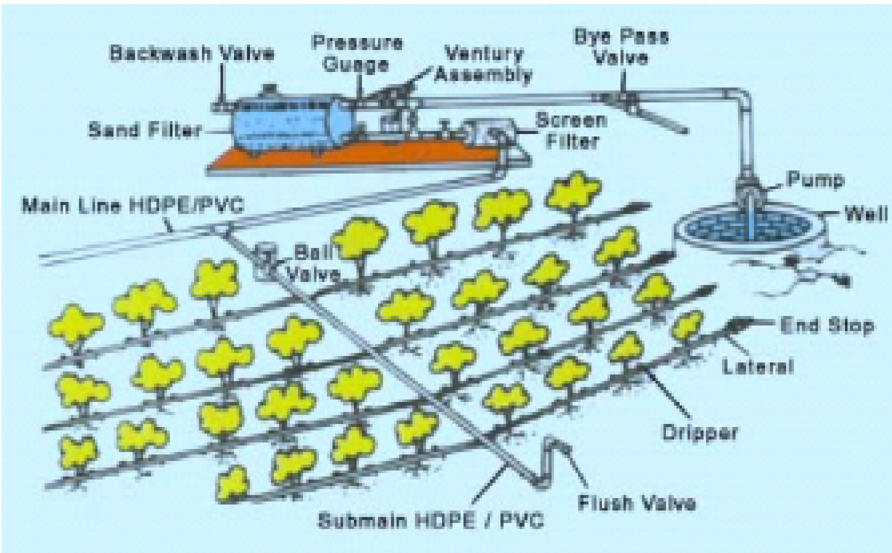

Fig. 1. Layout of different components of drip irrigation system

Why to use micro-irrigation?

Improved plant response: with micro irrigation crop can be irrigated frequently, enabling the soil moisture to be maintained at optimum levels for plant growth (Fig. 2). Crop yields increase 50 to 100 per cent mainly because plants are conditioned with proper air water balance and are free from low and high water stresses and shocks. The plant growth is faster and vigorous resulting in early yield. Purity and sucrose content in juice also improves.

Increased irrigation efficiency: Due to partial wetting of the soil surface, micro irrigation systems make irrigation more efficient and therefore require less applied water (Fig 3). Improved irrigation efficiency is achieved due to the following factors and conditions:

- Reduced soil evaporation losses due to a smaller portion of the soil surface area being wetted
- Reduced or eliminated run off
- Minimized deep percolation due to more precise water control
- Enhanced uniformity of water application

For sugarcane crop water utilization efficiency can be improved from 50 to 60% with flooding method to 90-95% with micro irrigation method. Due to water saving 40 to 60 per cent more land can be irrigated with the same amount of irrigation water.

Fig. 2. Lateral placement under paired row system

Improved chemical application: The consumption of fertilizers and chemicals can be reduced by up to 30 per cent, by using micro irrigation system since these are applied through water directly at the root zone of the plant in a uniform and effective way.

Reduced weed growth: Since water is applied directly to the base of the plant, weed germination between plants and plant rows is less to the extent of 50%

Fig. 3. Soil wetting pattern under drip irrigation

Decreased energy requirements: Since less water is pumped for micro irrigation, energy requirements are reduced. By irrigating one-hectare sugarcane crop with micro irrigation, 1059 kWh energy is saved when compared to flood method.

Adaptability: Micro irrigation can be used on steep or undulating topography and on soils that have low infiltration rates or low water holding characteristics. Saline soils and saline water can also be used for irrigation.

Maintenance

Occasional maintenance should be carried out on all micro irrigation systems. To do this, it is needed to inspect the emitters, flush the lines by opening the end cap, and clean the filter. Depending on water quality, the frequency of filter cleaning may vary. The design of the system using filtration and quality emission components will make maintenance a simple annual task. Visual inspection of the system is the best way to observe performance.

Tips for trouble free irrigation with micro irrigation system

Head Assembly

- Pump's suction pipe is elevated above bottom of pond. (Float the inlet 45 to 60 cm below the water surface.)
- Water source should not contain excessive amounts of algae. If so, then treat with a non-phytotoxic algaecide.
- Record water meter reading because decreased flow mean blockage and increased flow means leakage.
- Once the pipes fill up, check all gauges. Check pressure reading on gauges on either side of primary sand filters and if the difference in pressure is 0.35 kg/cm^2 or greater, the filters need to be backwashed.
- Check pressure reading on gauges on either side of the secondary filter. If there is more than 0.35 kg/cm^2 pressure difference between the gauges, clean secondary filter.
- Watch thread combinations and make sure that the same kinds of threads are put together. These are pipe thread and hose thread. These two types are not compatible and one will strip out if forced together.
- Check the water flow direction on each component. Water must flow in the correct direction for most items to work properly. Items that should be mounted in a certain direction have marking on the body.
- Use only Teflon tape to seal connections.
- Do not over tighten. Hand tight will be just fine on most items.
- Test for water flow on the head assembly before connecting to the poly tubing.
- Any head assemblies connected directly to a hose bib/hose faucet should be supported properly to prevent breaking of components.

Filtration

- Clean the screen inside the filter as often as needed. Having too much debris on the screen will hinder the water flow or block it completely.
- With extremely dirty water multiple filters might be needed.
- Use only Teflon tape for the threaded connections to prevent leakage of water.
- Make sure the water flow is in the same direction as the arrow on the filter.

Drippers

- Mounting drippers on the side of the lateral tube works best. Having them on the side allows for water to spill out easy and keeps hard water deposits from collecting. By placing emitters so, soil particles cannot enter in to the system and also inspection becomes easier.
- In undulated fields use of the pressure compensating drippers is preferred in order to ensure uniform discharge along the laterals.

Microsprinklers

- Take care when placing sprinklers so they will not be blocked by future growth of plants right next to them.
- Wind can affect the spray from microsprinklers. Try to water during a part of the day when there is normally no or very little wind.

Valves

- To extend the life of valves they should be installed after filter.

Fertilizer Applicators

- The fertilizer applicators should always be installed after a backflow device.
- Fertilizers, which are completely water-soluble, should only be used.

Results of the experiments on drip irrigation

Results of experiments conducted at different locations in India and elsewhere in the world shows that the use of drip irrigation saves considerable amount of irrigation water and nutrients, labour and energy (Tables 2 to 8). It also facilitates use of machinery and reduces weed growth. The yield and quality of produce is also improved when the crop is irrigated with drip system. Famers' income is increased due to higher input use efficiency, higher productivity and better quality of produce.

Table 2. Effect of irrigation methods on nutrient use efficiency

Nutrient	Nutrient use efficiency (%)		
	Soil application with flood irrigation	Soil application with drip irrigation	Drip fertigation
Nitrogen	30-50	65	95
Phosphorous	20	30	45
potassium	50	60	80

Table 3. Cost benefit, payback period of micro irrigation for sugarcane

Spacing of crop (m)	Cost of the system (₹/ha)	Payback period	B:C ratio
0.83x1.66 paired row	47500	1-2 years	3.45

Table 4. Effect of drip irrigation on water saving, yield and profit in Tamil Nadu

Yield (t/ha)			Profit (₹/ha)			Water saving over flood irrigation (%)
Flood irrigation	Drip irrigation	Drip irrigation with fertigation	Flood irrigation	Drip irrigation	Drip irrigation with fertigation	
120	160	207	30000	47000	68000	29

Table 5. Performance of sugarcane at different locations with sprinkler irrigation

Location	Yield (t/ha)		Irrigation water (cm)		Advantage of sprinkler irrigation	
	Flood irrigation	Sprinkler irrigation	Flood irrigation	Sprinkler irrigation	Water saving (cm)	Yield increase (t/ha)
Rahuri	79.21	86.63	245	188	57	7.42
Dharwar	48.0	55.7	51.5	43.5	08	7.70

Table 6. Effect of irrigation methods on irrigation efficiencies

Irrigation efficiencies	Methods of irrigation		
	Surface	Sprinkler	Drip
Conveyance efficiency (%)	40-50 (canal) 60-70 (well)	100	100
Application efficiency (%)	60-70	70-80	80-90
Surface water moisture evaporation (%)	30-40	30-40	20-25
Water Use Efficiency (kg/ha-cm)	323	461	727
Overall efficiency (%)	30-35	50-60	80-90

Table 7. Cost benefits, Payback periods of Micro irrigation for various crops

Crops	Spacing of crops (m)	Cost of the system (₹ ha^{-1})	Pay back period	B:C ratio
Grape	3.03*1.8	55000	1-2 years	3.28
Pomegranate	4.3*4.3	45000	2 years	5.16
Tomato	0.45*1.65 Paired row	45000	1 year	1.09
Papaya	1.81*1.81	45000	2 years	4.09
Sugarcane	0.83*1.66 Paired row	65000	1-2 years	3.45

Table 8. Water saving,yield and profit under drip and drip fertigation system

Crops	Water saving (%)	Yield (t/ha)			Profit (₹/ha)		
		Conventional	Drip	Drip + Fertigation	Conventional	Drip	Drip + Fertigation
Banana	35	26	30	37	81000	98000	120000
Sugarcane	29	120	160	207	30000	47000	68000
Tomato	32	45	56	65	56000	77000	95000

Results of experiments conducted during 2012-2015 at IISR, Lucknow with surface drip irrigation revealed that use of drip irrigation significantly improved sugarcane yield and irrigation water use efficiency (Table 9). Highest sugarcane yield of 91.36 t/ha was observed when drip irrigation was scheduled at two days interval with irrigation water equivalent to 80 per cent of pan evaporation. At this yield level, irrigation water use efficiency was 1029.29 kg/ha-cm. The higher sugarcane yield and higher irrigation water use efficiency is attributed to more number of millable canes of higher length and thickness (Table 10).

Table 9. Comparison of the effect of different irrigation treatments on irrigation water applied, sugarcane yield, irrigation water use efficiency and amount of water required to produce 1 kg of cane.

Fertigation treatments	Irrigation water applied (mm)	Yield (t/ha)	IWUE (kg/ha-cm)	Water required to produce 1 kg of cane (L)
Drip irrigation at 2 days interval with irrigation water equal to 0.6 E_{pan}	658.4	78.38	1190.46	84.0
Drip irrigation at 2 days interval with irrigation water equal to 0.8 E_{pan}	887.6	91.36	1029.29	97.2
Drip irrigation at 2 days interval with irrigation water equal to 1.0 E_{pan}	1109.7	90.56	816.08	122.5
Drip irrigation at 2 days interval with irrigation water equal to 1.2 E_{pan}	1131.6	85.37	754.42	132.6
Conventional flood irrigation with 8 cm irrigation water at 1.00 IW/CPE ratio	1109.7	72.65	654.68	152.7
SE mean ±		2.69	27.73	
CD (0.05)		5.76	59.47	

Table 10. Comparison of the effect of different irrigation treatments on number of tillers at onset of monsoon, number of millable canes, tiller mortality, cane stalk diameter and cane stalk length

Fertigation treatments	Number of tillers before onset of monsoon	Number of millable canes ('000)	Tiller mortality (%)	Cane stalk diameter (cm)	Cane stalk length (cm)
Drip irrigation at 2 days interval with irrigation water equal to 0.6 E_{pan}	256000	85200	66.72	2.24	227.3
Drip irrigation at 2 days interval with irrigation water equal to 0.8 E_{pan}	273000	90550	66.83	2.38	243.1
Drip irrigation at 2 days interval with irrigation water equal to 1.0 E_{pan}	265000	91000	65.66	2.34	239.4
Drip irrigation at 2 days interval with irrigation water equal to 1.2 E_{pan}	217000	87600	59.63	2..31	231.8
Conventional flood irrigation with 8 cm irrigation water at 1.00 IW/CPE ratio	243000	82800	65.93	2.23	221.6
SE mean ±	4312	2266	1.39	0.03	1.64
CD 0.05	9250	4861	2.99	0.06	3.52

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Moist Hot Air Treatment and its Impact on Disease Management

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Sugarcane (*Saccharum* spp. hybrid) is the most important commercial crop of India with an average productivity of 70.30 tonnes/hectare. Sugarcane growing countries of the world lie between the latitude 36.7° North and 31.0° South of the equator extending from tropical to subtropical zones. Sugar contains glucose, fructose and galactose and it is widely produced by sugarcane and sugar beet. A report said that an average person consumes about 24 kg of sugar every year and the world is producing around 174 million tonnes of sugar every year. There is no country where sugar is not being used. According to a recent report there are more than 120 countries producing sugar on large scale to meet their own needs and for export. Mostally (80%) of sugar is obtained from sugarcane and the other 20% is obtained from sugar beets.

There are various biotic and abiotic factors are responsible for its low yield, diseases are the major cause of concern. About hundred diseases of sugarcane have been reported from different parts of the world. Over 100 fungi, 10 bacteria, and 10 viruses and about 50 species of nematodes are pests of sugarcane in different parts of the world.

Important Diseases of Sugarcane

1. Red rot caused by *Colletotrichum falcatum*
2. Smut caused by *Sporosorium scitamineuma*
3. Wilt caused by *Fusarium sacchari*
4. Pokkah boeng caused by *Giberella moniliformis, Fusarium moniliforme*
5. Rust caused by *Puccinia melanocephala, P. kuehnii*
6. Leaf Scald caused by *Xanthomonas albilinians*
7. Ratoon Stunting caused by *Leifsoniaxyli* sub sp. x*yli*
8. Grassy shoot disease (GSD) caused by Phytoplasma
9. Sugarcane mosaic virus (SCMV) caused by virus
10. Sugarcane yellow leaf disease (SYLD) caused by virus

Red Rot

Red rot of sugarcane was first recorded from java in 1883 and in Indian subcontinent by Barber and later by Butler in 1906.

Disease Symptoms

The symptoms of red rot first appear on the midrib of leaves as red bright lesions with ash grey centre. Near harvesting of the crop (September-October onwards) the leaves show drooping and colour change of upper leaves. Initially, third or fourth leaf from the top show withering and finally the whole crown droop and withers.

History of red rot started with first report of Java (now Indonesia) by Went (1893). He named the fungus *Colletotrichum falcatum* as causal organism and the disease as 'het root snot' meaning 'red smut'. In India, large scale mortalities of sugarcane were first noticed in the Godavari delta of Andra Pradesh due to an discovered disease in late nineties of the 19^{th} century. The disease was first reported in India by Barber (1901) and he showed that it was caused by *Colletotrichum falcatum*. Butler (1906). He also proposed the common name 'red rot' and this name is now accepted universally. He conducted a studies on the disease, particularly on the causal organism, sources and mode of infection. Due to the vegetative nature of the crop, over time pathogen get accumulated in the plant and are transmitted through the seed cane setts. Most of the important diseases of sugarcane like red rot, smut, ratoon stunting, leaf scald, grassy shoot, yellow leaf and mosaic are essentially sett-borne and diseased cane setts play the pivotal role in the establishment of primary infection/inoculum in the field (Kishan Singh, 1973; Duttmajumder and Agnihotri, 1992). The impervious nature of the rind and size of the setts do not provide ample opportunity for the fungicides alone to act upon the pathogen residing in deeper tissues of the stalk and thus, efficiency of fungicidal treatment in the eradication of sett-borne inoculums is not up to the desired level.

Sources of infection

The perpetuation of red rot is through infected setts, diseased stubble/debris and by resting propagules in the soil. A major source of primary spread of the pathogen is by infected planting material (Butler and Khan, 1913; Agnihotri *et al*., 1979). The fungus is not a true soil borne organism and cannot persist more than 4½ months in soil (Chona and Nariani, 1952; Agnihotriet *et al*., 1979; Sharma *et al*., 1980; Singh and Singh, 1983). However, Singh *et al*. (1986) showed that the fungus could survive for 7 months in deep buried debris and 8–9 months when diseased debris was placed on the soil surface.

Dissemination

Secondary spread of the pathogen takes place mainly through rain and irrigation water. Heavy dew and wind also disseminate inoculum (Chona, 1950; Abbott and Hughes, 1961). The conidia produced on the rind wash down with water and cause infection through nodes. Dissemination of inoculum by means of wind appears more difficult because of the mucilaginous nature of the spore mass. But the occurrence of the disease in the upper portion of the canes provides an indication of an aerial mode of dispersal of the inoculum.

Mode of infection

The pathogen mainly infects canes through nodes and main portal of entry are leaf scar, growth ring, root primordia and buds (Steib and Chilton, 1951; Srinivasan and Alexander, 1966; Singh *et al*., 1977; 1983). The pathogen can also enter the stalk through root cuts, growth cracks and cut end, of the setts (Singh and Singh, 1989).

Management Challenges

The impervious nature of the rind and size of the setts do not provide ample opportunity for the fungicides alone to act upon the pathogen residing in deeper tissues of the stalk and thus, efficiency of fungicidal treatment in the eradication of sett-borne inoculums is not up to the desired level. Bio-agents and aerated steam therapy have been found to be ineffective in the control of red rot but not up to the economical level. Therefore, varietal resistance and Three-Tier Seed Programme has to be relied upon for durability of a variety and control of disease.

Smut of Sugarcane

The smut of sugarcane commonly known as whip smut is found in many sugarcane growing countries including India. The disease appears to move from wild canes to improved varieties.

Disease Symptoms

The disease show a whip-like black shoot at the apex of diseased plants which may be several feet in length and curved. The smut powder covered with a thin silvery membrane is attached to the whip. The membrane is ruptured and a thick mass of millions of smut spores is scattered by wind. In case of systemic infection, the nodes or eyes produce lateral shoots on affected plants which may also develop whip but if the infection is localized, main shoot may not develop the whip. The smut masses are present in several layers on whips.

Pathogen: The causal pathogen is *Ustilagoscitaminea* Syd. which belongs to family Ustilaginaceae, order Uatilaginales of the sub-division of Basidiomycotina. The smut spores are spherical, punctuate walled, light brown in colour about 5-10 μ in diameter. Under moist condition, the spores germinate and form a septatepromycelium. The sporidia develop from each cell of the septa which are elongated and develop infection threads after their germination. Sometimes the sporidia form more sporidia in chain. The spore germinates at a temperature of 25-40ºC with a relative humidity of 100%.

Disease Cycle: The sugarcane crop is available in the field throughout the year. The spores from the whip blown by wind are deposited on the junction of leaves and leaf sheaths of healthy plants and create infection at the nodal region. The infection occurs through germinating shoot on the host tissue or through the injuries made by insects. The disease perpetuates by planting diseased seed setts or through spores brought by wind on to the buds or through ratoon crops

Ratoon Stunting Disease (RSD)

Disease Symptoms

Diseased clumps usually display stunted growth, reduced tillering, thin stalks with hortened internodes and yellowish foliage (mild chlorosis). Coryneform Xylem limited fastidious bacteriainfects the vascular bundles of canes. When mature canesare split pen, vascular bundles appear discolored. In young canes, pink colour is seen in the formof minute pin head like areas near the nodes. The disease reduces the length, girth and the number of canes per clump. Affected plants are usually stunted and have poor root system.

Disease cycle

The disease spreads through use of diseased setts. The disease also spreads through cane harvesting implements contaminated with the juice of the diseased canes. Maize, sorghum, Sudan grass and Cynodonare some of the collateral hosts of the pathogen.

Leaf Scald

Disease symptoms

The disease can be latent, it can develop unseen for some time and when symptoms fi rst appear, the plant is already seriously infected.The first sign of the disease is the development of "pencil lines" of white with yellow borders following the veins on the leaf that lead to necrosis (death) of tissue.The term "scald" for the disease comes from areas of the leaf that loose their color and become a pale green (chlorotic) as they fail to produce chloroplasts.In nature the disease occurs in two distinct phasesacute phaseand chronic phase. In Acute phase, affected clumps suddenly show wilt symptoms and die without displaying any of the diagnostic symptoms. Whereas in chronic phaseit appears in plants growing under stress conditions, like drought, low temperature, poor soil fertility or in waterlogged condition.

Disease cycle

Pathogen survives in cane stubble and on agricultural implements and this is an important mechanism of spreading the disease. It can also survive on grasses, including elephant grass and may be transmitted from them to sugarcane.Favourable conditions are stress such as drought, waterlogging, and low temperature are reported to increase disease severity.

Grassy Shoot Disease (GSD)

Disease symptoms

Phytoplasma-infected sugarcane plants show a proliferation of tillers, which give it typical grassy appearance, hence the name grassy shoot disease. The plants appear bushy and 'grass like'due to reduction in the length of internodes, premature and continuous tillering. The leaves of infected plants do not producechlorophyll, and therefore appear white or creamy yellow.The leaf veins turn white (Albino) first as the phytoplasma resides in leaf phloem tissue. Symptoms at the early stage of the plant life cycle include leafchlorosis, mainly at the central leaf whorl. Infected plants do not have the capacity to produce food in the absence ofchlorophyll, which results into no cane formation. These symptoms can be seen prominently in thestubble crop. It is more severe in ratoon crops. Symptoms ofiron deficiency (interveinal chlorosis) are very similar to those of SCGS. It shows creamy leaves, but nochlorosisoccurs in leaf veins, and they remain green.

Disease cycle

Hytoplasmas, formerly calledmycoplasma-like organisms (MLOs), are a large group of obligate, intracellular, cell wallless parasites classified within the class Mollicutes. Sugarcane is a vegetatively propagated crop, so the pathogen is transmitted via seed setts/planting material and byphloemfeeding vectors as aphids, *viz., Aphis maidis, Rhopalosiphum maidis, Longiunguis sacchari, Melanaphis sacchari and M. indosacchari*. In addition, leaf hopper, *Proutistamoestaalso* involves in phytoplasma transmission in sugarcane. Sorghum serves as a natural collateral host.

Integrated disease management (IDM)

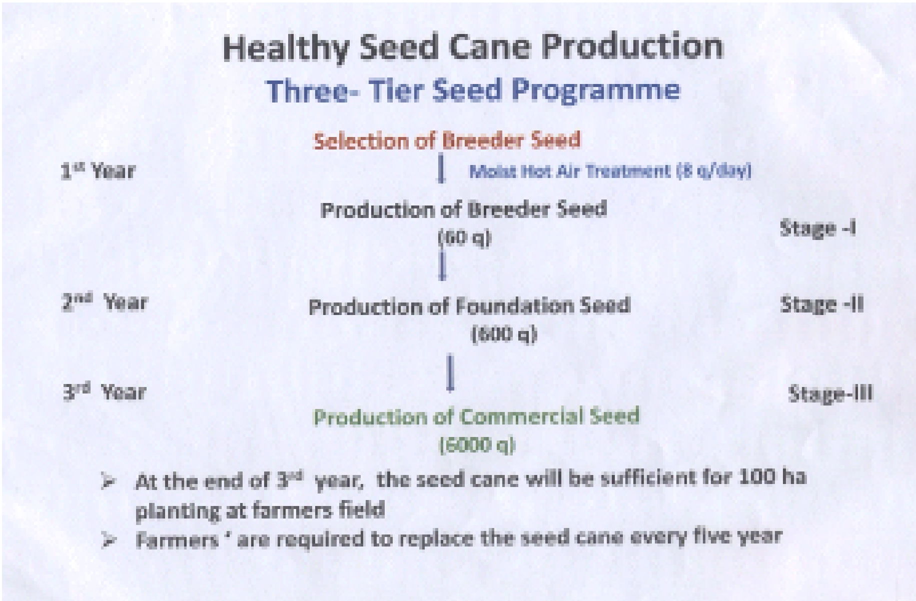
Components of IDM

- Use of healthy seed material
- Moist hot air treatment
- Selection of land
- Field sanitation
- Crop diversification
- Use of recommended (disease resistant) variety

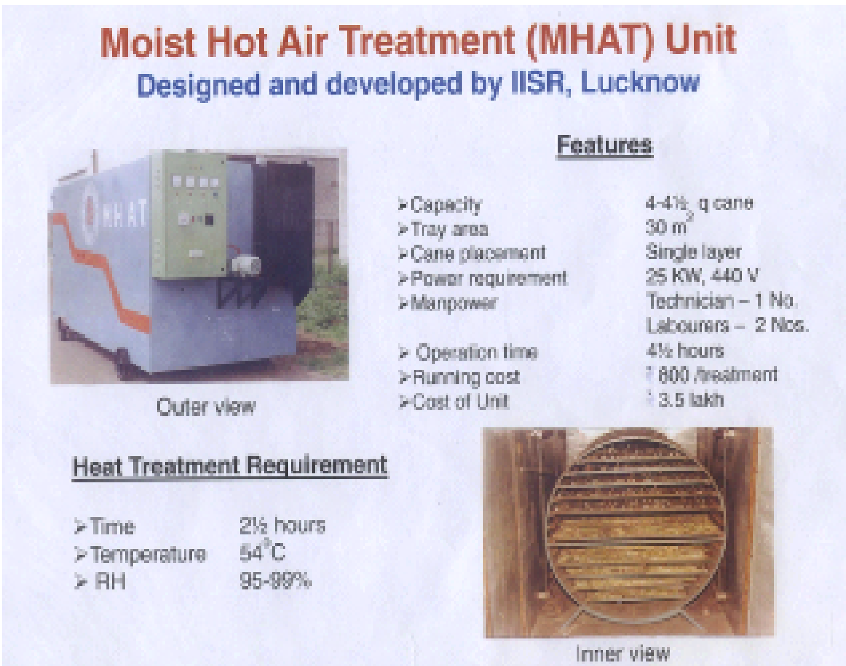
IISR technology of Moist hot air seed cane treatment unit:

The MHAT unit has been designed to control seed piece transmissible diseases like primary infection of red rot, primary infection of smut, grassy shoot, ratoon shunting and leaf scald of sugarcane, which otherwise pass from one generation to another. It also helps controlling the insect, pests like scale, mealy bugs etc.

Use of healthy seed material



Moist hot air treatment



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Insect-Pests of Sugarcane and Tools Used for their Management

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Intensive cultivation of sugarcane with introduction of new high yielding and high sugared varieties along with adoption of new agro-techniques has brought changes in the insect pest complex of sugarcane. Sugarcane as an agro-ecosystem contains many insect- pests both in aerial (above ground) and subterranean (below ground) habitats and about a dozen of them are more serious. These pests need to be managed timely without adversely affecting the environment.

Sugarcane Ecosystem

In subtropical belt, sugarcane grows under extremes of climate. It is a long duration crop with 1 or 2 ratoons provides continuous food and shelter to pests. Naturally occurring bio-agents serve to decimate the pests during different stages of their life-cycles. Their activity is dependent on host population, climate, alternate hosts, availability of food, etc. Thus, a careful study of all these factors is essential before devising IPM techniques or methods for sugarcane agro-ecosystem.

A. Subterranean pests

1. Termites, *Odontotermes* spp.

Termites are known to attack the crop just after planting when setts are still in germination stage and infestation continues till the harvest of crop. Young shoots, tillers and canes are equally damaged. Termites enter through cut ends of setts and feed on softer tissues. The setts are filled with soil leaving behind epidermis only.

The activity of termites is enhanced under drought conditions or where undecomposed FYM is added to the soil. During monsoon period, the swarming takes place at dusk. The adults shed their wings, pair off and burrow into soil where they mate and begin to reproduce. The queen lays @40,000 to 80,000 eggs per day. Eggs are kidney shaped and yellowish in colors and hatch out in a week or so. These nymphs develop into workers and soldiers in about 6 months. In the summer months, the eggs many give rise to reproductive forms which attain maturity in 1-2 years. These adults then emerge out and start a new colony.

2. White grubs, *Holotrichia consanguinea* Blanch. and *H. serrata* Fab.

This is a serious pest in Rajasthan and Gujarat. The grubs feed on roots of sugarcane but adult beetle feed on foliage of trees like *Ber*, *neem, sheeshum* etc.Plants wilt and gradually dry up due to feeding of grubs on roots. The canes in affected clumps fall down.

Recently a white grub species (grubs and beetles) has been reported from Bihar causing severe damage to both plant and ratoon crop.

B. Borer pests

3. Root Borer, *Polyocha depressella* Swinhoe

The larvae of the pest infest young plants but mature canes are also attacked. The damage is very peculiar because caterpillars enter at the base of stem, very close to the surface of soil and these is only one entry hole near the base of the shoot. The larvae do not move upward but remain at the base. The 'dead hearts' formed due to attack of root borer can be differentiated with other borer's infestation. The 'dead hearts' do not emit any offensive smell and can not be easily pulled out. The female moth lays eggs during April/May on lower most part of plant (leaf and stem) singly or sometimes together on the underside of leaves. These eggs hatch within 3-4 days and larval period lasts for about 40 days. Pupal period lasts for about 10-12 days. The total life cycle is completed within 2 months.

4. Shoot borer, *Chilo infuscatellus* Snellen

The damage is caused by caterpillars by boring into cane stalk laterally by one or more holes. They move upward and downward as for as roots, there by cutting off the central leaf spindle which dries up forming a 'dead heart'. The central leaf sheath within the stem gets rotten and when pulled out gives a very offensive smell.

Female moth lays creamy white eggs in clusters of 2 or 3 overlapping rows on the undersurface of the leaf. The eggs hatch in less than a week. The young larvae feed on inner surface of lowest leaf sheath from where they move to bore into plants. The larval period lasts for 3-4 weeks and pupal period for about a week. The larvae of shoot borer can be easily identified by the presence of 5 violet stripes on dorsal side and semicircular crochets on the prolegs.

The over wintering caterpillars give rise to I brood during March, II brood in May III brood in June and IV brood during July-August. The infestation of shoot borer is high during premonsoon period from April to June. High temperature and low to moderate humidity is conducive for its development.

5. Top Borer, *Scirpophaga excerptalis* Walker

In subtropical region of our country this is most dangerous pest as it infests crop at all the stages of growth. The newly hatched caterpillars after remaining for sometime on the leaves enters the top shoot of the cane through the midrib of the leaf. The tunneling causes white streak which turns reddish brown. The caterpillar reaches central core of the spindle through unfurled leaves which becomes visible in the form of shot holes on unfurling of leaves. The larva feeds by boring into the narrow central core towards growing point, it also nibbles the inner half of the leaf surrounding the feeding zone. The damaged leaf dries up and forms 'dead hearts' when fourth instar larva cuts the growing point. The dead hearts thus formed cannot be easily pulled out. When central shoot has been damaged, side shoots develop and produce which is known as 'bunchy Top'.

The moths emerge out from over wintering larvae during March which start egg laying in clusters on underside of the leaf and are covered with brown hairs from the anal tuft of the female moth. The larvae hatch out from these eggs within a week which takes about 1 to 1½ months for full development. The pupa forms from these larvae takes about a week to form adult moth.

The pest has five generations in Sub-tropical belt as detailed below:

I Brood	-	March II week to May III week
II Brood	-	May II week to June IIweek
III Brood	-	June I week to Aug. I week
IV Brood	-	Aug. I week to Sept. III week
V Brood	-	Sept. III week to Feb. I week (Over wintering of larvae)

It is the III generation which causes heavy loss to the crop. Hence, efforts be made to manage the pest in time.

6. Stalk Borer, *Chilo auricilius* Dudgeon

The damage is caused by caterpillars. The larvae soon after hatching wander for sometime on leaf surface and move downward to central whorl where they feed by scrapping the leaf sheath. Longitudinal orange yellow streaks are observed from tip to base on the both side of midrib. The third instar larvae bore into shoots and internodes of the canes and feed on soft tissues.

The eggs are laid in masses on the underside of leaves from which larva comes out within one week. The pupal period lasts for about 1 week from which the moth emerges out. There are 3 generations in U. P. but sometimes 5 to 6 generations may occur.

7. Internode borer, *Chilo Sacchariphagus indicus* Kapur

The damage caused by the pest is rot very alarming but efforts be made to manage the pest in time so that it does not flare up in future. The newly hatched larvae feed on leaf sheath by scrapping which are visible in the form of white streaks on leaf opening. Later the larvae bore into tender cane top. The borer feeds on inner tissues and frass is pushed out to exterior. The damaged nodes get hardened thus become difficult for crushing. In grown up canes a constriction (spiral) in infested joints is clearly visible as a sign of infestation.

8. Gurdaspur Borer, *Acigona steniellus* (Hampson)

The pest was for the first time reported from Gurdaspur (Punjab) during 1925. The larvae pass through gregarious and solitary phases. In gregarious phase they crawl along the midrib to the cane on which they move for some time and later on segregate on first internode from top. All the newly hatched larvae from one egg mass enter into one top internode through a common hole. The larva feed gregariously for about a week afterwards they come out and migrate to canes individually in solitary phase .The entrance hole is always made on sheath-less internode and is never below the third internode from the top.

C. Sucking pests

9. Pyrilla, *Pyrilla perpusilla* Walker

The damage is caused both by nymphs and adults by sucking the sap from the under surface of the lower leaves near midrib resulting into yellowish white spots. The bugs secrete a sweet fluid (honey dew) on foliage on which sooty mould (*Capnodium* sp.) develops as a result photosynthesis is hindered. Excessive desapping of cell sap renders cane useless as the recovery of *gur* and sugar gets reduced considerably. Female lays eggs in clusters on the underside of leaves near the midrib. The eggs are covered with white cottony wax filaments from the anal tuft of the female.

10. Black Bug, *Cavelarius sweeti* Slater & Mugomoto and *Dimorphopterus gibbus* Fab.

It is a major pest of ratoon of premonsoon period. The nymphs and adults are found in the leaf whorls and under sheathing bases of leaves. Both nymphs and adults suck the sap from leaves which turn pale yellow with brown patches. The tips and margins of the leaves dry up gradually and sometime entire plant wither. The quality of juice is also affected.

11. Scale Insects, *Melanspis glomerata* Green

The pest is prevalent in tropical belt of our country .The scales are grayish black in color. They infest the cane in large numbers under the leaf sheath in nodal region .A thick encrustation gets deposited on the internodes, the canes shrivel up and growth is stunted.

12. Sugarcane Woolly Aphid, *Ceratovacuna lanigera* Zehntner

The pest appeared during 2002 in Maharashtra, later on the epidemics appeared during 2004 in Maharashtra, Karnataka and Andhra Pradesh. The pest has been reported from Bihar, Uttar Pradesh and Uttaranchal also.

The leaves of the infested plants look white due to white woolly coating of the insects. Both nymphs and adults suck the sap from the leaves which adversely affect the sugar recovery. The aphids also secrete honey dew on which sooty mould fungus develops which hinders the photosynthesis activity of the plant. The white moulted skin of the aphids and their white powdery secretions fall on the ground and lower leaves giving an appearance of white chalk powder coating on the ground and leaves.

Minor Sucking Pests

13. White flies

There are three species of white flies, *Aleurolobus barodensis* Mask. *Neomaskellia bergii* Sign. and *N. andropogonis* Corbett among which *A. barodensis* becomes sometimes quite serious. The leaves of affected plants turn yellowish and later on dry up. During heavy infestation black sooty mould develops on leaves causing hindrance in the photosynthesis. The damage caused by the pest results into retardation in plant growth besides reducing the sugar content in the canes.

14. Thrips

Stenchaetothrips saccharicidus (Ramk) is a pest of premonsoon period. The nymphs rasp the upper surface of leaves and suck the oozing sap as a result leave tips are rolled. Besides above insects some occasional pest viz., leaf hoppers and aphids which cause minor loss to the crop.

Table 1. Factors favouring pests proliferation

Factor	Pest
High temperature and low humidity during pre-monsoon	Shoot borer
Medium temperature and high humidity	Top borer, Stalk borer, Internode borer
High temperature and low humidity during pre-monsoon	Shoot borer
Adequate irrigation during pre-monsoon	Reduces shoot borer
Frequent irrigation during summer	Heavy top borer egg laying
High seed and fertilizer	Borer incidence increases
Narrow row spacing	Increase shoot borer incidence
Luxuriant crop growth	Pyrilla
High temperature and low humidity during pre-monsoon	Shoot borer
Medium temperature and high humidity	Top borer, Stalk borer, Internode borer
Adequate irrigation during pre-monsoon	Reduces shoot borer
Frequent irrigation during summer	Heavy top borer egg laying
High seed and fertilizer	Borer incidence increases
Narrow row spacing	Increase shoot borer incidence
Ratoon crop	Black bug, white fly and scale insect

15. Mealy Bugs, *Sacchari coccus sacchari* Cockerell Pseu*dococcus saccharifolli* Green The pink mealy bug (*S.coccus sacchari*) is most common pest of occurrence. The oval and flattened nymphs stick in wax over the nodal region below the leaf sheath. Both nymphs and adults suck the sap which creates cavities inside the cane and buds loose vitality.

Defoliators

Sometimes grasshoppers (*Hieroglyphus* spp, *Atractomorpha* sp.), Armyworm (*Mythimna separata* W.) do appear on the crop and cause minor to moderate damage.

Economic threshold level: The pest density at which control measures should be applied to prevent an increasing pest population from reaching Economic Injury Level.

But latest concept is **“The density of pest at which the loss through damage just exceeds the cost of control.”**

Table 2. Extent of losses due to insect pests

Pests	Yield	Losses in Quantity	Others
Termite White grub	2.5% 80-100%	4.5% in sugar	30-60% of buds
Shoot borer	22-30%	12.0% sugar recovery, 27% in jaggery	26.65% mother shoots. 6.4, 27.1% 75% of primary secondary & tertiary tillers
Stalk borer	17-33%	1.7-3.7 units in sugar recovery	
Top borer	18.5-44.8%	0.2-4.1 units sugar recovery	100% shoots die and 3-4% of cane growth suppressed
Gurdaspur borer	5-15.0%	29% in sucrose, 17% in total solids	84.4, 59.9 and 19.5% in cane height in I,II & III generations
Plassey borer	8.12 to 48.6%	10.7-48.6% in sugar	
Scale insect	2-9% (Adsali Co 740) 25-30 t/ha	0.3-41.1% in juice content 8.0 % in sucrose (BO 11) 5.9-7.2% in sucrose	Germination - 33.3%
Growth - 5.5-29.3%			
Girth - 2.8-12.1%			
Root borer	10.0%	0.3 units in sucrose	52% of shoots
Mealy bug	20.0%	30.0% in sucrose, 16.2% in brix	Poor germination
Pyrilla	28.1 in epidemic year.	1.6 units in sucrose 2.2 to 4.5% jaggery	
Internode borer	10.7%	1.12% in sugar recovery	
Rodents	16.7%	23 kg/ha in sugar	

Table 3. ETL of different insect pests of sugarcane

Pest	ETL
Shoot borer	15-22% incidence
Top borer	2-3 egg masses/m row length
Internode borer	17-28% bored canes/6 m row length
Stalk borer	12-16 larvae/6 m row length
Pyrilla	3-5 nymphs +adults/leaf

Integrated pest management system

Integrated pest management is a system approach conceived during 1959. IPM in agriculture is one of the requirements for promoting sustainable agriculture and rural development. IPM is the coordinated use of pest and environmental information along with available pest management tools, including cultural, biological, genetic and chemical methods to prevent unacceptable levels of pest damage by the most economical means and with least possible hazard to people, property and the environment.

The following techniques and methods may be employed to manage the pests of sugarcane without adversely affecting the environment.

1. Cultural Control

A method of crop protection using careful timings and a combination of agronomic practices as tillage, planting etc. which makes the environment less favourable for pest multiplication. Deep ploughing, proper crop rotation, healthy seed setts, resistant/tolerant varieties, well rotten FYM, rouging of disease infected plants etc. are worth to be taken under consideration for raising a good crop.

Earthing up during May	Reduces shoot borer
Avoid irrigation at the time of top borer emergence	Reduces top borer
Heavy manuring at tillering	Infructuous attack of top borer
Late planting	Avoid shoot and top borer
Trash mulching	Protect crop from shoot borer
Potash application	Increases resistance of crop

Mechanical Control: Clipping of leaves having egg masses of borers and removal of deed hearts to be adopted for management of borer pests.

2. Biological Control: The manipulation of naturally occuring bio- agents for the suppression of insect- pests of crop is referred as biological control

Egg parasitoids: *Trichogramma chilonis, T. japonicum,Telenomus beneficiens* have been most successfully used. The inundative release of these parasitoids from July to October reduces the infestation of many species of borers.

Larval and pupal parasitoids : *Cotesia flavipes, Stenobracon deese,Rhaconotus scirphagae, Isotima javensis, Camyloneurus mutator,* and *Sturmiopsis inferens* have been quite successfully used.

3. Chemical Control

Insecticides may be used as last resort to control pests, still their use should be need based and judicious.

Pheromone Traps: Sex lure traps are quite useful for monitoring of moth borer pests. Five traps/ha are sufficient for the purpose.

Integrated management schedule for sugarcane pests:

Selection of seed: The seed should not be taken from those fields which have infestation of pests more than 20%.Such of those setts which have borer infestation, should be discarded.

Seed treatment: Moist hot air therapy treated seeds along with dipping in solution of dimethoate 0.08% for 15 minutes for scale insects.

At planting time:

Termites, and root borer: Apply chlorpyriphos @ 1 kg a.i. ha^{-1} or imidacloprid @ 100 g. a.i. ha^{-1} in 1600 litres of waters over cane setts at the time of planting.

Shoot borer

- Drenching of cane plants below leaf whorl with Chlorantranilprol 16.5 SC @ 375 formulation/ ha in 800 liters of water in the month of April.
- Release of egg parasitoid, *Trichogramma chilonis* @ 50,000 adults ha^{-1} at 7 days interval in Southern India. Spray of shoot borer granulosis virus (G.V.) 10^7-10^9 I.B ml^{-1} in Tamil Nadu and Karnataka. Release of *Sturmiopsis inferens* @ 125 gravid females ha^{-1} in coastal Tamil Nadu is recommended.

Premonsoon (March-June)

Top borer: Apply carbofuran @ 1 kg a.i ha^{-1} or phorate @ 3 kg a.i. ha^{-1} in root zone in soil against third brood during III-IV week of June when sufficient moisture is available in the field.

Release of *Isotima javensis* in peninsular India has been found quite effective.

Release of *Isotima javensis* @ 125 gravid females ha^{-1} from July to August. Release of Tricho cards containing *Trichogramma japonicum*@50,000 adults/ha at 10 days interval from July to October

Root borer, Stalk borer, Internode borer and Gurdaspur borer: Release of egg parasitoid, *Trichogramma chilonis* @ 50,000 adults ha^{-1} at 10 days interval starting from July to October.

Stalk borer, Internode borer: Release of larval parasitoid *Cotesia flavipes* @ 500 gravid females ha^{-1} at 7 days interval from July to October.

Pyrilla

i) Remove and destroy the lower most leaves bearing egg masses during April- May

ii) Redistribute of *Epiricania melanoleuca* from heavily parasitized field to negligible parasitized fields.

iii) Release of 4000-5000 cocoons or 4 to 5 lakhs eggs ha^{-1} of *Epiricania melanoleuca* during July-August

iv) Whenever Pyrilla population is more than 5 nymphs+adults $leaf^{-1}$ and *Epricania is* almost absent, wait for about a week for appearance of *Epiricania* which will reduce Pyrilla. Spraying of insecticides is not recommended without advice of pest specialist.

v) Foliar spray of *Metarhizium anisopliae* @ 10^7 spores ml^{-1} or release of 250 adults of Pyrilla ha^{-1} loaded with *Metarhizium anisopliae* spore dust has been found quite effective.

Sugarcane Woolly Aphid, *Ceratovacuna lenigera* Zehnt.

Release of *Dipha aphidivora* @1000 larvae ha^{-1} or *Micromus igorotus* at fortnightly intervals may be done to contain the pest.

Black bugs

i) Spray directed towards whorls with dimethoate 0.03%

ii) Release of 5000 adults ha^{-1} seeded with spores of *Beauvaria bassiana* to check carry over population

Thrips: Spray with monocrotophos 0.04% or dimethoate 0.03%

Mites : Spray with Kelthane 0.1% or chlorfenvinphos or monocrotophos both at 0.04% conc.

White Grub

i) Collect beetles during night through light trap

ii) Apply phorate or quinalphos granules @ 2.0 kg ha^{-1} in soil

iii) Spray host trees like *ber, khejri, babbl,sheeshum* etc. for the control of beetles.

Post monsoon (September to harvest)

i) Detrash the dry leaves at monthly interval and remove late water shoots.

ii) Harvest the crop quite deeply and burn the trash

List of banned pesticides for use in sugarcane

Insecticides: Endosulfan, Thiometon, Malathion.

Acaricide : Dicofol,

Tools used in chemical control

Pesticide application equipment should be capable of uniform deposition of the pesticide on the target in least time using minimum labour without any wastage of the material.

Different types of appliances enable the applications of chemicals in different formulations. The appliances are broadly classified as sprayers, dusters, fog, smoke and vapour generators etc.

Sprayers are classified on the basis of energy employed to atomize and project the spray fluid.

1. Hydraulic-energy sprayers

   A closed container is partially filled with spray fluid. Hydraulic energy is used to produce droplets. Spray fluid is pressurized by the help of positive displacement pump, or an air pump.

2. Gaseous-energy sprayers

   High velocity air stream atomize the spray fluid. Ex. Motorized knapsack sprayer.

3. Centrifugal energy sprayers

   The liquid is fed under low pressure to the centre of a high speed rotating device and is atomized by centrifugal force, as it leaves the periphery of the atomizer.

4. Kinetic energy sprayers

   Spray fluid flows by gravity to a vibrating or oscillating nozzle.

Power operated sprayers

Sprayers with hydraulic pumps

These sprayers may be stretcher type, wheel barron type, trailer type, or tractor or truck mounted type. These are engine operated sprayers and may be fitted with various types of booms. Sprayers used for field crops, orchards, and shade trees are usually of this type.

1. Sprayers with air pumps

Engine power is employed for creating a cushion of compressed air over the spray fluid in the tank. Compressed air form a single cylinder air –cooled compressor, driven by a V-belt from a small engine, is forced into the liquid container. The outlet hose form the spray container may be fitted with a lance or a gun, or a small boom.

2. Gaseous Energy Sprayers

These are low volume and low pressure sprayers. Atomization of the spray fluid is caused by the injection of the spray liquid into air of high velocity; therefore these sprayers are also called as blow applicators, air-blast sprayers, blowers or mist blowers. Motorized knapsack sprayer of this type is now well established in pesticide applications.

A part of the air generated by the blower is diverted into the hopper to form an air-cushion over the liquid in the tank. This ensures a uniform delivery of the liquid. The liquid form the tank passes through a tube to the nozzle on the spray lance by gravity, partly helped by the air pressure. The knapsack sprayers are versatile and simple machines.

3. Ultra-Low Volume Sprayers

Most of the ULV Sprayers employing energy, use a blower for creating a blast of air for atomizing the spray fluid. A restrictor is used in the nozzle assembly which enables a reduced liquid output. The small droplets need to be propelled form the machine at a high velocity. High velocity is necessary to enable the minute droplets to reach the target and to penetrate the air-cushion around it.

Centrifugal Energy Sprayers

A fan or blower, either of the axial flow or centrifugal type is usually employed to supply air for picking up the droplets and conveying them to the target.

In a hand carried mist sprayer, thin metal discs are mounted on a shaft in the fan outlet. The spray fluid is fed to the revolving discs which eject radial films of liquid in to an axial air blast. Portable light weight, electrical operated units are commercially available.

Knapsack mist blowers operate like motorized knapsack sprayers. The atomization of the liquid is mostly done by a rotary atomizer. The atomizer is a freely revolving cylindrical wire-gauze fitted to an aerofoil. It is placed in the sprayer's air stream which rotates the aerofoil and the gauze at a very high speed (1200 to 22,000 rpm) the spray fluid is fed to the revolving gauze under low pressure and is thrown off by it in the form of minute droplets. The size of the droplets is determined by the centrifugal force with which they leave the gauze.

The cost of the ULV applications is usually higher than that of the conventional spraying. The main difference is in the high cost of the LVC formulations. Where storage battery is used to run the motor, the rotational speed of the spinning disc falls when the input p.d. is reduced. This results in the increase in droplets size. Therefore, the batteries are to be replaced before the speed drops considerably.

Sonic Energy Sprayers

The atomizing nozzle uses sound waves to break the spray fluid into fine droplets of mist size. Compressed air is passed at a high velocity through the centre of the nozzle into a resonator cavity (cup). This results in the production of a sonic-energy field between the nozzle exit and the resonator. The spray fluid passing through the outer annuls of the nozzle into the sonic energy field explodes into a mist. The nozzle requires low air and liquid pressures in comparison with the air atomizers, but it needs the higher airflow. Even a viscous fluid can be applied because of the large orifice.

Dusters

Dust formulations used as pesticides are sprayed with the help of dusting machines. Essential components of a duster are hopper with an agitator, an adjustable orifice and delivery tubes. A rotary fan or a bellows supplies air stream.

It is a common observations that dust can be applied more effectively on wet surfaces. Wet dusters on spray dusters are developed to discharge a fine mist of water and a cloud of dust simultaneously, so that the two mingle before reaching the target.

Depending upon the source of power used dusters are classified as (i) manually operated dusters and (ii) power- operated dusters.

Rotary dusters

A blower fan is rotated at high speed by a crank coupled with gear box. An agitator made of brush or other type also gets rotated and the dust is fed into the suction pipe. By steadily turning the crank handle, a uniform cloud of dust can be obtained, unlike the puff produced by a hand plunger or a bellows duster.

Power operated dusters

The basic mechanism of power operated dusters is the same as that of manually operated dusters except that the source of power is mechanical. Motorized knapsack sprayers-cum dusters fitted with a wide swath dusting attachment are available.

The IPM concept is ecologically sound, economically viable and socially acceptable. The Government of India reoriented its plant protection policies during 1980 adopting IPM as its cardinal principal and main plank of plant protection strategy in the overall crop production programme. The IPM being knowledge intensive and skill oriented empowers the farmers in decision making in management tactics. IPM should be well equipped with suitable tools for using insect pest control method to get expected satisfactory results.

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Recent Development in Sugarcane Harvesting Machinery

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Sugarcane is an important industrial crop of India. Harvesting of sugarcane and its transportation to sugar mills is an energy and labour intensive operation. Sugarcane harvesting is an energy intensive operation and involves human drudgery when performed manually. Harvesting of cane involves cutting of cane stalks, detopping and detrshing of cane stalks, making bundles of 10 to 12 stalks and finally loading of clean cane bundles into transport vehicles. In India, harvesting is performed manually using different types of knives. The harvested cane is transported to sugar mills for its processing using different modes of transportation viz., bullock carts, tractor operated trailers and trucks. Basically, two types of harvesting systems are prevalent worldwide i.e. green cane harvesting and burnt cane harvesting. The green cane harvesting is performed without burning the standing crop. The green cane harvesting is preferred due to superior quality of juice. Also, this method allows green top to be used as fodder and incorporation of trash into the soil. In case of burnt cane harvesting the cane field is first burned. The cane is harvested once temperature goes down to the operating comfortable level. In India, generally green cane harvesting is practiced. As the availability of labours is precarious and varies with the season, the availability of cane to the mills become uncertain. This necessitates the adoptability of mechanization of harvesting operation of sugarcane along with suitable transportation system.

Present scenario

Presently harvesting of sugarcane is done manually using different types of knives. The mechanization efforts in the country have been basically limited to the development of whole stalk harvesters for the partial mechanization of sugarcane. These harvesters were basically designed to cut the cane and in some cases to de-top the green top also. The remaining operations such as detrashing, bundle making and loading were to be performed manually. At few places such as in Andhra Pradesh and Maharashtra whole stalk harvesters were imported and evaluated for partial mechanization of sugarcane (Singh *et al.,* 2010). So far these harvesters are still under development and evaluation stage. Of late, combine chopper harvesters have been imported at few places in Tamilnadu and Maharashtra. These harvesters are intended to mechanize the whole operation of sugarcane and found acceptability at few places at limited scale. Combine chopper harvesters are capable of harvesting green as well as burnt crops and also heavy yielding and lodged crops unlike whole stalk harvesters. Whole stalk harvesters are suitable for harvesting of erect and medium tonnage crops.

The available sugarcane harvesting options can be grouped into

A. Manual harvesting

B. Mechanical harvesting

(i) Whole stalk harvesters -linear windrowing, transverse windrowing

(ii) Self propelled whole stalk harvesters

(iii) Self propelled chopper harvesters

A. Manual harvesting

In India, harvesting of sugarcane is done manually using conventional harvesting tools. The productivity of manual cutters can be improved by giving them proper training, the use of correct cane knife, balance diet, etc. On an average an output of 0.8 to 1.0 tonne per man-day is obtained. Human drudgery involved in cane cutting, detrashing, detopping and carrying head loads to the transport wagon together with shortage of labour during harvest season, is compelling the cane growers to look for alternate viable options for mechanizing of harvesting operation (Singh *et al.,* 2016).

Fig. 1. Different types of sugarcane harvesting knives

B. Mechanical harvesting

Attempts have been made at different places to develop and adopt mechanical harvesters for sugarcane. Mechanical harvesters can be grouped into (i) whole cane and (ii) combine chopper harvester.

(i) Whole cane harvester

A tractor operated side mounted whole harvester was developed for cutting of single row of cane. Power to the cutting blade was provided from P.T. O. of the tractor through chain sprocket and P. T. O. pulley. Stationery guider was provided to guide the cut cane stalks for the windrowing. The equipments needed for space for the tractor and could be operated only in one direction. The harvested cane needed to be lifted prior to cutting of next row of the cane. Due to this the equipment could not be taken for further trial.

A tractor front mounted sugarcane windrower harvester at Indian Institute of Sugarcane Research, Lucknow (Sharma and Singh, 1992). It was reported that with the help of this harvester two rows of sugarcane was cut simultaneously and windrowed at the centre of the rows. Removal of green tops and dry trash, bundle making and loading into transport vehicles, were performed manually. The major components of the harvester were main frame, drive system, base cutters and rotating crop dividers and front reels. The drive from tractor pto was through double chain and sprockets. Base cutters consisted of a disc carrying three cutting blades. Crop dividers having spirals, rotating in opposite directions were provided to facilitate harvesting of lodged crop and proper windrowing.

Performance of imported sugarcane harvesters, *viz* Bonnel, Carib, Cameco and indigenous model VSI-Merado were also reported (Devnani and Prasad, 1994). Bonnel sugarcane harvester consisted of a front mounted and three point link mounted, side harvesting cum windrowing unit on a standard tractor chassis. The detopped cane were cut at the base by twin disc blades and windrowed with the help of a conveyor along the direction of travel. Carib whole stalk harvester is a single row harvester on a standard tractor base, having two spiral scrolls to separate standing canes which are either lodged or bent and for gathering canes towards the centre of the cutting row for base cutting. The base cutter is a twin blade cutter having adjustable depth wheels to take care of field undulation to maintain a constant height of cut. The cut cane stalks are windrowed beneath harvester along the travel direction thereby overlaying harvester canes over each other. Cameco whole cane harvester is a single row machine having a single spiral scroll at the left to separate entangled and lodged cane stalks from the adjoining rows of standing crops. It has upper and lower conveyors to gather and convey standing cane stalks for base cutting along row. Height of these conveyors can be adjusted independently. Base cutter height can be adjusted by hydraulic power and is always inclined to the ground. Windrowing unit has a conveyor which can discharge detopped and base cut canes at any angle, to a maximum, perpendicular to the direction of travel. The topper detops and shreds immature green tops and leaves. All the functional components and sub systems are hydraulically powered. The VSI- Merado prototype is similar to Carib model having a detopper at the front to detop immature green tops. It has twin base cutter powered by tractor power take off. A front detrashing roller is mounted to remove dried and loose leaves adhered to the cane stalks. The base cut canes are windrowed underneath the harvesting machine along forward travel. It has twin spiral scrolls to separate entangled stalks and for gathering lodged or bent cane stalks towards base cutter.

A tractor front mounted sugarcane harvester was developed for cutting and windrowing of two rows of cane. Windrowing of one row is in transverse direction while the other row is windrowed linearly to the direction of travel of the tractor (Singh *et al.,* 2009). Attachments, consisting of a M.S. frame and hydraulically controlled arms through hydraulic cylinders, were developed for raising and lowering of harvester during transportation as well as field operation. Power to the cutting blades was provided through tractor PTO. Attachments were also provided with the main frame for windrowing of harvested cane by guiding the cane towards cutting blades during harvesting operation and up to some extent for raising the partially lodged canes. The harvester was tested at IISR farm at different speeds of cutting blades (300-350, 450-500 and 600-650 rpm). The cutting was clean without any splitting and rupture of cane stubbles at cutting blade speed of 450-500 rpm. The cutting and windrowing was satisfactory for crops which were not lodged and where the canopy was not intermingled with the other rows. Equipment needed free space towards right hand side to facilitate transverse windrowing of cut cane stalks. Due to this it could be operated in one direction only. During return equipment is not engaged in cutting. Due to these limitations, the equipment was not taken for commercial exploitation.

For removal of green top as well as dry trash from the harvested sugarcane a power operated detrasher was developed (Srivastava and Singh, 1990; Shukla *et al.,* 1991; Singh and Sharma, 2009; Singh and Solomon, 2015). Equipment consisted of mechanisms for cane feeding, detrashing and delivery. It separates the top from the cane by breaking it from the natural weak point at the joint of immature top with mature cane stalks. It can be transported on three point linkage of the tractor and operated by a electric motor, diesel engine or tractor PTO. Performance of the equipment was evaluated by feeding different varieties of harvested canes, with their tops first, to the detrashing rollers through the feeding chute. The trash left on the cane after passing through the detrasher varied from 1.5 to 6.6%. Trash removal efficiency varied from 77.5 to 94.5% depending upon the variety. The output of the detrasher was 2.4 t/h for feeding of 2-3 cane stalks at a time. There was a saving of about 17% in cost of operation and 84% in labour requirement using the detrasher as compared to manual method.

Fig. 2. IISR tractor operated front mounted sugarcane harvester

Fig. 3. IISR sugarcane detrasher in operation

(ii) Self propelled whole stalk harvester

Self propelled whole stalk harvesters were imported in Tamilnadu from China. It was a Hansen make whole stalk harvester. It performs cutting and detrashing. The cut and detrashed cane stalks were delivered to the rear side of the harvester which is needed to be collected manually or could be collected in a bin attached with the rear of the harvester in the later models. The field testing of these harvesters are conducted in Sathy sugar mill area in Tamilnadu. The manufacturers are trying to modify the harvester in collaboration with local manufacturer from Coimbatore (M/s LCT) to make it more suitable to the local conditions of Tamilnadu.

Fig. 4. Self propelled whole stalk cane harvester imported from China in field operation at Sathy (Tamilnadu)

Fig. 5. Self propelled whole stalk Japanese (Bunmai make) sugarcane harvester

(iii) Self propelled chopper harvester

Austoft 7000 sugarcane harvesters were imported from Australia at Sakthi Sugars Limited, Sakthinagar (Tamilnadu). These were combine chopper harvesters. With the help of this harvester cane is cut, cleaned and loaded into an articulated infield transporter. The harvested cane was transported to the mill using trucks. It has been reported that the harvester is commercially used. The average quantity of sugarcane harvested in a day was reported as 200 tonnes per day. The maximum quantity harvested in a day was 405 tonnes (Nagendran, 1999 and Vachaparampil, 1999).

Fig. 6. Self propelled imported sugarcane copper harvester

Under NATP different types of combine chopper and whole cane harvesters were evaluated. The net cane output of combine chopper harvester (Austoft 7000) was found to be 24 to 30 tonnes per hour (Anon, 2002). The minimum working row space for this harvester was 150 cm. The cost of harvesting varied from Rs 157 to 200 per tonne in case of mechanical harvesters, which could be lowered by increasing the total tonnes of cane harvested per day by operating the harvester for longer hours per day.

Presently few firms in India (New Holland, John Deere, Shaktiman) are manufacturing the self propelled chopper harvesters. These harvesters are suitable under row spacing of 150 cm. They have also manufacturing the harvesters for 120 cm row spacing. Wider row spacing could be achieved by adopting paired row planting of 30:120 cm row geometry without sacrificing the plant population per unit area.

Future strategy

More focussed research is required for development of a whole cane/ chopper harvester for small holdings.

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Management of Sugarcane Ratoon for Improving Crop Growth and Yield

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Sugarcane is a perennial crop and regeneration from similar stubble after harvesting of plant crop provides successive ratoons. Once the sugarcane setts are planted, normally two or three ratoons can be profitabley taken. It is general perception that ratoon gives lower yield as compared to plant crop (main crop). However, after following proper management practices, higher yields of ratoon up to the plant crop could be possible. If we see its historical background, ratooning in sugarcane is an age old practices adopted in the world. In South East Asian countries and Mauritius where as many ratoon crops are taken, 85% of the cane milled each year is produced by ratoon cane. In India, According to the Indian Sugar Committee Report (1920) ratooning of cane was not a common practice wherever indigenous poor ratoonable cane varieties were grown during that time. But, the introduction of “Co” canes revolutionized the situation and lead to the rapid increase of the area under ratoon crop and at least 1-2 ratoon crops are preferred. The pace of increase emphasizes the economic viability of ratoons on account of its reduced cost of cultivation owing to savings in seed material, land preparation and planting operations. In addition, the early harvesting of rations with relatively higher sugar recovery extends opportunity to run sugar mills early in crushing season. In non-sugar mills areas, ratoon paves the way of producing *jaggery* early in the market and fetches higher price to the farmers.

Ratoon crop occupies a sizeable share (around 60%) in sugarcane acreage annually. The poor productivity of ratoon cane includes gappy stands as a result of failured bud sprouting under low temperature conditions, accumulation of toxic exudates due to intensive monoculture and less efficient shallow root system. The ratoons are more prone to insect-pests built up and diseases as well, contributing negatively in improving yields. Therefore, for improving sugarcane production on sustainable manner while adopting ratoon crop, it becomes very important to follow appropriate crop management techniques to improve the yield viz., sugarcane seed selection, adopting ratoon management device (RMD)/ratoon promoter/ ratoon manager developed, bio-manuring for sustaining the soil fertility and quality and sustaining soil health and nutrients availability through trash mulching. Ratoon Management Device performs all the initial operations in one pass and effectively saves expenditures incurred on laborers. Sgarcane harvesting at ground level is recommended for better ratoon initiation. If the plant crop stubbles of more than 1-2 inchers are left, stubble shaving is recommended for good ratoon crop. Cost of mechanical stubble shaving is about 50 per cent lesser than manual practices followed for sugarcane rationing. Ratoon crop has some limitations but its better understanding and proper management may give improved cane yield and productivity while improved sugar recovery percentage.

A. Ratoon crop production constraints

For the better management of ratoon crop while utilizing minimum resources, good knowledge of crop, soil, insect-pests and diseases and also environmental conditions is mandatory. The ratoon crop has some limitations, to tackle effectively may reduce cost of production too. The major constraints in ratoon crop cultivation is described below –

Crop-based constraint: The maturity in the ratoon crop sets in prior to that of plant crop. Under identical growing conditions, it has been observed that in subtropical climatic conditions, the normal growth and vigour in both plant and ratoons remains conspicuous till elongation phase (mansoon). Thereafter, the plant crop takes a lead and develops more vigorously than ratoon. Besides this, sugarcane produced shorter roots die out quickly with little scope for substantial lateral growth, thus occupying smaller soil volume with limited foraging capacity and more prone to lodging. Arrowing is also characterized by cessation of crop growth and in case of ratoons, it sets in early than plant crop. Ratoons are also reported to have more pith than plant crop and thus cause less cane weight.

Soil-based constraint: The compactness of the soil mainly during ratooning system build-up weed flora and insect - pests and diseases which contribute to the loss of productive capacity of sugarcane-growing soils. Besides this, shallow root system of the ratoons crop reduces nutrient quenching ability and eventually makes the ratoon crop more sensitive to drought stress and more demanding for available nutrients /addition of fertilizers. Because of the faulty (flooding) and frequent irrigations, weeds along with their associated problem create menace to proper plant growth and reduce number of millable canes.

Biotic constraints: Ratoon cane is subjected to biotic stresses like red rot, wilt, smut, grassy shoot, ratoon stunting and leaf scald diseases. The insect-pests like root borer, top borer, stalk borer, pyrillaand scale insect are the major pests causing damages to the crop in northern India.

Environmental constraints: These are mainly temperature and soil moisture induced constraints. In subtropics, the harvesting of sugarcane starts during peak of the winter season in low to very low temperature. Stubble bud gets exposure to such odd ambience and usually creates yields gaps and also late harvesting too dries out bottom buds of stubble and reduces plant population in sub-tropical India.

Socio-economic constraints: Adequate, balanced and timely use of agricultural inputs is essential to obtain desired ratoon crop yield. Since sugarcane is grown under highly diverse agro-climatic conditions,ignorance about the actual requirement of the ratoon cane for its nutrition, plant protection measuresand other critical inputs for specific conditions result in low ratoon cane productivity (Shukla *et al.,* 2017).

B. Technological Interventions in Ratoon Crop Cultivation

In order to raise the productivity of ratoon cane, it is essential to apply the developed agro-techniques suitable for ratoon cane under different agro-climatic conditions.Detailed information is described below.

Adoption of organic nutrition modules: For enriching rhizospheric microbial pool and maintaining soil health is viable package of practices of sugarcane production. These are as follows.

1. Irrigate the field 12-15 days after planting in spring and 18-20 days in autumn.
2. Blind hoeing at optimum field moisture to ensure adequate germination.
3. The irrigation and hoeing operations may be repeated at 15-20 days interval.
4. Earthing-up by mid of July for autumn and by mid of August in spring planted crop
5. Thereafter fixing and propping may be done to avoid lodging.
6. Autumn planted crop is harvested in February and spring planting in March.
7. Trash is aligned in the wind rows to facilitated operation for ratoon initiation.
8. Field is irrigated and inter-culture operation done at optimum field moisture.
9. Bio-manures *viz*., well composted SPM 10 t/ha + FYM 10 t/ha or SPM 10 t/ha + *Gluconacetobacter* proves ideal organic farming module

Adoption of zone/location specific suitable sugarcane varieties: Sugarcane varieties considered possessing high regeneration capacity. An early sugarcane variety Colk 94184 (Birendra) developed by Indian institute of sugarcane Research, Lucknow has good ratooning potential and performs well and moderately waterlogging/drought conditions. The variety covering sizable sugarcane area in North Central and North East Zone of the country (Shukla *et al.,* 2018).

Planting techniques and method of harvesting: Although for subtropical region, there is general recommendation of sugarcane planting at 90 cm, but there is a positive interaction between row spacing and soil fertility. Under low level of soil fertility, closer row spacing is better while in case of well fertile soils, wider row spacing is more remunerative (Singh *et al.,* 1984). Tiller mortality is reported to be more in cases of 60 cm and 75 cm than 90 cm. Ring pit method of planting fetched the highest ratoon yields under multiple ratooning system at ICAR-IISR, Lucknow. Sugarcane ratoon yield also depends on planting method followed. In Mujaffarnagar and Gorakhpur locations of subtropical region in India, trench planting gave higher yield of subsequent ratoon than that obtained from the flat method of planting (Chauhan, 1993).

Favourable climatic conditions during ratoon initiation: Proper development of ratoon crop is essentially dependent on sprouting of underground buds. Bud sprouting and germination is the function of optimum temperature, moisture and general vigour of the bud itself. Research evidences suggest that the ratoon obtained after winter harvesting fetched 33.5% loss in yield as compared to spring harvested cane under Pantnagar conditions of Northern India (Verma, 2005 and Verma *et al.,* 1988).

Proper stubble shaving: If the crop has been harvested close to the ground after flattening of ridges, then there is no need for stubble saving. But under farmers' practice where cane is harvested at 5-10 cm above ground level, stubble saving is essential because bud sprouted at apical portion dries up in due course of time due to lack of support, nutrients and water from the soil. This give rise to gappy stands in the field. Generally a sharp edged stainless steel chopper is used for harvesting or stubble saving. Precautions are taken that that the stubble remains intact while practicing stubble saving operation mainly in shallow planting otherwise plant population may reduce (Singh et al., 2005).

Off-barring: In order to modulate rhizospheric environment, practice of off barring which connotes cutting older roots and creating space for own root system to support the clump for its nutrition needs and provide proper anchorage during elongation is an essential part of ratoon culture. This involves cutting older roots from both sides of the cane row followed by fertilizer application near root zone when the soil attains proper tilth after irrigation (Shukla *et al.,* 2017). Due precautions are taken against approaching the cultivator beneath the stubble which may eventually disturbing it.

Plant population management: A close look at the field for observing gaps and there by taking appropriate steps to nullify their negative impact on overall performance of the crop is inevitable to maintain desired plant population. If the gaps are more than 15 per cent of the total clump population (27000-29000/ha) the productivity of the ratoon is adversely affected (Chauhan, 1992). Gaps could be reduced by putting sprouted stubbles of the same variety or through polybag raised sugarcane settlings. Material for gap filling (sprouted setts) should be 30-35 days old generally preferred.

Use of Ratoon Management Device - An Integrated Approach: For raising a good ratoon crop above mentioned cultural operations*viz.* stubble saving, off-baring, fertilizer application and deep tilling in inter-row spaces are inevitable.To perform all these operations in time is an arduous task and labour intensive. The situation is more alarming for availability of manual workforce owing to Government aided different employment guarantee programs in the countryside. In order to provide a viable option to lend a technical support to the peasantry, the Indian Instituteof Sugarcane research, lucknow has developed a machine called Ratoon Management Device (RMD), which can be operated by 35 HP tractor. The machine performs all the operation viz. stubble shaving, deep tilling, off-barring, placing of fertilizer/bio-agents and earthing-up simultaneously in a single pass (Shukla *et al.,* 2017).

Nutrients Management: Various technologies have developed to provide nutrient requirements during sugarcane cultivation. These are as follows.

- High C: N ratio at initial stage and less efficient root system of ratooncane responds well with 25% more nitrogen than plant crop. Split application improves N use efficiency. Balanced nutrition is essential for both cane productivity and juice quality.Secondary and micronutrient are becoming critical in monoculture systems and must be supplemented wherever noticed.

- An integrated approach of nutrient management using organic manures, crop residues, green manures and bio-fertilizers with inorganic fertilizers is more effective in maintaining soil fertility and sustaining crop productivity.
- Intercropped green manure crop in plant cane and its residues in first ratoon increase the N use efficiency in terms of cane yield by 5.2% in the former and 13.4% in the latter case.
- Application of *Gluconacetobacter diazotrophicus* based bio-fertilizer saves 25-50 kg of chemical N/ha. *Berseem* (green manure) is reported to have increased the availability and uptake of water-soluble phosphorus (P) in the soil.
- The severity of chlorotic symptoms appear to be associated with: low protein, P, NO_3 contents, higher percentage of Na and reducing sugars, low K/Na ratio and high N/P, lower Zn, Cu, Fe contents and lower Fe/Mn ratio.
- Manganese deficiency in sugarcane can be corrected by spray of 125 ppm Mn which also improves cane quality. Amelioration of lime-induced chlorosis could be achieved through application of $FeSO_4$ and $MnSO_4$.

Water management: Ratoon cane transpire less water than plant crop but the amount of water required to produce per unit of dry matter is more in case of ratoon. The shallow root system and relatively more compact soil medium prefers light but frequent irrigation scheduling in ratoon crop. In subtropics the crop responds well when irrigated at 12-15 days interval depending upon the nature and type of the soil and crop stage. In tropical region the water requirement is about three times more than that of its subtropical counterpart. Water is a precious commodity and scarce natural resource that needs to be used in judicious manner (Prasad *et al.,* 1987).

Weed management: In ratoons the "rapid-close-in" is much earlier than plant crop as the tillers emerge quickly just after harvesting as the apical dominance is removed. So, desirable weed free environment in ratoon fields is the first 10-12 weeks after its initiation. Various methods, generally employed for controlling weeds in ratoon sugarcane include cultural, chemical, mulching and integrated approach. Among cultural methods use of trash mulch has been found quite effective. Mulching in inter rows with cane trash holds promise as it is easily available in the field for ratoon crop (Shukla *et al.,* 2019). I t has been observed that a uniform 10 cm thick layer of trash gives desired level of weed control. Integration of chemical methods with trash mulching adequately contols the weeds. Triazines particularly atrazines and metribuzin (2 kg a.i./ha) applied at ratoon initiation stage as pre-emergence treatment (inrelaion to weeds) have been found quite effective in controlling weeds in ratoon fields (Annual Report, IISR, 2003-04). However, *Cyperous rotundus* is least affected with these treatments. A post-emergence application of 2, 4-D (0.5kg a.i./ha) could yield desired results.

Crop Residue management: The crop residues (trash) left in the field after sugarcane harvesting accounts for about 10-15% of the weight of the cane harvested and left over root biomass in the soil constitute 5% of the cane harvest. Upon decomposition, this trash may supplement 30 kg N, 9 kg P and 24 kg K/ha. Conventionally the trash is burnt in situ to prevent the harboring of insects and pathogens as well as weeds and to clear the field at one go. The experiments have shown that for sustainable productivity under multiple ratooning systems, trash mulching is more useful than to burn it out. For accelerating decomposition of trash, application of *Trichoderma* is suggested. Trash mulching is done on alternate rows of ratoon cane to facilitate the irrigation and other cultural operations without interruption (Shukla *et al.,* 2019).

Retention of water shoot: These are called water shoots or late shoots or lalas which are often thick, succelent and appear later when early tillers are fully developed. The retention of such shoots during late harvesting of plant crop give good ratoon crop. Heavy earthing up, fertilizers application and frequent irrigation are essential for satisfactory ratoon yields.

C. Crop Protection Measures

For efficient and effective insect-pests and diseases management of ratoon crop principally involves the selection disease resistant sugarcane varieties (wherever available and appropriate), selection of healthy seed cane and the employment of sound agronomic practices and other management approaches. Here management of some major insect – pests and diseases is described (Table 1 & 2).

Table 1. Integrated pest management schedule against major insect pests of sugarcane/ratoon crop

Insect - pest	Management practice
Pyrilla, black bugs, armyworm	• Stubble saving, removal of water shoots, burning of all remainants of previous crop residues.
Termites	• Application of chlorpyriphos @5.0 liters/ha through irrigation water.
Borers (root, shoot and top borer)	• Collection and destruction of egg masses and infested shoots
Scale and mealy bugs	• Drench spraying with 0.1% Dimethoate @ 0.06% after removal of lower dried leaves at 4-5 internode stage.
Black gugs	• Drench spraying with chlorpyriphos/quinalphos @ 0.2 kg a.i./ha.
Pyrilla	• Conserve *Epiricania malanoleuca* cocoons in the area @ 4000 to 5000/ha and 4-5 lakh eggs/ha.
White fly*	• Fields prone to water logged by sprayed with Dimethoate with 0.06 % solution in fields of susceptible varieties in case of heavy buildup of the pest.
White grubs	• Collection of adult beetles through light and sex pheromones and their destruction. • Soil application of chlorpyriphos 5 G granules @ 25kg/ha.
Gurdaspur borer and Plassey borer	• Destruction of infested shoots in gregarious stage of the rests.
Stalk borer*	• Detrashing of dried foliage. • Removal of late shoots at 15 days interval till harvest of the crop.
For pests in general	• Pest control strategies recommended against the different insect pests in plant crop may also be adopted as the need based in ratoon crop.

Table 2. Integrated disease management against major diseases of sugarcane/ratoon crop

Diseases	Management practices
Red rot	• Grow disease resistant • Healthy looking seed cane • Uproot the infected plants and burn them • Avoid replanting sugarcane crop at leat 3 years in the same field • Treat seed with Aretan for 2-3 minutes during sowing.
Wilt	• Grow disease resistant varieties • Select healthy looking seed cane
Smut	• Growing resistant sugarcane varieties • Disease-free seed cane • Disease-free planting material can usually be obtained by subjecting seed to a Hot Water Treatment • Roguing of diseased clump and burn them
Ratoon stunting disease	• Cultivation of disease tolerant sugarcane varieties
Grassy shoot of sugarcane	• Disease-free seed cane can be obtained by tissue culture (Meristem Tip Tissue Culture), or after Hot-Water Treatment of sugarcane or Moist Hot Air Treatment (3 hours at 50ºC)
Yellow Leaf Disease of Sugarcane	

Sugarcane is preferably cultivated in tropical countries of the world. Ratooning is a regular practice in sugarcane cultivation and is considered more profitable as compared to plant crop as it reduces investment in land preparation, planting operation and seed cane. In India, about 60 per cent of sugarcane area is under ratoon crop annually. However, despite the advantages like early and synchronous tillering and fast initial growth allowing longer duration for cane elongation compared to plant crop, the average yield of ratoon crop in India is around 60-65 t/ha, much below the plant crop productivity of >80 t/ha. The adoption of good agronomical and mechanical practices along with crop protection measures may increase ratoon crop yield. The methods/approaches recommended for raising good ratoon crop includes timely ratoon initiation, cane harvesting flush to the ground followed by off-barring to get rid of suberized roots, supply of nutrients close to the root zone and effective management of weeds, use of machines like ratoon management device (RMD), ratoon promoter and ratoon manager developed by research, bio-manuring for sustaining the soil fertility and overall soil health along with mulching of trash from previous plant crop adds to ratoon yield and productivity positively.

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Mechanization of Sugarcane Ratoon Management Operations

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About 55-60 per cent of the total sugarcane area is occupied by ratoon crop in India. It is an integral part of sugarcane cultivation being a profitable proposition. Raising ratoon crop of sugarcane has economic benefits not only for cutting down the cost of land preparation, seed material and cost of planting, but also ensure an economically high recovery in the initial phase of the crushing season because of early maturity than the plant cane. In the countries having sugar export oriented economy, taking 3-5 ratoon is quite common, but in India only 1-2 ratoon is common. Keeping a good ratoon crop is always a problem and it is often less cared for. On an average yield of conventionally grown sugarcane ratoon crop is lower than the sugarcane plant crop. Investigations reveal the fact that the productivity of sugarcane ratoon crop could be improved by applying crop inputs orderly in time and by executing cultural operations like i) shaving stubbles close to the ground surface, ii) off-barring or cutting old roots on either side of the stubbles, iii) interculturing, iv) deep tilling or breaking soil hard pan, v) applying fertilizer, manure, insecticide or pesticides and finally vi) by providing desired amount of soil cover over stubbles or to the plantlets as the case may be. These operations are not only difficult and arduous but also far too uneconomical to be carried over by using conventional tools like spades, cultivators, ridgers etc.

Efforts were made to develop independent tools like stubble shaver, stubble shaver with off-barring and fertilizer application, chemical applicator, power weeder, cultivators, earthing- up equipment, and rippers with limited success. In the present context of increased global competition in world sugar market, there is need to increase the sugar productivity at reduced cost of operation. These objectives could be achieved by breaking the myth that ratoon is a free gift of nature. Due attention is needed to be paid for raising ratoon by performing requisite cultural operations in time in cost effective manner. Mechanical alternatives for accomplishing the cultural operations may be explored to achieve these objectives. Adoption of appropriate mechanical tool to undertake majority of the cultural operations simultaneously in a single pass, will be a major step towards increasing the productivity of ratoon at reduced unit cost of operation. IISR has made concerted efforts and developed a multipurpose equipment to undertake most of the cultural operations simultaneously in a single pass (Srivastava, 2000; Singh *et al.,* 2011; Singh, 2017).

Concerted efforts have been made at Indian Institute of Sugarcane Research (IISR), Lucknow for development of machineries for accomplishing the requisite cultural operations of sugarcane ratoon.

Multi-purpose stubble shaver

During eighties a tractor operated two row multi-purpose stubble shaver was developed at IISR (Srivastava, 1977; Sharma and Srivastava, 1979; Sharma and Singh, 1984). The equipment performs stubble shaving, off-barring & interculturing, and fertilizer application simultaneously in its single pass (Fig. 1). The equipment consisted of the following sub-units

(i) Main M.S. Angle Iron frame with three point linkage system for mounting with hydraulic system of the tractor.

(ii) Gear drive unit taking drive from the tractor PTO shaft through a telescopic shaft and universal joints.

(iii) Rotating disc with blade holders.

(iv) Shaving blades (2 nos.), bolted to the blade holders.

(v) Auxiliary frame with fertilizer metering / dispensing system and 7 tynes with reversible double point shovels for off-barring / interculture.

Fig. 1. Tractor operated two row multipurpose stubble shaver

After harvesting of the plant crop, the trash remained in the field is handled properly either for using as mulch or through burning, as the case may be. For obtaining the best performance from the machine, management of trash is essential and the moisture in the field should be optimum so that shaving is proper without uprooting of the clump (Singh *et al.,* 2012). Planting in straight rows is desirable to avoid uprooting while using the equipment. After ascertaining the field condition, the equipment is checked for the sharpness of the shaving blades and the wearing of the off-barring/ interculture shovels. In the last, but not of least importance is the skill of the operator. The driver should be properly trained because the operation requires simultaneous operation of PTO shaft while driving the tractor. If used, properly, two rows stubble are shaved, old root system chopped off so as to promote new rooting at a faster rate, interspace between the rows is tilled and fertilizer is also applied beside the clump in the close proximity of the root zone (Singh and Sharma, 1986).

Ratoon management device (RMD)

Of late equipment called Ratoon management device (RMD) was developed at IISR. The equipment performs all the recommended cultural operations viz. stubble shaving, off-barring & deep tilling, fertilizer, manure and chemical application, interculturing & soil-covering in its single pass. It consisted of units for performing all recommended cultural operations independently or in a single pass of the tractor. It is a two row tractor mounted type equipment that requires a minimum of 35 hp to execute operations in field (Anon, 2006). Equipment has been released for its commercial use. The equipment consisted of following sub-units (Fig. 2).

Stubble shaving unit

Parts of stubbles that are left above ground surface while harvesting sugarcane are cut above ground surface through a sharp edged concave spinning disc. It is however not advisable to shave the stubbles in fields with piece meal harvesting schedule of the preceding crop.

Off-barring and deep tilling unit

Old roots of either side of stubbles are sheared without any damage. Compact or impervious or dense soil beneath the surface are break-opened by a pair of long and curved specially designed ripper having sleek shovel at its lower end. Rippers are configured or attached in a staggered manner to encounter any accumulation of crop residue in operation.

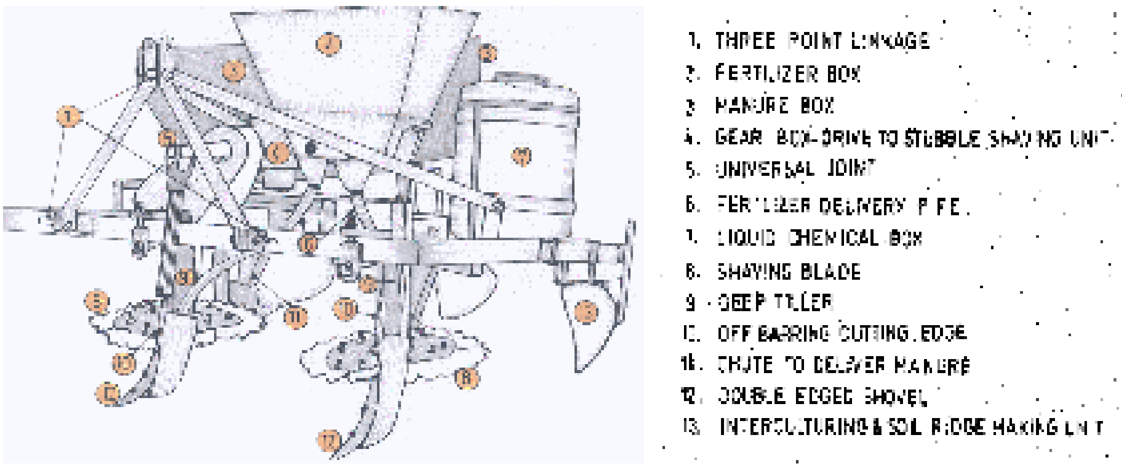

Fig. 2. Ratoon management device

Manure, fertilizer and liquid chemical dispensing

Manure, fertilizer and chemicals in free flowing granular form are metered through a pair of spiral mechanism (for each row) and are dropped through gravity in the slit behind the tines. Chemicals or vegetative extracts in liquid form are applied into soil gravitationally through the tubes and nozzles or holes of requisite size.

Earthing up unit

Earthing unit consisting of share mounted with mould board takes a bite of soil- chunk from in between rows of the stubbles to pulverize and to provide soil cover over the stubbles/shaved stubbles in form of a ridge. It also serves as an interculturing tool.

Ratoon management device was field tested at IISR farm (Fig. 3). Front line demonstration of the equipment was conducted at farmers' field in Barabanki, Sitapur, Lakhimpur Khiri and adjoining districts of Lucknow. The performance of the equipment was satisfactory and output of

Fig. 3. Ratoon management device (RMD) in operation

equipment was 0.40 ha/h. Farmers found the machine very useful for managing the sugarcane ratoon crop and getting increased yield.

Disc type ratoon management device

This machine performs stubble shaving, off- barring and fertilizer application in sugarcane ratoon for widely spaced crop (Fig. 4). It covers single row and apply fertilizer at both side of the row (Singh *et al.,* 2017). Subsequent fertilizer application could be done without disturbing the trash used for trash mulching. The capacity of this machine is 0.30-0.35 ha/h.

Fig. 4. Disc type ratoon management device

Maintenance and operational adjustments

It is important to observe following points before operating the equipment in a field.

- Adjust the distance between the pair of rippers according to inter row spacing.
- Clean the spirals for feeding manure.
- Check the drive system.
- Tighten all nut-bolts with the help of proper tools. Fill the hoppers with input like manure, press mud, bio-fertilizer and fertilizer in a homogenous form having no stones, clumps and/or big chunks for smooth metering.

- Apply grease and lubricating oil to the moving parts.
- Attach the equipment to tractor through three point linkage and pto through its coupling.
- Engage pto to check the metering system.
- Operate the equipment in field with caution. Let the plants and /or stubbles be not damaged in any form. If need be bring the ripper more closely to each other in between the rows.
- Drive tractor initially at second low forward speed to get feel of the operation in the field.
- PTO should be always operated at rated engine speed to provide 540 ± 10% rpm for smooth scissoring of stubbles.
- Clean the equipment after finishing the operation. Chemicals tend to corrode hopper and metering mechanism.
- Provide a thin layer of grease on the moving surfaces and if feasible over the equipment as a whole to safeguard it while storing it for log duration say after the season.
- If possible store the equipment in a shed.

Trouble shooting

Some of the troubles which are faced in fields and need immediate remedial measures are listed below.

- **Rippers not going deep:** Adjust the top link of the three point linkage of the tractor.
- **Stubbles being uprooted:** Rotational speed of the pto needs correction through engine throttle or through drive system. Ensure the angle of tilt of the spinning blades. Serrated blades must be checked for choking or for sharpness of the cutting edge. Inter-row spacing of the tillers needs to be checked and adjusted.
- **Manure/fertilizer being disbursed improperly:** Ensure that the metering unit is not clogged and the material to be metered is not moist or having stones and any other foreign materials. Also ensure that the free flow of the material is maintained unto the soil-slit through funnel.
- **Liquid chemical not being dropped desirably:** Ensure that the liquid –solution is free from debris and there is no choking of the orifice/ tube/nozzle.
- **Soil cover is not in order:** Ensure that all the earthing-up units are at same level and are in order. Adjust the in between distance among these units. Amount of soil to be dug and thrown near the base of tillers can also be adjusted through top link.

Most of the tools and machinery described in the article have demonstrated at limited scale at different places. These have been found effective in saving of time and cost and have potential to make sugarcane cultivation more profitable besides reducing human drudgery. There is a need for concerted efforts by different organisations including sugar industry, State Agricultural Universities, Research Organisations, Cane departments, etc, for popularising these equipments. All these useful time, labour and cost saving devices can be taken to the farmer fields with the joint efforts of all those involved in the pursuit of increasing sugarcane productivity. Suitable liaison with the implement manufacturing industries should be developed and prototypes be fabricated and demonstrated on a large scale in order to create awareness among the farmers. Private entrepreneurs could be encouraged to provide these useful equipments to the farmers on custom-hire basis.

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Trash Management Machines for Sugarcane

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Sugarcane straw, also known as sugarcane trash, comprises mostly of plant tops (the green plant tips) and dry leaves (older senescent leaves). About 10-20 t ha^{-1} trash is left in the field after sugarcane harvest which is usually removed or burnt for performing interculturing and fertilizer application. Trash management, without burning, is a major challenge which farmers are facing particularly in contest of the changing scenario where use of field trash for rural house hold activities (making shelters to animals, feeding chopped plant trash to animals, use of dry trash for jaggery furnace etc.) are declining. In conventional method, after sugarcane harvesting, trash including dried and semi dried leaves are heaped or spread uniformly in the field. Farmers find it convenient to burn the field trash, if they do not require it for fuel and make the field free of trash for beginning cultivation of next crop. Now a days burning of trash has been prohibited due to environmental concern and farmers are being educated about the adverse effects of burning on soil friendly microbes and soil health. Few machines have been introduced for trash management particularly in cereal crops by *in situ* shredding the trash for its faster decomposition. Happy seeders have also been introduced for direct sowing of next crop after harvesting of paddy.

It is estimated that around 500 MT of crop residue is generally generated in the country. Cereals are the largest producer of crop residues followed by sugarcane (141 MT). Trash management in sugarcane has different challenges than cereal crops. Because in case of cereal crops after harvesting of one crop field is free for either using trash management machines or using zero-till seed drill like Happy seeder for sowing of next crop. But in case of sugarcane generally three ratoon crops are taken. Hence, there is need to study the effect of trash management machines on raising ratoon crop in sugarcane. Moreover, cultural operations like stubbles shaving, off-barring, fertilizer application have to be performed for better ratoon initiation after harvesting of sugarcane.

Effort were made at IISR, Lucknow and Disc type ratoon management device (Disc RMD) was developed for performing ratoon initiation operations in the presence of field trash left during harvesting. However, it does not perform trash shredding. Commercially available trash shredder and mulcher are used for trash management particularly for cereal crops.

Very little information is available on use of machine for trash management in sugarcane. Development of a tractor operated plant residue shredder has been reported at IISR but information on its use in sugarcane trash management is not available. Past researches have mainly focused on the beneficial effect of trash mulching and its decomposition into the soil on improved soil health.

Trash burning resulted in loss of organic carbon, plant nutrients (such as N and S), with important implications for soil quality. On an average, sugarcane straw presents N, P, and K nutrient concentrations ranging from 4.4 to 5.4, 0.1 to 0.7, and 2.8 to 10.8 g kg^{-1}, respectively. Crop residues remaining on sugarcane fields provide numerous ecosystem services including nutrient recycling, soil biodiversity, water storage, carbon accumulation, control of soil erosion, and weed infestation. Furthermore, several studies reported higher sugarcane production under straw retention on the field. Pest control is among the parameters favored by straw removal, while N_2O emissions are increased only if straw is associated with the application of N fertilizer and vinasse. Long-term benefits of surface retention of trash resulted in increased soil organic matter, improved physico-chemical properties and ultimately crop yields.

The unburnt trash remains as surface mulch resulted in annual recycling of 105 kg N ha^{-1} $year^{-1}$ and therefore complemented to the fertiliser needs. Most of the agronomic and environmental benefits are achieved when at least 7 Mg $ha^{-1}$of dry straw is maintained on the soil surface. Further, surface retained trash is expected to improve soil water and thermal regimes in ratoon sugarcane during the following summer season. Removal of large amounts of straw reduced sugarcane yield, indicating a higher root: shoot ratio in treatments under straw maintenance above 10 Mg ha^{-1}. The sugarcane root system plays a fundamental role in the regeneration of ratoons after harvesting and thus directly influences the uptake of water and nutrients, in addition to determining drought tolerance. The removal of straw for bioenergy production can result in sugarcane yield reductions of around 5 Mg ha^{-1} yr^{-1}.

Compared with other crops, sugarcane production requires intensive mechanization, which may cause physical soil degradation, increasing soil density and soil resistance to penetration. These factors are associated with lower soil porosity, lower soil aggregation, and consequently, reduced water infiltration rates and lower water availability for plant growth. The soil macrofauna are strongly influenced by the amount of straw present, demonstrating greater density, richness, and diversity when soil was covered by more than 50% straw (i.e., 7.6 Mg ha^{-1}). The C and N microbial biomass of areas covered with sugarcane straw were 102% and 34% higher than those with no straw coverage, respectively. These results indicate that straw mulching creates an improved environment for soil biological communities and serves as food for microbial and soil invertebrate communities.

The size reduction of trash by shredding and treating it with chemical adjuvant for faster decomposition is alternative to burning. Shredding of the trash would make the particle size smaller, increasing the surface area from which microbes could degrade the residue quickly. Soil incorporation of harvest residue would also increase the amount of residue surface that would come in contact with soil microbes and thus should hasten decomposition.

Sugarcane trash shredder

Sugarcane trash shredder (leaf chopper) which is a trailed type tractor PTO operated machine as reported (Fig. 1) consists of two units namely aspirator and shredder unit. Aspirator unit lift the sugarcane leaves from the ground by sucking action and then convey it to shredder attached behind it. The shredder chops the leaves into smaller pieces and spread it on ground behind the machine. The suction unit has four wings. The wings of aspirator are of arc shape. The wings are welded to vertical shaft which gets power from tractor PTO through gearbox. The wings rotate in horizontal plane in counter clockwise direction. The shredding unit consists of cylindrical drum and counter bars. The cylindrical drum is mounted in transverse direction to direction of travel. The drum consists of eight bars mounted on circular disc. Serrated blades are mounted on these bars at fixed spacing. There are three counter bars which are fixed to upper casing of drum. Serrated blades have been fixed on counter bars facing downward. The shredder gets power from gear box through V-belts and pulleys. A blower is provided on machine to give protection to operator from dust. Brief description of sugarcane trash shredder is given in Table 1.

Fig. 1. Sugarcane trash chopper-cum-spreader machine during field operation

The reported performance of this machine were average field capacity as 0.38 to 0.43 ha/h with average forward speed of 2.76 to 3.20 kmph and at straw load from 9.98 to 10.54 t/ha. The straw lifting efficiency was observed from 85.2 to 92.8 per cent. The average leaf size of sugarcane trash before and after the use of machine was observed from 100 to 175 cm and 8 to 12 cm, respectively. The quality of mulch and spreading of trash was uniform and satisfactory. The uniformity coefficient was from 0.90 to 0.95. The average width of shredding was 1.72 to 1.78 m. Field efficiency of machine was observed from 76.5 to 80.8 per cent.

Commercial Machines

These are tractor PTO drawn machine, used for chopping the dry leaves & crop residue on the fields in to small pieces. The commercially available rotary mulcher shreds the crop residues into small pieces and spread on the field, which serves as bio mulch and decomposes gradually. The knives which are jointed on the roller, rotates vertically. The other type of machine, Thrash-shredder (Leaf Shredder) works on vaccum principal & Cutter bar assembly. The vaccum drum; sucks the dry leaves from the field & feeds them in to cutter bar assembly, where the leaves are cut in to small pieces & spread back on the ground.

Fig. 2. Commercially available (a) Rotary mulcher *(Tirth Agro Technology Pvt. Ltd. "Shaktiman")* (b) Trash shredder *(Deccan Farm Equipments)*

IISR Plant Residue Shredder

At IISR, equipment for sugarcane trash management has been developed and is under extensive field trials. The equipment is mounted with the tractor and is operated by PTO shaft. The system picks up trash, passes it on to the chopping unit where trash is chopped into small bits. Provision has also been made for applying chemical/ other substances for quick decomposition of trash.

Fig. 3. IISR plant residue shredder

Disc type ratoon management device (Disc RMD) (Fig. 4) is capable of performing cultural operations needed during sugarcane ratoon initiation in the presence of field trash but it does not perform trash shredding.

Trash mulching improves yield and economic returns in sugarcane ratoon crop. Nevertheless, practice of surface retention of trash in ratoon sugarcane is not becoming popular due to non-availability of appropriate machines for trash shredding and simultaneously carrying out recommended cultural operations like stubble shaving, off barring and fertilizer application during initiation of ratoon after harvesting. There is need for a new machine which could perform ratoon initiation operations as well as trash management in sugarcane.

Fig. 4. IISR disc type ratoon management device (Disc RMD)

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Economics of Improved Sugarcane Machinery Use in India

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Mechanization is a crucial input for agricultural crop production and one that historically has been neglected in the context of developing countries. Factors that reduce the availability of farm power compromise the ability to cultivate sufficient land and have long been recognized as a source of poverty. Increasing the power supply to agriculture means that more tasks can be completed at the right time and greater areas can be farmed to produce greater quantities of crops while conserving natural resources. Applying new technologies that are environmentally friendly enables farmers to produce crops more efficiently by using less power. In South Asia, Bangladesh turned to a most mechanized agricultural economies in early 1970s. On the other hand, Africa with comparatively most abundant land resources, has less than 10 percent of mechanization services provided by engine power. India has also progressed on the mechanization front. Farm machines have revolutionized agriculture and reduced drudgery for millions of farm families and workers in India. However, the machinery of tomorrow will have to do more than that. It will have to contribute to agriculture that is environmentally sustainable. India's commitments to Sustainable Development Goals also calls for research and development of agriculture machinery that is environmentally sustainable.

Mechanization Growth in India

Mechanization has been well received in India as one of the important elements of modernization of agriculture. The spectacular rise in agricultural production in the last six decades is largely a result of application of new technology, increased use of improved seeds, chemicals and fertilizers, irrigation and mechanization, coupled with incentives for production and greater access to credit. This has put Indian agriculture at a higher level in world ranking. India has made remarkable progress in the development of Agricultural Mechanization technology. It is now recognized that availability of mechanical power and improved equipment has enabled States like Punjab, Haryana and Western region of Uttar Pradesh to achieve high levels of land productivity. Tractor growth in the country in terms of production and sale was many folds. A tractor could be found after every 25 ha cultivated area in span of 57 years. In States where agricultural mechanization has made good progress, its benefits are being shared by all farmers irrespective of the size of their operational holdings and whether they own tractors and machinery or not. The machinery developed in the country has well penetrated to grass-root levels and as per available statistics around 61 million farmers were using agriculture tractors and 7.9 million farmers were using power tillers by 2010-11. Around 52 million farmers were having diesel or electric motors to facilitate different types of farm work (Table 1).

Indian agriculture was powered by about 131.1 million agricultural workers, 80.4 million draught animals, over 0.43 million motors and engines and 0.037 million tractors during 1960-61. This figure has changed to about 272 million agricultural workers, 53 million draught animals, over 25 million motors and engines, and 5.2 million tractors (Table 2) by the year 2013-14 reflects the unique Indian approach to mechanization.

Farm mechanization status is often expressed in terms of power availability per unit area. The average farm power availability in India has increased from about 0.30 kW/ha in 1960-61 to about 2.02 kW/ha in 2013-14. Over the years, there has been the shift towards the use of mechanical and electrical sources of power. While in 1960-61 about 92.30% farm power was coming from animate sources, in 2013-14 the contribution of animate sources of power reduced to about 11.80% and that of mechanical and electrical sources of power increased from 7.70% in 1960-61 to about 88.20% in 2013-14. This shows that the additional need of farm power is being met through mechanical and electrical sources. Productivity and unit power availability is associated linearly.

As the power availability increased on Indian farms, cropping intensity increased and side-by-side cropping pattern also changed. Now the more emphasis is being given on fruits and vegetable crops, and commercial crops like sugarcane. The average supply of power to agriculture is targeted to increase to 2.0 kW/ha to achieve the planned production level. Appropriate and selective mechanization of agriculture is to be encouraged by using a proper blend of conventional and renewable energy sources for enhancing agricultural productivity.

Table 1. Extent of machinery use in India

Sl. No.	Machinery and equipments in use	Number of farmers (Million)
1	Agriculture Tractors	61.13
2	Power Tillers	7.95
3	Diesel engines	30.08
4	Electric engines	22.76

Source: GOI, 2015

Table 2. Farm power sources in India (Million)

Year	Agril. Workers	Draft Animal Power	Agril Tractors	Power tillers	Diesel Engines	Electric Motors
1960-61	131.10	80.4	0.037	0	0.23	0.20
1990-91	185.30	70.9	1.192	0.0323	4.80	8.03
2000-01	234.10	60.3	2.531	0.1147	5.90	13.25
2013-14	272.00*	52.0	5.237	0.4409	8.45	17.00
GR 1960-61 to 1990-91	1.16	-0.42	12.27	6.25	10.66	13.12
GR 1990-91 to 2013-14	1.54	-1.33	6.65	12.03	2.50	3.29

*estimated, GR = Compound Annual Growth Rate

Source: Singh *et al.,* 2014

The extent and spread of mechanization could be seen from the availability and use of diversified equipments and machines per farmer. During the past six decades, a large number of farm tools, implements and machines have been developed for different farm operations such as land levelling, seed bed preparation, sowing and planting, weeding and hoeing, plant protection, harvesting, threshing, de-husking, decorticating, etc. The rate of growth, however in animal operated machinery has remained low as compared to tractor or power operated machinery. Table 3 indicates the extent of penetration/adoption of different categories of farm equipments and machinery in India per 100 operational holdings. Hand-operated implements are used by majority of the farmers followed by

Table 3. Extent of implements and machinery use in India (per 100 farmers)

Coverage	Hand operated implements	Animal operated implements	Power operated implements
Less than 1 per cent	-	-	Tractor Drawn Potato Digger, Aero-Blast Sprayer, Power Weeder (Self Propelled), Pneumatic Planter (Tractor Drawn), Self Propelled Rice Transplanter, Straw Combines (Tractor Drawn), Disc Plough (Tractor Drawn), Ground Nut Decorticator, Tractor Mounted Reaper, Raised-Bed Planter (Tractor Drawn), Zero-Till Seed-Cum-Fertilizer Drill (Tractor Drawn), Strip-Till-Drill (Tractor Drawn), Sugarcane Cutter Planter (Tractor Drawn), Self Propelled reaper, Powercane Crusher
1-2 per cent	Paddy drum seeder, Paddy Transplanter	Cane Crushers, Potato and Groundnut digger	Tractor Drawn Planter, Cage Wheel, Power Maize Sheller, Vegetable Transplanter (Tractor Driven), Combine Harvester (Self Propelled), Combine Harvester (Tractor Powered)
More than 2 to 5 per cent		Seed Planter, Bund Former, Animal DrawanPuddler	Power Chaff Cutter, Rotavator, Sprinkler Used For Irrigation Purposes, Drip Irrigation Set
More than 5 to 10 per cent	Pedal operated Thresher, Maize sheller, Wheel Hoe,ConoWeeder	Disc Harrow	Tractor Drawn Leveler, Tractor Drawn Seed Cum Fertilizer Drill, Tractor Drawn Disc Harrow, Tractors Drawn Board Plough, Power Tiller, Power Operated Sprayer/Duster, Cultivator (Tractor -Drawn)
More than 10 to 20 per cent	Hand seed drill, Winnowing Fan, Blade Hoe	Mould Board Plough,Cultivator-Triphalli, Seed cum Fertilizer Drill/Seed Drill	Power Threshers, Electric Pumpset
More than 20 to 50 per cent	Chaff Cutter, Hand Operated Sprayer/Duster	Wooden Plough, Levelling Kahan	Agricultural Tractors (44%), Diesel engine pumpset (22%)
More than 50 per cent	Hand Hoe	-	-

Source: GOI (2015)

animal operated and power operated equipments. While tractor use have been penetrated up to 44% of Indian farmers, the use of most of the tractor operated implements is limited to just 10 per cent farmers. The tractor drawn planters and combine harvesters are being used by 1 to 2 per cent farmers. Tractor drawn levellers, seed cum fertilizer drill, disc harrows, board ploughs and cultivators are being used by 5 to 10 per cent farmers. Tractor-drawn specialised crop equipments like potato diggers, pneumatic planters, disc ploughs, reapers, raised bed planters, zero seed cum fertilizer drill and sugarcane cutter planters are being used by less than one per cent farmers in India. The use of power tillers is limited to use by 5.8 per cent farmers. Electric pumpsets are being used by the farmers in the range of 10-20% while the diesel engines are being used by around 22% farmers.

Sugarcane Cultivation: Mechanization and Economics

Sugarcane crop cultivation in India is most labour intensive and least mechanised (Sharma and Prakash, 2011). The labour requirement for one ha of sugarcane cultivation is quite high compared to other crops like wheat, rice and cotton. At all-India level, the human labour use per ha is around 167 person days compared to 42 person days in wheat crop and 81 person days in rice crop per ha (Table 4). Despite high labour use in sugarcane, the extent of mechanization in sugarcane farming is quite low compared to that existing in rice and wheat crop. The proportion of machine labour use in total operational cost of cultivation of sugarcane is just 6.09 per cent at all-India level in sharp contrast to wheat crop where its extent is 26.46%, and rice crop (18.65%). Further, most of the machinery use is almost hired and the extent of hired machinery use is up to 88% of the total

Table 4. Extent of labour and machine use in different crops in major cane growing states in India, 2016-17

Crop	U.P.	Maharashtra	National Average
Human Labour* (person days)			
Sugarcane	142	159	167
Wheat	50	55	42
Paddy	89	152	81
Cotton	-	119	103
Machine labour as % of A1 Cost			
Sugarcane	3.59	19.17	6.09
Wheat	26.49	24.2	26.46
Paddy	15.69	13.02	18.65
Cotton	-	9.36	11.19
Share of Hired Machine Labour in Total machine labour in sugarcane cultivation	76.82	96.42	87.89
Cost of sugarcane cultivation			
Total Cost (Thousands ₹)	98.5	154.5	142.3
Operational Cost as % of total cost	51.7	67.2	62.0
Human Labour Component as % of operational cost	62.0	40.4	59.9
Machine Labour as % of operational cost	2.7	16.2	5.0

Source: CACP, 2016

machinery use charges per ha. The per ha operational cost of cultivation of sugarcane is quite high compared to cereal crops, and it varies for Rs. 51000 (51.7% of total cost) in UP to Rs 1.04 lacs (67.2 % of total cost) in Maharashtra, out of which 62.0% in UP and 40.4% in Maharashtra is the human labour component. Hence, there is scope for the mechanization of sugarcane crop by encouraging the more use of sugarcane machinery either by owning themselves by the farmers or by hire purchase of costly sugarcane machinery. This will help in reducing the human labour component, and thus the cost of cultivation of sugarcane.

Sugarcane cultivation machines

Sustainable mechanization can: i) increase land productivity by facilitating timeliness and quality of cultivation; ii) support opportunities that relieve the burden of labour shortages and enable households to withstand shocks better; iii) decrease the environmental footprint of agriculture when combined with adequate conservation agriculture practices; and iv) reduce poverty and achieve food security while improving people's livelihoods. In India, IISR, Lucknow has pioneered the responsibility for design and development of agricultural machinery for sustainable sugarcane cultivation. Since its inception in 1952, IISR has evolved tools and equipments to increase labour and energy input-use efficiency. It has developed various types of tractor operated multipurpose equipments for sugarcane agriculture. Institute also developed different variants of sugarcane cutter planters to suit the different planting methods like deep furrow, trench and zero till planting. Institute has also developed machinery for inter culturing and ratoon management. Appropriate machinery for planting of inter-crops with sugarcane under conventional as well as FIRB system has also been developed (IISR, 2004).

Economics of using IISR developed sugarcane cutter planter

Sugarcane cutter planter is operated by small tractor (mostly 35 hp) and its field capacity is 0.2 ha/h (or 1 ha in 5 h) with field efficiency of more than 80%. The planter plant 1.6 ha per day (8 h) on an average. It performs all planting operations as one operation and takes only 5 machine hours, along with some manual labour (4 person hours) for planting of cane in one ha. The planters have the provision for fertilizer and weedicide application too. The use of this planting machine eliminates manual seed distribution and planting operation and results in the saving of 35 mandays per ha in the planting of cane, and therefore, in the reduction of operational cost of cane cultivation per ha by ₹ 10,500 at a wage rate of ₹ 300/day. The cost of operating a tractor along with sugarcane cutter planter is ₹ 400 per hour or ₹ 2000 per ha. In addition, ₹ 1200 may be added due to 4 associated labour days. Hence, ₹ 3200 is the cost of planting with the cutter planter whereas it was ₹ 13700 in conventional method, including that of machine hours (8 h/ha) for forming ridges and furrows. Hence, the net saving by using the sugarcane cutter planter is ₹ 10500 per ha.

Impact of R & D in sugarcane machine development

It has been found that sugarcane cutter planter has very good acceptability and its use is resulting in reducing the labour requirement per ha and in reducing the cost of cultivation. The number of sugarcane cutter planters in operation in India has increased substantially in almost all cane growing states of India. The sugarcane cutter planters have been purchased by all types of cane holdings. There are about 2.63 lacs cane growers who are using sugarcane cutter planters. These sugarcane cutter planters are also very popular with the small cane growing holdings as the growers are using these machines constitute 62.75% of the total users of the machine. A look into the state-wise users of the machine reveals that UP is having the largest number of users (76,734) followed by Tamil Nadu (53,851), A.P. (45,310) and Haryana (19,278). The extent of cost reduction in sugarcane cultivation in India has been worked out to the extent of ₹ 182 Crores (Sharma, 2019). The machine is also good on equity considerations as about ₹ 103 Crores is the saving on the farms of small holders. The benefit-cost analysis highlights that the investment for research and development of sugarcane cutter planter has been quite profitable at ₹ 35 per rupee invested.

Popularising sugarcane machinery among farmers

Investment in machinery is considerable, and the clever and effective use of machinery is a prime driver in achieving substantial productivity gains over many years. The decision to buy machinery invariably involves the assessment of a wide range of factors and potential benefits, many of which are difficult to quantify. These can include the potential for productivity improvements, risk of breakdowns, operator comfort and ease of use, timeliness risk, potential for environmental benefits, and workplace health and safety considerations. Whether valid or not, the colour of the paint and the desire to have the newest and best can also be important in the final decision. Farmers generally do not take account of the real value of the machine to the business or the risks of the investment. Farmers need to be made aware of simple economic analyses to support the decision process involving machinery purchases at both a strategic (whole-of-business) level and tactical (individual-machine level) (ISU, 2015).

At Whole-of-Business level, appropriate level of investment in machinery for business is decided. There are two ratios which are commonly used within mixed-farming businesses to benchmark machinery investment. These ratios relating to the cost of producing the commodity for which the machinery is being used are as follows: (i) machinery investment (₹) per tonne of cane produced, and (ii) machinery investment (₹) / gross farm income.

At Individual Machinery level, machinery costs can be divided into two areas: fixed (or overhead costs); and operating costs. More details are given in Box-1. Overhead costs are the costs that are incurred irrespective of whether the machine is actually used. These include insurance and registration (if applicable), depreciation, the opportunity cost of capital, shedding and operating costs. Depreciation is usually calculated by estimating the value of the machine at the end of its use in the business and allocating this reduction in value on an annual basis over its years in the business. Another approach is to use a percentage annual reduction in value (for example, seven to 12 per cent, depending on the machine). The opportunity cost of capital reflects either the borrowing costs of financing the machine or the alternative return that could have been achieved on cash equity funds used to purchase the machine (this will often equate to bank deposit interest). This is usually calculated on the expected average value of the machine over its ownership. The rate used will depend, to an extent, on the current interest rate cycle, but would normally be expected to be between five and 10 per cent. Normally allow 0.5 to one per cent of machine value for shedding. Operating costs include fuel, labour, repairs and maintenance. Growers are usually quite comfortable in estimating costs in this area. It is important to value labour on a commercial basis even if own labour is being used to operate the machinery. Table 5 sets out a simple example of the total annual ownership costs of a Tractor. In this example, it is interesting to note that fixed or overhead costs amount to more than half of the total annual machinery ownership costs. It is an important rule of thumb, which drops out of much machinery analysis, that often more than 50 per cent of the costs of

Table 5. Annual Machinery Costs Calculation

Particulars	**Indicator/Abbreviation**	**Amount (₹)**
Purchase price Assumed (₹)		300,000
Estimated salvage value (₹)		120,000
Estimated life (years)		8
Opportunity cost of capital (%)		7%
Shedding cost (% of new cost)		0.75%
Annual fixed (or overhead) costs		
Depreciation (purchase price – salvage value)/estimated life	A	22,500
Opportunity capital cost (average price * OCC%)	B	14,700
Shedding	C	2250
Insurance	D	800
Registration	E	200
Total overhead costs	(Sum A-E)	40,450
Annual operating costs		
Fuel and oil	F	15,000
Repairs	G	10,000
Tyres and batteries	H	1500
Labour	I	12,000
Total operating costs	(Sum F-I)	38,500
Total annual machinery costs		
Overhead		40,450
Operating		38,500
Total		78,950
Estimated annual usage (hours)		300
Estimated cost per hour (excluding allowance for profit)		263

Note: The estimates used in this example are for demonstration only and should not be considered indicative of actual costs incurred in owning and operating a Tractor. Individual circumstances will vary and decision-makers should adopt their own estimates.

Box-1. Estimating the costs of owning and operating farm machinery

Machinery and equipment are major cost items in farm businesses. Larger ma-chines, new technology, higher prices for parts and new machinery, and higher energy prices have all caused machinery and power costs to rise in recent years.**Machinery Costs:** Farm machinery costs can be divided into two categories: annual **ownership** costs, which occur regardless of machine use, and **operating** costs, which vary directly with the amount of machine use. The true value of these costs cannot be known until the machine is sold or worn out. But the costs can be **estimated** by making a few assump-tions about machine life, annual use, and fuel and labor prices. **Ownership** costs (also called **fixed** costs) include depreciation, interest (opportunity cost), taxes, insurance, and housing and maintenance facilities.**Depreciation:** Depreciation is a cost resulting from wear, obsoles-cence, and age of a machine. The degree of me-chanical wear may cause the value of a particular machine to be somewhat above or below the aver-age value for similar machines when it is traded or sold. The introduction of new technology or a major design change may make an older machine suddenly obsolete, causing a sharp decline in its remaining value. But age and accumulated hours of use are usually the most important factors in determining the remaining value of a machine. Before an estimate of annual depreciation can be calculated, an **economic life** for the machine and a **salvage value** at the end of the economic life need to be specified. The economic life of a machine is the number of years over which costs are to be es-timated. It is often less than the machine's service life because most farmers trade a machine for a dif-ferent one before it is completely worn out. A good rule of thumb is to use an economic life of 10 to 12 years for most farm machines and a 15-year life for tractors, unless you know you will trade sooner. Salvage value is an estimate of the sale value of the machine at the end of its economic life. It is the amount you could expect to receive as a trade-in allowance, an estimate of the used market value if you expect to sell the machine outright, or zero if you plan to keep the machine until it is worn out.**Interest:** If you borrow money to buy a machine, the lender will determine the interest rate to charge. But if you use your own capital, the rate to charge will depend on the opportunity cost for that capital elsewhere in your farm business. If only part of the money is borrowed, an average of the two rates should be used. For the example we will assume an average interest rate of 7 percent. Inflation reduces the real cost of investing capi-tal in farm machinery, however, since loans can be repaid with cheaper Rupees. The interest rate should be adjusted by subtracting the expected rate of inflation. For our example we will assume a 2 percent inflation rate, so the adjusted or "real" interest rate is 5 percent. The joint costs of depreciation and interest can be calculated by using a **capital recovery factor**. Capital recovery is the number of Rupees that would have to be set aside each year to just repay the value lost due to depreciation, and pay interest costs.**Taxes, insurance, and housing (TIH):** These three costs are usually much smaller than depreciation and interest, but they need to be con-sidered. Property taxes on farm machinery are exempt in India. Hence, a cost estimate equal to 1 percent of the average value of the machine is often used. Insurance should be carried on farm machinery to allow for replacement in case of a disaster such as a fire, flood or accident. If insurance is not carried, the risk is assumed by the rest of the farm business. Current rates for farm machinery insurance may be assumed at about 0.5 percent of the average value. There is a tremendous variation in housing provid-ed for farm machinery. Providing shelter, tools, and maintenance equipment for machinery will result in fewer repairs in the field and less deterioration of mechanical parts and appearance from weather-ing. That should produce greater reliability in the field and a higher trade-in value. An estimated charge of 0.5 percent of the average value is sug-gested for housing costs.**Total Ownership Cost:** The estimated costs of depreciation, interest, taxes, insurance, and housing are added together to find the total ownership cost. **Operating costs** (also called **variable** costs) in-clude repairs and maintenance, fuel, lubrication, and operator labor. **Repairs and Maintenance:** Repair costs occur because of routine mainte-nance, wear and tear, and accidents. Repair costs for a particular type of machine vary widely from one geographic region to another because of soil type, rocks, terrain, climate, and other conditions. Within a local area, repair costs vary from farm to farm because of different management policies and operator skill.**Fuel:** Fuel costs can be estimated in two ways. The average fuel use in litres per ha for many field operations is multiplied by the fuel cost per litre to calculate the average fuel cost per ha. Secondly, Average fuel consumption (in litres per hour) for farm tractors on a year-round basis without reference to any specific implement can also be estimated with these equations: 0.044 x maximum PTO horsepower for diesel engines.**Lubrication:** Surveys indicate that total lubrication costs on most farms average about 15 percent of fuel costs. Therefore, once the fuel cost per hour has been estimated, you can multiply it by 0.15 to estimate total lubrication costs.**Labor:** Because different size machines require different quantities of labor to accomplish such tasks as planting or harvesting, it is important to consider labor costs in machinery analysis. Labor cost is also an important consideration in comparing ownership to custom hiring. Actual hours of labor usually exceed field machine time by 10 to 20 percent, because of travel and the time required to lubricate and service machines. Consequently, labor costs can be estimated by mul-tiplying the labor wage rate times 1.1 or 1.2. **Total Operating Cost:** Repair, fuel, lubrication and labor costs are added to calculate total operating cost. **Total Cost:** After all costs have been estimated, the total ownership cost per hour can be added to the operating cost per hour to calculate total cost per hour to own and operate the machine.

machinery ownership occur before you purchase and start the machine. Another ‘rough’ rule of thumb is that the total annual costs to own and operate a machine will be usually about 25 to 30 per cent of the value of the machine. This rule can allow a prospective purchaser to undertake a first ‘quick and dirty’ analysis of the financial effects of a machinery purchase.

Way forward in sugarcane mechanization R&D

Soil tillage is one of the two main farming activities that have the greatest impact on the environment because it can severely damage soil ecology. Sugarcane cultivation machinery needs to be intelligent, lean, precise and efficient in order to minimize the impact on the soil and the landscape. Considering these aspects, sugarcane mechanization in general calls for that the government policies should encourage the agricultural machinery sector to develop markets for sugarcane mechanization, especially to establish the required infrastructures. Such support, especially to the smallholder sector (rural artisans, youths), can have a dramatic impact in moving farm families out of poverty into a more profitable, commercially oriented agriculture. The agricultural machinery industry should provide more support to smallholder farmers with equipment designs and models that better suit the needs of smallholder farmers and service providers. Increasing levels of mechanization does not necessarily mean big investments in tractors and other machinery. Farmers need to choose the most appropriate power source for any operation depending on the work to be done and on who is performing it. The level of mechanization should meet their needs effectively and efficiently. The power sources (human, animal or motor-based) need to be adapted to necessities from an ergonomic, social, cultural and economic point of view. The reduction of drudgery is a key element of sustainable mechanization and contributes to reducing farmers' hard workload by taking into consideration technologies apt to their needs and improving their access to appropriate forms of farm power.

Farm power input in sugarcane farming has to be increased further to achieve higher sugarcane and sweeteners production. Further, the composition of farm power from different sources is to be properly balanced to meet its timely requirements for various farm operations. Mechanization of other operations in sugarcane farming such as inter-culturing and harvesting has also shown a steady increase over the years as the private sector participation in R&D of mechines increased.

In order to ensure low cost sugarcane cultivation, the use of sugarcane cutter planters needs to be popularised by encouraging rural artisans and youths to establish start-ups in sugarcane machinery repair and development or in initiating custom hiring services to small holders in sugarcane cultivation business (Sharma and Prakash, 2014). Appropriate policy initiatives towards establishing machine hubs in villages will be the need of the hour.

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Promoting Sugarcane Mechanization through Developing Custom Hiring Centers

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Indian agriculture in general is characterized by small and scattered type operational holdings and sugarcane cultivation is no exception. As reflected in 2015-16 census, more than 86.2 percent of the land holdings are less than 2.0 ha farm size and are in the category of small and marginal farmers, 13.2 percent of the farmers are in the range of medium farmers having holding size in the range of 2-10 ha. Small size and scattered holdings make the mechanization scenario more complicated and thus need a special strategy and considerations so as to make the proposition feasible and economically viable. In addition, the machinery required for Sugarcane cultivation are special purpose type and having low utilization index, further strengthens the case of developing suitable model of Custom hiring service centers so as to make the farmers enable to avail the benefits of newly developed Sugarcane machinery.

Benefits of Mechanization

Why we need Mechanization? Availability of Agricultural laborers in sufficient number at proper time and at reasonable wage rates, has now become a major problem and as a result farmer has to delay or altogether skip many critical operations resulting in to reduced productivity and thereby profitability.

Indian agriculture is undergoing a gradual shift from dependence on human power and animal power to mechanical power because of diminishing animal power and scarcity of human labour. Further, use of mechanical power has a direct bearing on increasing the productivity by way of timely accomplishing the agricultural operations, reducing cost and human drudgery.

Thus, there is a strong need for taking up farm mechanization

However, the farm power distribution is quite uneven across the States, wherein the highest use of mechanical power is in the order of 3.5 kW/ha in Punjab and less than1kw/ha in States like Bihar, Orissa, and Jharkhand etc. Mechanical power is largely consumed in big land holdings and is still beyond the reach of small/marginal holdings which constitutes around 80% of the total land holdings. This is due to the fact that the small/marginal farmers, by virtue of their economic condition are unable to own farm machinery on their own or through institutional credit. Therefore, in order to bring farm machinery available within the reach of small/marginal holdings, collective ownership or custom hiring centers need to be promoted in a big way.

Objectives of Custom Hiring Centers

- To make available various farm machinery/equipment to small and marginal farmers
- To offset the adverse economies of scale due to high cost of individual ownership
- To improve mechanization in places with low farm power availability
- To provide hiring services for various agricultural machinery/implements applied for different operations
- To expand mechanized activities during cropping seasons in large areas especially in small and marginal holdings
- To provide hiring services for various high value crop specific machines required for different operations.

Establishment of farm mechanization centers (CHC's) to cater to the mechanization needs of small and marginal farmers.

Sub-mission on Agricultural Mechanization (SMAM) schemes are proposed to be implemented in all the states to promote the usages of farm machinery and increase the ratio of farm power to cultivable area up to 2.5 kW/ha. The center sector schemes, the Govt. will contribute 100% whereas central sponsored schemes, central and state govts. Will contribute in the ratio of 60:40.

Strategy of SMAM

- Conducting performance testing of various farm machineries with the help of SAUs, and ICAR institutes to ensure the availability of quality machinery.
- On field and off field trainings and demonstrations. Cropping system based large scale field demonstrations will be organized and will include newly developed machines and implements and custom hiring centers participation will be ensured.
- Providing financial assistance to farmers for procurement of farm machinery and implements.
- Establishing Custom Hiring Centers (CHCs) of location and crop specific farm machinery and implements Providing financial assistance to small and marginal farmers for hiring the suitable machinery.

Establishment of Farm Machinery Banks for Custom Hiring-Financial Assistance

1. Procurement of farm machinery and implements subsidy for establishment of Custom Hiring Centers up to project-based cost ₹ 10.0 lakh, 40% limited to ₹ 4.00 lakhs, whichever is less.
2. Procurement subsidy for establishment of Custom hiring centers with project-based cost up to ₹ 25 lakhs, 40% limited to ₹ 10 lakhs, whichever is less.

3. Procurement subsidy for establishment of Custom hiring centers with project-based cost up to ₹ 40 lakhs, 40% limited to ₹ 16 lakhs, whichever is less.

Development of an Entrepreneur model for custom hiring centers in Sugar Industry.

Sugar Industry can become a pivotal point to establish custom hiring centers in their catchment areas to cater to the farm machinery and implements need of the small and marginal cane farmers adopting sugarcane-based cropping system. The cane development staff of Sugar mill in collaboration with private partners can easily initiate this activity in their area by way of developing Cane grower entrepreneurs to the benefit of both-the sugar mill and the farmers. SMAM guidelines will form the base for the activity. A successful project involving Pragmatix Research Advisory services as implementing partner, IFC (World Bank) and DCM Shriram Sugar units at Loni, Rupapur, Hariawan and Ajbapur have has laid the foundation with great success and the model is also being taken up in other cane growing states.

The model comprises of the selection of skillful entrepreneurs among the progressive cane growers of the mill zone area who are having basic agricultural equipment with them and are willing to promote their own business by way of hiring the agricultural machinery on rental basis to the needy cane growers in their area besides their use in their own fields The model comprises of the selection of skillful entrepreneurs among the progressive cane growers (ATSPs) of the mill zone area who are having basic agricultural equipment with them and are willing to promote their own business by way of hiring the agricultural machinery on rental basis to the needy cane growers in their area besides their use in their own fields

Selection Criteria of the Entrepreneurs – Agricultural Technical Service Providers (ATSPs)

- Age group between 21–45 years
- Able to speak and ability to explain the importance of the activity
- Education – Able to read/ write and keeping records of the daily activity
- Progressive farmers with learning ability
- He/she owned some machinery (basic requirement)
- Knowledge and practices for Package of Practices
- Financial background for investment and risk appetite for supply chain / or entitlement for bank loans etc.

Supporting components for Farm Mechanization

1. ATSPs will support adoption of standard package of practices in Sugarcane farming System to apply in large area.

2. High quality support mechanism for sugarcane crop, which enable farmers to accept and apply the suggested sugarcane package of practices and get high yield.
3. From cut to crush, all mechanized services through ATSPs.
4. Effective land use by outsourcing the package of practices.
5. On time support to sugarcane crop to focus the yield component.

Implementation Mechanism

Following steps need to be followed up in the sequence for successful implementation of the entrepreneur model of custom hiring

1. Need assessment –identification and selection of ATSPs and farm activities to be taken up in the farmers' fields.
2. Selection of suitable machineries and reliable machinery manufacturers and developing financial linkages for financial assistance.
3. Developing business plan of each entrepreneur
4. Training on repair and maintenance and operational activities of sources of power and machineries
5. Fixation of rates of hiring of the machines keeping in view the interests of the entrepreneurs and the farmers.
6. Capitalization of Govt. funding's to strengthen the concept
7. Training of mill staff and others involved in monitoring and facilitating the mechanized operations and ensuring the quality and payment part for the accomplished operations
8. ICT approach for e learning module to be used at farmers/entrepreneurs' level.

Proposed Structure for A Custom Hiring Centre By an Entrepreneur for Sugarcane Based Cropping System

	Name of equipment/machinery	**Cost Price (₹ Lakh)**
a.	45-50 hp Tractor (preferable >50HP)	6. 50
b.	Harrow 16 Disc	0.50
c.	Cultivator 9/11 tyne	0.20
d.	Subsoiler 02 tyne	0.25
e.	Reversible moldboard plough 02 bottom	1.30
f.	Power harrow	1.50
g.	Laser Leveler	3.35
h.	Trench opener	0.25

i.	Mechanical trench planter	1.50
j.	20 hp 4WD tractor with attachment for intercultural	4.50
k.	Sprayer	0.75
l.	Trash mulcher	1.60
m.	Tipping trolley	0.40
n.	Ratoon manager	0.50
	Total (₹)	23.10 Lakh

Assuming 40% subsidy, total investment made will be 60 % *i.e.* ₹ 13.86 Lakh

Now as assumed on an average 2,500 use h/year and taking on an average ₹ 1000/h as rental charges, an entrepreneur can have a total income of ₹ 25 lakh/year. Based on calculating cost of operations of tractor plus implement per hour considering fixed and variable cost of operation of both, on an average it comes to be ₹ 500 per hour, meaning thereby a net income of ₹ 12.5 lakh/year.

Total number of hrs. required/ha for accomplishing all the cultural operations right from land preparation to transportation of cane to the mill will be on an average 40 h/ha. Thus, an entrepreneur can cover about 50 ha of area under cane.

Consolidated numbers of developed agri-entrepreneurs

Year Wise Summary - ATSPs	Total	Jan – Dec		
		2017	2018	2019
Final working ATSPs (Full time + Part time)	214	84	63	67
Drop out from working ATSPs	7	2	5	-
Overall Selection for ATSPs	444	183	130	131
Success ratio to become ATSP	48%	45%	45%	51%

Consolidated area covered (Ha) status by CHCs

Summary- Area Coverage (ha)	2017	2018	2019
Land levelling (Laser guided/Manual)	3,290	4,246	3,977
Deep ploughing - MB Plough (Single side only)	192	285	698
Rotavator Only	123	4,432	6,941
Deep ploughing - Sub Soiling	6	163	206
Trench planter	1,962	2,254	2,056
Mechanized trench planter	991	517	746
Inter-culture operation	1,262	203	245
Trash shredding	89	242	1,174
Spray tank-Foliar spray	4,581	2,679	3,380
Sub total	12,496	15,021	19,424

Consolidated business (₹) status of CHCs

Summary- Area Coverage (ha)	2017	2018	2019
Land levelling (Laser guided/Manual)	5,922,000	7,644,600	9,823,783
Deep ploughing - MB Plough (Single Side only)	480,000	712,500	1,723,961
Rotavator Only	305,000	11,080,000	17,143,084
Deep ploughing - Sub Soiling	15,000	410,000	407,629
Trench planter	4,905,000	5,635,000	4,062,952
Mechanized trench planter	4,464,000	2,322,000	3,317,694
Inter-culture operation	1,891,500	304,500	364,290
Trash shredding	222,500	605,000	2,320,871
Spray tank-Foliar spray	2,290,500	1,340,000	8,347,365
Sub total	20,495,500	30,053,600	47,511,631

Return on Investment (ROI) of different machineries and Implements

Laser leveling

Total days of work available/year	=	150 days (10 h/day)
Output/day of 8-10 h work	=	1.5 ha
Capacity to cover total area (1 machine)	=	225 ha/year
Total cost of operation @ ₹ 570.50	=	1500 x 570.50 = ₹ 8,55,750
Total income/year@ ₹ 800/h (price)	=	800 x 1500 = ₹ 12,00,000
Net profit/year, ₹ 12,00,000 – ₹ 8,55,750	=	₹ 3,44,250

Sub Soiler

Total days of work available/year	=	120 days (8h /day)
Output per day	=	2.5 ha
Capacity to cover total area (1 machine)	=	300 ha/year
Total cost of operation @ ₹ 486.07	=	960 x 486.07 = ₹ 4,66,627
Total income per Year@ ₹ 700/h (price)	=	700 x 960 = ₹ 6,72,000
Net profit/year, ₹ 6,72,000 – ₹ 4,66,627	=	₹ 2,05,373

MB/RMB Plough

Total days of work available/year	=	60 days (8h/day)
Output per day	=	2.0 ha
Total cost of operation (500 h)	=	500 x 525.30 = ₹ 2,62,650
Total income @ ₹ 800/h (price)	=	₹ 4,00,000
Net profit /year, ₹ 4,00,000 - ₹ 2,62,650	=	₹ 1,37,350

Power Harrow

Total days of work available/year	=	60 days (8h working)
Output per day	=	2.0 ha
Total cost of operation (500 h)	=	500 x 5,66,68 = ₹ 2,83,340
Total income @ ₹ 800/h (price)	=	800 x 500 = ₹ 4,00,000
Net profit /year, ₹ 4,00,000 - ₹ 2,83,340	=	₹ 1,166,60

Sugarcane Planter

Total days of work available/year	=	100 days (8h working/day)
Output per day	=	1.5 ha
Total cost of operation @ ₹ 628.83/h	=	₹ 5,03,064
Total income@ ₹ 800/h (price)	=	₹ 6,40,000
Net profit /year, ₹ 6,40,000 - ₹ 5,03,064	=	₹ 1,36,936

As sugar industry in India plays an important role in developing its economy, farm mechanization of sugarcane agriculture occupying an area of 54.4 lakh hectares may have a big dent on the overall degree of mechanization in the country and there by accruing the benefits. For achieving the end objectives of SMAM. Concerted efforts of all the stake holders involved in association public private partnership model for establishing custom hiring centers to promote mechanization, is essential.

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Entrepreneurship Development in Sugarcane for Enhancing Farmers' Income

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Entrepreneurship is a key factor for the survival of small scale farming in an ever-changing and increasingly complex global economy. But what is entrepreneurship in agriculture? How does it relate to small-scale farmers who operate on the edges of the economy?

Entrepreneurship, value chains and market linkages are terms that are being used more and more when talking about agriculture and farming. Many small-scale farmers and extension organisations understand that there is little future for farmers unless they become more entrepreneurial in the way they run their farms. They must increasingly produce for markets and for profits. Becoming more entrepreneurial can be a challenge for small-scale farmers. They will need help from extension workers and other institutions.

Entrepreneurship development among rural people is increasingly being recognized as a means to overall development of the rural community. The problem posing to our rural masses is not so much in terms of creation of productivity and wealth as that of developing the capacities and ensuring utilization of human potential in creating wealth. Motivating the rural folk towards entrepreneurship in the area of agriculture and dairying would go a long way in mitigating their problems of unemployment and poverty.

The basic concept of entrepreneurship connotes effectiveness, an urge to take risk in the face of uncertainties and an intuition i.e. capacity of showing things in a way, which afterwards proves to be true. Various concepts and theories propounded by researchers seem to indicate that the emergence of an entrepreneur in a society depends upon closely interlinked economic, social, cultural, religious and psychological variables for healthy development in agriculture and allied sector, there must be men and/or women, who possess drive, ambition, foresight and imagination to breakthrough traditional barrier, overcome social inertia and transform theory into practice, Individuals performing these functions are the entrepreneurs and their enterprising ability and skill can be understood as entrepreneurship.

However, question arises that are all people engaged with agriculture and farming can be entrepreneur? Nonetheless, entrepreneurs would certainly be different from non-entrepreneur in terms of their psychological and social disposition, but need not have all these characteristics together. There is no evidence that entrepreneurs cannot be successful without some of these traits. Entrepreneurs with strengths in creative abilities may emerge successful without possessing many of these characteristics. Empirical studies have worked out some important characteristics., which can provide a working profile of farm entrepreneurs. List of these characteristics include need for achievement, risk taking, self confidence, problem solving, locus of control, effective communication leadership, originality, use of feedback, profit orientation and personal efficacy. Farm entrepreneur may not need all these traits; but the more he has, the greater the chances of being an entrepreneur.

Concept of entrepreneur

"What accounts for the rise in civilization is not the resources such as markets, minerals or factories but the entrepreneurial spirit, which exploits the resource-a spirit found most often among enterprising men called entrepreneurs".

The word "entrepreneur" appeared in French language long before the emergence of the concept entrepreneurial function. The literal meaning of this French word is 'between-taker' or 'go-between'. An early example of the earliest definition of an entrepreneur as go-between is Marco Polo, who attempted to establish trade routes to the Far East. In the early 16th century it was applied to those who were engaged in military expeditions. In the 17th century, it was extended to cover civil engineering activities. The entrepreneur and his unique risk bearing function was first-identified in the early 18th century by Richard Cantillon, an Irishman living in France, who defined an entrepreneur as person who buys factor services at certain prices with a view to sell its product at uncertain prices in the future. The 'classic' definition, which was to survive for almost two centuries, was given by an aristocratic industrialist, J.B. Say, who define entrepreneur as most important agent of production who provides continuing management and coordinate the functions to bring together factors of production.

In the late 19th the early 20th centuries, entrepreneurs were frequently not distinguished from managers and were viewed mostly from the economic perspective. In the middle of the 20th century, the notion of an entrepreneur as an innovator was established. An entrepreneur is basically an innovator who introduces something new into the economy, also capable of taking investment decisions, calculated risk under uncertainty, prompt and wise decisions in selection of a product or product mix, technology mix and marketing (Bheemappa, 2003).

Who is an entrepreneur?

An entrepreneur is someone who produces for the market. An entrepreneur is a determined and creative leader, always looking for opportunities to improve and expand his business.

An entrepreneur likes to take calculated risks, and assumes responsibility for both profits and losses. An entrepreneur is passionate about growing his business and is constantly looking for new opportunities. Entrepreneurs are also innovators. They always look for better and more efficient and profitable ways to do things. Being innovative is an important quality for a farmer-entrepreneur, especially when the business faces strong competition or operates in a rapidly changing environment

Can small-scale farmers become entrepreneurs?

Yes. Small-scale farmers all over the world have shown a remarkable ability to adapt. They look for better ways to organise their farms. They try new crops and cultivars, better animals, and alternative technologies to increase productivity, diversify production, reduce risk – and to increase profits. They have become more marketoriented and have learned to take calculated risks to open or create new markets for their products. Many small-scale farmers have many of the qualities of an entrepreneur.

The farmer-entrepreneur produces a clear picture in his mind of what is possible and the future he wants. He knows that what is possible is determined by the market. The farmer-entrepreneur is always looking for new opportunities. He knows that new opportunities are found in the market. The farmer-entrepreneur wants to make profits. He knows that profits are made in the market.

Smallholder farmers usually farm for one of four reasons:

1. Exclusively for home consumption with rarely any surpluses produced;
2. Mostly for home consumption, but with the intention of selling surpluses on the market;
3. Partly for the market and partly for home consumption;
4. Exclusively for the market.

Concept of entrepreneurship

"It will not be less than correct to mention that entrepreneurship has become the buzzword of the day"

Entrepreneurship can be described as a creative and innovative response to the environment. Such responses can take place in any field of social endeavour – business, industry, agriculture, education, social work and the like. Doing new things or doing things that are already being done in a new way is, therefore, a simple definition of entrepreneurship. Entrepreneurship refers to a set of attributes which the entrepreneurs possess and a set of activities which they perform in relation to the expansion of their units. According to Desai (2000) entrepreneurship is a composite skill, the resultant of a mix of many qualities and traits these include tangible factors as imagination, readiness to take risks, ability to bring together and put to use other factors of production, viz., capital, labor, land, as also intangible factors such as the ability to mobilize scientific and technological advances.

The experiences from developing countries all over the world favor the hypothesis that entrepreneurship can be developed through planned efforts. Therefore, one can notice some attempts by the government's development agencies and other institutions to undertake the task of entrepreneurial promotions (Deshpande, 1984). Most of the promotional activities are directed around the financial and physical facilities. But the experiences say that financial and physical facilities are not the only crucial inputs in the development of entrepreneurship. There are other inputs also which one has to consider in developing any model for entrepreneurship development. The models suggested for the development of entrepreneurship can be stated in three main categories (Deshpande, 1984). They are; psychological, sociological and integrated models.

a) The Psychological Model

McClelland (1961) has given a significant lead in identification of determinants of entrepreneurship. He recognized motivation as a primarily result of the ideological arousal of latent need for achievement among adults. After identifying achievement orientation as the key variable, McClelland suggested motivation training programme for entrepreneurship development.

Kunkel (1970) suggested that entrepreneurial behaviour is a function of the surrounding social structure both past and present and can really be influenced by manipulable economic and social incentives.

b) The Sociological Model

F. W. Young's theory of entrepreneurship is a theory of change based upon society's incorporation of reactive sub-groups. The reactiveness of a sub-group which experiences low status in the larger society will lead to entrepreneurial behaviour if the group has better institutional resources than others in the society at the same level. Young's model of entrepreneurship suggests creation of supporting institutions in the society as determinant of entrepreneurship.

c) The Integrated Model

T.V. Rao (1975) in his model identified five important stages in entrepreneurship development. These are; i) entrepreneurial disposition comprising need for motive, long term involvement, resources and socio-political system; ii) percepting factors; iii) acquisition of personal resources; iv) acquisition of material resources; and v) starting the business. K.L., Sharma (1978) suggests that entrepreneurial growth is governed by three sets of entrepreneurial determinants, namely; need for achievement motivation, socio-economic background of entrepreneur and political milieu.

Factors in entrepreneurship

Although, entrepreneurship is a function of several factors, out of those, three sets of factors could be identified, which mainly mainly influence entrepreneurship (Rao and Pareek, 1978). These are: i) The individual; ii) socio-cultural factors; and iii) support system.

i) The Individual

The individual constitutes the most important element in entrepreneurship. The entrepreneur as an individual takes the decision to start or not start an enterprise. And it is who strives to make it success. Again, three main factors, which influence the individual behaviour are his/her motivational factors, factors concerning various skills that entrepreneur possess, and the factors relating to his knowledge of several relevant aspects that are likely to contribute to success of the entrepreneurial roles. The motivational factors i.e. inner urge of the individual to do something new in a particular field has been found very important.

ii) Socio-Cultural Factors

Family background, norms and values of the immediate social circle contribute substantially to entrepreneurship development. The values and attitude an individual has, are a function of the socio-cultural millieu. Behaviors which reflect inclinations towards initiative and risk taking, dependence or independence, working with one's own hands on tasks requiring manual handling etc. are a result of the socialization process in the family, the school and society. Behaviour rewarded through appreciation, encouragement, and other extrinsic as well as intrinsic devices gets reinforced and related values and norms develop.

iii) Support System

Possibility of the success of an entrepreneur generally gets enhanced by efficient and effective operation of the support systems. The support systems may be an organization or an institution. The support system may be an organization or an institution.

"Anderson" defined organizations as those classes of human relationship structures wherein people purposefully associate in systematically arranged units to promote and achieve some common purposes or interests that are not specifically expressed in institution (Anderson and Parker, 1964). Organization operates as a clearly defined entity having a specific objective with officers and membership. An organization differs from an institution by its focus on a narrowly limited purpose. Characteristics of organization are:

1) Clearly defined limits.
2) Formal membership, status and role.
3) Restrictive qualification for membership.
4) Administrative structure.
5) Operative principles, procedures and goals.
6) Provision for control and authority.

Examples of organization are banks, research organization (under Govt. and private), development departments, project, NGOs, private agency, dairy plants etc.

An institution on the other hand pursues broader and more general purposes and is basically a set of socially sanctioned procedures involving patterned behaviour, norms, and roles. An institution is an organized system of social relationship, which embodies certain common values and procedures and meets certain basic needs of society (Horton and Hunt, 1964).

Examples of institution are family, relatives, private money lender, cooperatives, input delivery system, milk procurement system, etc.

Several agencies and organizations operate to help and support the process of entrepreneurship. A few of those are listed below:

a) Financing including commercial and cooperative banks.
b) Extension services of the various concerned departments of industries.
c) Research/Development/Educational institutions.
d) Development administration of the state at district level.
e) Corporations specially set up to develop entrepreneurship in the region.
f) NGOs, consultants, private agencies, training institutions etc.

Entrepreneurship Dynamics

When a farmer introduces a new enterprise into his farming system, there are different stages of development that the enterprise goes through. The skills of the farmer must also change and develop to meet the management demands of the enterprise.

Entrepreneurial businesses evolve through five phases:

Establishment → Survival → Early growth → Rapid growth → Maturity

Establishment

Farmers require skills to negotiate with banks and other agencies in order to get the assistance they need to establish their new enterprise. The key questions are:

- *How can this become a profitable business enterprise?*
- *How will it impact on my farm as a whole?*
- *How can I establish a market?*
- *Do I have enough money to cover the cash demands in setting up the enterprise?*

Survival

Starting a new enterprise shows that the farmer has some entrepreneurial skills. Surviving the first stage shows that the new enterprise has short-term viability. In the survival stage, the focus is on the relationship between the income earned and the costs entailed. The key questions are:

- Can I generate enough income to break-even in the short-run and to replace capital equipment?
- Can I generate enough income to expand or diversify production according to market demands to ensure long-term viability?

Early growth

To achieve this, the farmer needs to develop a broader product and buyer base while ensuring that the farm business remains profitable. He must also ensurethat farm operations are efficient, find the information needed for better management and hire more skilled staff to cope with the increased production, marketing and management activities. While the organization may still be simple, growth requires more managerial skills and qualities to cope with the more complex farm management activities and decisions.

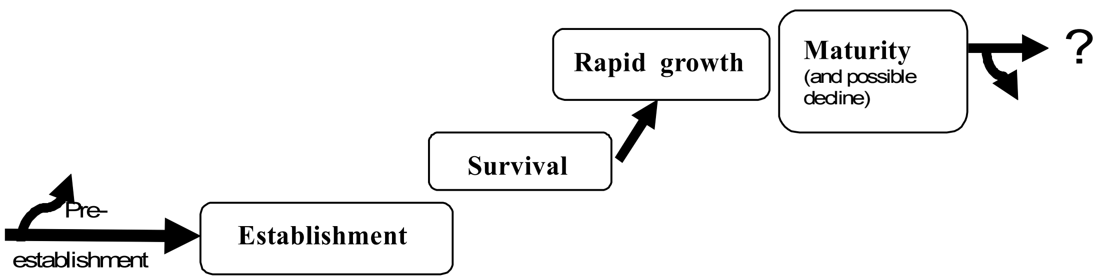
Rapid growth

Once the farm enterprise is working as a well-integrated farm business, it is in a position where it can achieve rapid growth. One way to grow is by increasing the amount of land planted and/or raising more livestock. This will give more product to sell. Another way is to add value to the product by processing it and/ or packaging it.

Maturity (and possible decline)

Eventually, the farm business reaches maturity. This means that it stops growing or xpanding. It reaches a point of balance where land size, market opportunities and the scope of activities are in balance with the skills and vision of the farmer. As long as the farmer and the farm business continue in this balance the farm business will continue. If the enterprises are profitable and the farm is well managed, the business can be sustained.

Farm enterprises generally move through these five stages:



Success story

Entrepreneurship Development Programme (EDP) was implemented for cane growers in Sitapur District of Uttar Pradesh. They were imparted training on Entrepreneurship to develop their entrepreneurial skills and technological interventions were introduced along with other interventions to harness the benefit out of their enhanced skill and ability.

Three technological intervention modules was introduced

- Module I- Seed cane production
- Module II- Ratoon cane production
- Module III- Intercropping in sugarcane

Development Interventions introduced

- Strategic plan encompassing identification of technological interventions
- Sensitization of stakeholders through interface meetings and group discussion

- Deploying scientific manpower with active cooperation and logistic support from cane development department, Govt. of Uttar Pradesh & sugar mills.
- Seed cane production and distribution
- Large scale adoption of early maturing high sugar variety in Uttar Pradesh

Quantifiable Impact: WONDER

The programme was jointly implemented by IISR, cane development department, sugar mills and farmers in the Uttar Pradesh in PPFP mode. The results achieved is even beyond expected and that's why we may call it as ***"WONDER"***.

Impact at Farmers' Level

(i) Seed Cane Production: enhanced farmers' profit

Table 1. Yield, Seed cane utilization, economics of seed cane crop (n= 200)

Intervention	Avera-ge yield (t ha^{-1})	Average cost of cultivation (₹ ha^{-1})	Seed cane Utilization Pattern		Return (₹/ha)			Net Profit (₹ ha^{-1})
			For Seed Multipli-cation	Crushing	Seed @ 390 q^{-1}	Crushing @ 315 q^{-1}	Total	
Seed Cane Production	110	1,10,000	70%	30%	*300300*	103950	4,04,250	2,94,250
Farmers' practice	70	90,000	20.00%	80.00%	54600	176400	231000	141000
% Increase	59.09	22.22					75.00	108.69

As evident from results obtained in table 1, the average yield of seed cane crop was 110 t/ha which was 40 t/ha more the yield obtained conventional method. Although the cost of cultivation was 22.22% higher in seed cane production but it was well compensated as total return (₹ 2,31,000) and net profit (₹ 1,41,000) enhanced by 75 and 108.69 per cent, respectively, over the conventional method.

Table 2. Enhanced yield and profit with ratoon promoter machine

Intervention	Average yield (t ha^{-1})	Average cost of cultivation (₹ ha^{-1})	Return (₹ ha^{-1})	Net Profit (₹ ha^{-1})
Ratoon Promoter Machine	80	75,000	2,52,000	1,77,000
Farmers' practice	60	75,000	1,89,000	1,14,000
% Increase	33.33	0.0	33.33	55.26

(ii) Ratoon cane production: enhanced yield and profit with ratoon promoter machine

As evident from the figures presented in Table 2, the average yield obtained for interventions on ratoon promoter machine was 80 t/ha which was 33.33 per cent higher than the farmers' practice. The net profit earned by farmers in intervention plots was ₹ 1,77,000 per ha which was

55.26% more over conventional method. In addition to this farmers also saved time in managing ratoon plots with ratoon promoter machine as it performed all operation needed at the time of ratoon initiation in one pass only with the help of two labours.

Table 3. Economic analysis of intercropping with sugarcane (n=100)

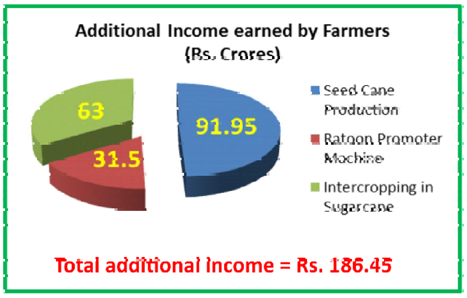
Cropping system	Yield (t ha^{-1})		Return (₹ ha^{-1})		Net Profit (₹ ha^{-1})	% Increase in profit
	Cane	Inter crop	Cane	Inter crop		
Sugarcane	70	-	220500	-	130500	-
Intervention-Intercropping in Sugarcane						
Sugarcane + Vegetable Pea	90	7.5	283500	135000	276000	111.49
Sugarcane + Potato	85	29.0	267750	232000	350500	**168.58**
Sugarcane + Lentil	84	1.5	264600	72000	220600	69.04
Sugarcane + Kidney beans	88	1.95	277200	107250	265000	103.07
Sugarcane + Mustard	83	1.60	261450	60800	226500	73.56
Sugarcane+ Cabbage	94	15.5	296100	124000	300800	130.50

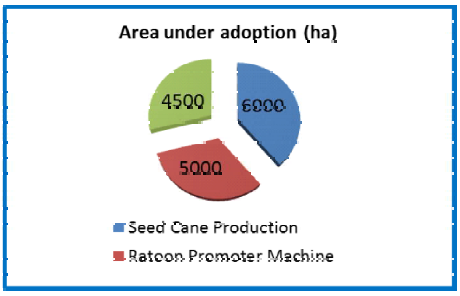
(iii) Intercropping in sugarcane: profit enhancement and nutritional food security

The results presented in table 3 clearly depict that raising intercrops with autumn sugarcane enhances system yield as well as net profit of farmers. Sugarcane yield increased by 13-24 t/ha, whereas farmers net profit enhanced by 69.04% to 168.58% depending on the intercrop grown there. The intercropping of pulses and vegetables with autumn planted cane provides ample opportunity to the farmers to earn considerably high profit as well as to ensure nutritional food to their family members. At the same time intercropping also help in improving soil health through in-situ mulching of intercrops bio-mass after harvest and fixing of atmospheric nitrogen in the soil.

Table 4. Impact on production, productivity and profitability

Interventions	Enhancement in cane yield (t ha^{-1})	Increase in net income of farmer (₹ ha^{-1})	% increase in farmers' income (ha^{-1})	Adoption area in ha (tentative)	Additional income earned by farmers (Crores ₹)
Seed cane Production	40	153250	108.69	6000	91.95
Ratoon Promoter Machine	20	63000	55.26	5000	31.50
Intercropping in sugarcane	13-24 + intercrop yield	140000	107.28	4500	63.00
Total				15500	186.45





The Monetary impact

The total area under adoption of all three interventions introduced there is about 15500 hectares.

- Additional profit earned by farmers in project area is ₹ 186.45 crores.
- Total farmers benefitted by the project are 20000.
- Additional profit earned per farmer in project area is ₹ 93225.

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Processing Technologies for Jaggery Manufacturing

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Sugarcane is a major cash crop of India,which is grown for making three major products *viz.* sugar, jaggery (*gur*) and *khandsari*. Utilization of sugarcane for sugar production has increased over the past years and consequently, share for jaggery and *khandsari* has decreased. However, liking for jaggery by the people in general and rural mass in particular has not waned. It is used for preparation of several *Ayurvedic* medicines. It is cooling, diuretic, aperient, refreshing, improves throat conditions and acts as tonic. sugar and *khandsari* are merely sweeteners but jaggery is a food material as well due to presence of nutrients needed for our body. Compostion of jaggery is presented in table 1.

Table 1. Composition of jaggery (Per 100 g)

Constituent	Value
Sucrose	80-85 g
Reducing sugars	5-15 g
Protein	400 mg
Fat	100 mg
Calcium	8.0 mg
Iron	11.4 mg
Phosphorus	4.0 mg
Total minerals	0.6-1.0 g
Moisture	3-10 g
Energy	383 kCal

Jaggery is called as *Gur* in India, *Desi* in Pakistan, *Panela* in Mexico, *Rapadura* in Brazil, *Chancaca* in Chile and Peru, *Hakuru* in Sri Lanka, and *NaamTaanOi* in Thailand (Sharon *et al*., 2013). Despite many medicinal and nutritive advantages of jaggery, it is a general feeling that there are higher post-harvest losses in cane used for jaggery as compared to sugar. However, loss of nutrients is negligible as compared to sugar. It is only the processing losses, which are more in jaggery. In sugar industries, more sucrose is extracted due to higher pol extraction but reducing sugars and minerals, which are more vital from health point of view, are lost.

Jaggery serves as safety valve for the cane growers in a situation when sugar mills are not in a position to consume all of their sugarcane. Thus it saves them from the losses. Due to this reason or the nutritive and medicinal aspects of jaggery; this industry will continue forever with cultivation of sugarcane. The scenario of per cent utilization of sugarcane in India for different purposes over the past five years is given in Table 1 (Anon., 2017).

Table 1. Per cent utilization of sugarcane for different purposes

Year	Sugar	Seed, feed, chewing etc.	Jaggery and *khandsari*
2012-13	73.45	11.82	14.73
2013-14	67.64	11.16	21.20
2014-15	75.37	11.45	13.18
2015-16	67.87	11.62	20.51
2016-17	63.06	11.70	25.24

The major unit operations involved in jaggery production are: Juice extraction from cane stalks, filtration, heating, clarification, boiling, concentration, puddling and cooling and moulding. Packaging is another aspect from marketing and distribution point of view. Cane crushing, heating, boiling and concentration are the major energy intensive operations consuming more than 80 per cent of the total energy demand. Despite importance of jaggery from time immemorial, this industry lacked research and development support it deserved. At most of the places still traditional way of jaggery production under unhygienic conditions is being followed using inefficient processing devices. Due to this, the productivity, quality and profitability of jaggery is badly affected.

System of jaggery production

There are five systems of jaggery production prevailing at different places:

1. Jaggery manufacturing by the jaggery plant owner himself from his own cane or purchased from others and partly engaging his family labour;
2. Jaggery plant owner giving his plant on hiring without labour; farmers bring their cane and rentals are hired on the basis of (i) weight of cane crushed (ii) weight of jaggery made or (iii) hours of crusher operation.
3. Plant owner giving his plant on rent with labour and charging on above three bases.
4. Contract system for each operation like cane crushing, fuelling, juice concentration and for every quintal of jaggery made.
5. Plant owner charging on the basis of sugarcane area without labour engagement.

Sugarcane crushing

Sugarcane crushing or juice extraction is the first and foremost important unit operation in jaggery production. Juice extraction is directly related to jaggery recovery and productivity. Losses occurring at juice extraction level alone accounts for revenue loss of several million rupees per annum. Over the long usage, performance of crushers goes down due to wear and tear of crusher rollers and other parts. Farmers are not aware of reduction in juice extraction. Hence it is imperative that the crusher is tested and set at regular interval. A good crusher should give 60-65 per cent of extraction on cane basis. Extraction beyond 70 per cent is very difficult to achieve. Normally people think that sugar mill crusher gives up to 98 per cent extraction. But it may be noted that this extraction is pol extraction; not the juice extraction. Secondly, fibre content in cane also affects juice extraction directly as well as indirectly due to more reabsorption of juice by the bagasse. It may be made customary to calculate juice extraction at 12.5% fibre content (reduced extraction) as being done in sugar mills for pol extraction. Below-mentioned formula can be used for calculating reduced extraction (Baboo and Anwar, 1995):

$$RE = [12.5/FC](JE-100) + 100 \qquad (1)$$

Where, RE = Reduced extraction, % cane

FC = Fibre content, % cane

JE = Actual juice extraction, % cane

Juice settling

After the juice is extracted, it should be thoroughly filtered preferably by a five-layer filter. Manual handling of juice should be avoided; instead, it should travel to the juice settling tankby means of pipes. This juice should again be filtered through a muslin cloth placed on the juice settlig tank. In this way all the coarse impurities like bagasse particles, leaves, *etc*. are removed. Juice is settled for about 20 minutes for settling of all the heavy impurities to the bottom.

Table 3. Vegetative clarificants used for jaggery preparation

Name of plant	Part of plant used	Quantity (g)/quintal juice	Usage
Deola (Wild Okra)	Stem and roots of green plant	40 – 45	Crush and rub in water till mucilagenous extract is obtained
Okra		45–50	
Falsa	Stem of green plant	50–55	
Semal		55–60	
Suklai	Dry bark of plant	45–60	Soak in water for some time then crush and rub in wated till mucilagenous extract is obtained
Castor	Seed	70–75	Grind water soaked seeds in some more water. After straining, use milky liquid
Groundnut		70–75	
Soybean		30–40	Grind water soaked seeds in some more water. After straining, use milky liquid or use in flour form

Juice heating and clarification

Juice from juice settling tank is pumped to the pans of jaggery making furnace. In this way, again manual juice handling is avoided. Juice is now heated upto 80^{o}C and before that mucilagenous extract from vegetative clarificants are added. This makes the scum containing colloidal impurities floating to the surface, which is removed using ladle.

Extent of juice clarification largely determines the quality of jaggery. People like light colour jaggery. For this, chemical like sodium hydrosulphite, popularly known as hydros, is excessively used. Jaggery, which is prepared by using higher quantity of sodium hydrosulphite, contains much above prescribed limit of 50 ppm sulphur dioxide. Awareness about harmful effect of this chemical must be propagated. This bleaches out the colour of jaggery without removing impurities in true sense. Other chemicals like calcium hydroxide, alum, phosphoric acid *etc*. are also used for some specific purposes. It is better to use clarificants of vegetative origin as they do not have any harmful effect on human health.Some of the vegetative clarificants are listed in table 3.

It has been observed that the scum, which is obtained by using vegetative clarificants, contains 10%, 54% and 36% sludge, clear juice and froth respectively by volume. It is recommended to use scum settling tank for recovery of trapped juice.

Juice boiling and concentration

Normally sugarcane juice is boiled and concentrated over open pan jaggery furnaces. These furnaces are made by local artisans and have low thermal and heat utilization efficiency. However, some of the improved furnaces have also been developed but lots of improvement is still needed. Indian Institute of sugarcane Research, Lucknow has also developed a 2-pan and 3-pan furnace with better efficiency over the traditional ones. Step grate and fixation of different pans at different height are the special features. This facilitates efficient burning of fuel and transfer of juice through gravity respectively. A novel concept of increasing area of heat receiving surface of juice boiling and concentrating pans may serve as a solution. For this, fins provided to the pans of IISR 2-pan furnace yielded bagasse saving to the tune of 30 per cent with time saving and improvement in jaggery productivity as 17 and 20 per cent respectively (Anwar, 2010). A concept of efficiency boosting device may also be tried (Anwar, S.I. 2015).

Jaggery is produced in three forms *viz*. solid, liquid and powder (granules). Sugarcane juice is concentrated over the furnaces till its striking point is reached i.e. 114-116 ºC for solid, 105-108 ºC for liquid and 118-120 ºC for powder/granular jaggery (Baboo and Anwar, 1995).

Cooling, moulding and packaging

Once the striking point is reached the concentrated sugarcane juice (slurry) is poured into a cooling pan made of wood. It is cooled here for some time and then is puddled using ladle. At the moment the shine of slurry goes off, it is ready for moulding.

Jaggery is produced in many shapes and sizes. Most of these shapes pose problem in moulding, packaging, handling and distribution and many of them are not attractive in look. To overcome these problems, ICAR-Indian Institute of Sugarcane Research, Lucknow has developed jaggery moulding frames for producing jaggery in cubes of 1 inch weighing 20-22g each. Besides ease in moulding, these cubes are very attractive and can be easily packed in attractive packets keeping it away from insects, dust and direct contact with hand while handling and distribution. Marketing of jaggery can also be enhanced by highlighting composition and health related aspects of jaggery consumption printed on these packets.

Value addition in jaggery

Value added products of different kinds are gaining more popularity nowadays. They are liked for their taste as well as added nutrition, flavour *etc*. and are more profitable to the manufacturer. Although jaggery already contains substantial amount of nutrition yet its value addition may improve it nutritionally. Indian gooseberry (*Aonla*) can be added to jaggery for enriching it with vitamin C (Anwar *et al*., 2009). The taste of such jaggery is also good. A complete process technology has been developed (Anwar *et al.*, 2011). Indian spices can also be added in jaggery for improving its medicinal value. An effort has been done at Indian Institute of Sugarcane Research, Lucknow and following materials and their quantity has been identified for addition (Anon., 2016-17):

Table 2. Quantity of spices added to jaggery for value addition

Name	Quantity to be added (g/kg of jaggery)
Dried ginger powder	25
Turmeric powder	15
Carom seeds	10
Black pepper powder	15
Asafoetida powder	1
Sesame seeds	400
Nigella seeds	15

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Processing of Sugarcane to Produce Value Added Products for Increasing Farmers' Income

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Sugarcane is one of the major cash crops in India. About 70% of its' total is utilized for production of white sugar and remaining 30% goes for manufacturing jaggery, khandsari, and also for seed, feed, chewing, fresh juice for drinking, and vinegar etc.(Singh and Singh, 2017). Cane juice and jaggery are considered as energy foods because they are rich sources of vitamins and minerals and have potential to fight health and food insecurity particularly in rural areas. The main causes of health and food insecurity are unemployment and economic capacity to afford nutritious food and also their non- availability (Singh *et al.,* 2011). Low–cost technologies (Singh *et al.,* 2012) for manufacturing various value added products from sugarcane juice (viz; quality jaggery, value added jaggery of different kinds and also with fortification of Vitamin C using Aonla (Anwar *et al.,* 2009) and vinegar are discussed. Since large population living in rural sector suffers due to under nutrition and mal nutrition as the common Indian diet is deficient in nutrition, to meet their requirements of proper food and nutrition, there is need not only to manufacture but also to multiply improved and hygienic technologies and pilot plants to make above value added products from cane juice in plenty in different areas in the country.

Process for manufacturing value added products

Desired shaped solid jaggery

Matured sugarcane is harvested, de-trashed, transported to processing unit site, cleaned, and crushed for juice extraction. The juice is simultaneously filtered in three to four stages (Singh 1998). The cleaned juice is processed further for making different value added products such as cubical, and trapezoidal shaped solid jaggery, liquid jaggery, granular jaggery, Vit. C fortified jaggery, and also fermented products from juice like vinegar etc. It is loaded in open pans on triple pan furnace and heated with bagasse as fuel. Herbal clarificant namely Deola (*Hebiscuss esculentus)'s* extract is mixed @ 45g/100kg juice to clarify above juice in pans from impurities. The clear juice is then boiled further till it reaches striking point temperature as per requirements. After this stage concentrating sample is unloaded/transferred into wooden pan and mixed thoroughly with ladle (Singh, 1998; Singh 2008 and Singh *et al.,* 2012). The slurry is then poured into molding frames of desired designs. These samples, after well setting are removed by dismantling the frames, and properly dried either either in shed, solar dryer or mechanical dryers. Later these sample are packed in 250 gram capacity 400 gauge polyester polyethylene packets.

Liquid jaggery

It is an intermediate product collected during jaggery making process (Singh, 1998). The concentrating juice is removed from boiling pan at striking point temperature of 103 to 106 ^{0}C (Singh, 2008) depending on variety and agro-climatic zone and processed further to make liquid jaggery.

Granular jaggery

The fresh cane juice s heated in open pan till striking point temperature of 120 -122 $^{\circ}$C is achieved, after which the concentrating mass is transferred in wooden pan and churned thoroughly by ladle and later left without stirring for few minutes for good crystal formation. During solidification the mass is immediately made into powder/granules manually with the help of wooden scrappers and allowed to cool. Later the samples are sun dried from about 12% to 1.5% moisture content and later sieved by 1- 3 mm sieves, and packed in 400 gauge polyethylene polyester bags/ bottle/ sachets (Singh, 1998).

Jaggery chocolate

Chocolates, available in markets are generally low in protein and fiber content and have high fat value. Therefore, supplementation of fiber and protein rich, low fat chocolate with equal textural and organoleptic qualities are desirable. In Ayurveda, jaggery is considered to be best of all sugarcane preparations as medicinal sweetener. The color, texture and sweetness of jaggery make it suitable for chocolate like preparations/products. An appropriate quantity of freshly prepared jaggery before setting is put into the preheated pan and mixed. Then ingredients are added in an appropriate quantity and mixed. 10% chocolate mix was poured in the moulds and allowed to cool until it sets (Singh, 2008; Singh, 2009). Later it was removed from the mould and put on an aluminum foil and was allowed for natural drying continuously for period of 24 hours after which the jaggery chocolate was wrapped in aluminum foil and sealed in polythene bags for storage.

Vitamin C fortified jaggery

Vitamin C is added to jaggery through a natural source ie. Aonla. Such jaggery helps in fighting malnutrition. *Aonla* fruits are cut into small pieces, sliced and shredded, and dried up to about 10% moisture content using a mechanical dryer. Samples made into powder and grated forms are mixed with jaggery separately (Anwar *et al.,* 2009).

Fermented cane juice products

Wine

Since sugarcane juice, available in abundance, is used for making wine. It contains fermentable sugar, amino acids, minerals and other growth factors (Nigam, 2002). Cane juice fermented into wine may be available at cheaper rates to the laborers etc. as nutritious alcoholic drink. It has good market potential in the country.

Rum

From cane juice Contesssa brand rum is produced in Rampur (India). It is reported to have an international recognition and is exported to foreign countries and earns foreign exchange.

Gasohol

Currently, efforts are being made to use gasohol as a fuel in IC engines. Studies conducted in various research organizations have revealed that about 20% anhydrous ethanol blended with petrol could be used without changing designs of IC engines and the carburetors. In addition to being ecofriendly it will also save foreign exchange. Juice obtained from staled canes, ie. canes which are not worth for extraction of juice for making other valuable products, may be used for production of alcohol (Nigam, 2002) from economic point of view.

Vinegar

The vinegar, made from sugarcane juice after its fermentation, is used in pickles, table salads and vegetables etc. It consists of acetic acid and water. Acetic acid is produced through fermentation of ethanol by acetic acid bacteria. Its color ranges from dark yellow to golden and dark brown. It is also used as preservatives, antiseptic and medicine.

Yeasts

Fermenting molasses of cane juice obtained from mills baker's yeast and pharmaceuticals yeasts are produced which are better for edible purposes. These yeasts sell at a higher prices in compressed yeast form and also in dry yeast form. The quality of yeasts from cane juice fermentation is superior for edible purpose and fetches a premium price.

Innovative Scheme Initiated by Govt. of India

The Govt. of India has launched a scheme for promotion of innovation, entrepreneurship, and agro- industry under the Ministry of Micro, Small and Medium Enterprises which has several components favouring to rural people to become self-dependent. It is advised to take advantage of the scheme for development of value added products from cane juice adopting above processes (Singh and Singh, 2017). It would benefit rural youths and entrepreneurs involved in plant's activity in second largest cottage industry in rural sector. Pilot plant developed by IISR, Lucknow is multiplied and installed in different sugarcane growing states in India by ICAR-IISR, Lucknow with support of the Government. Rural people in general, youth and women in particular can undergo training and learn technologies to improve their skill to operate these plants which would provide higher food and nutritive value jaggery at lower cost and boost-up rural economic system.

Different value added products from sugarcane juice have export potential because there are many countries in the world similar to our country where lot of people suffer from under nutrition and mal nutrition. Establishment of sugarcane processing pilot plants for production and processing of various value added products from sugarcane for benefit of rural masses may be promoted through KVKs for more effectiveness.

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Drying of Jaggery Using Solar Energy

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Sugarcane is a cash crop in India. It occupies 5.3 million hectares area with 3.67 million tonne production. Out of total sugarcane production, 74.3% is utilized for sugar production and 14.2% for jaggery and khandsary. It is one of the important sources of nutrition required for the growth and development of human being. In addition, it has a great potential for export and employment generation. It is observed that fresh jaggery prepared from the sugarcane juice has 12-14% moisture content. It is required to be dried up to 5-6% moisture content for packaging and safe storage. For the study of jaggery drying , a thermal model has been developed to predict the jaggery temperature, the greenhouse air temperature and the moisture evaporated during the drying of jaggery under natural convection conditions. An attempt has been made to evaluate the convective mass transfer coefficient during drying of jaggery in a controlled environment. It was found that the convective mass transfer coefficient is a strong function of mass of jaggery, temperatures and relative humidity for a given size of greenhouse. Earlier experiments conducted has established that temperature in the range of 45-50ºC was sufficient for jaggery drying and it is well within the reach of simple and low cost solar energy collecting systems. Most of the villages spread all over, lack facilities of conventional sources of energy (viz. electricity and fossil fuels, etc.) to be used freely for drying as well as other purposes. And the fact remains that solar energy is available in abundance for such purposes free of charge. In view of the increasing energy crisis and above facts, a solar dryer has been developed.

Development of Solar Dryer

1. Design of the different components of dryer

A. Design of drying chamber

Assumptions:

Weight of jaggery taken	x	=	100 kg
Initial moisture content	m_1	=	12% (w.b.)
Final moisture content	m_2	=	6% (w.b.)
Quantity of water to be removed,	W	=	$\frac{(m_1 - m_2) \times 100}{(100 - m_2)}$
		=	$\frac{12-6}{100-6} \times 100$
		=	6.38 kg

Time duration of drying, t = 6 hours

Requirement of moisture removal rate, Y $= \frac{6.38}{6}$

$= 1.06$ kg/h

Assuming Ambient temp. $= 25^oC$

And dry air temp. $= 45^oC$

Sensible heat of water, h_1 = Y x 1 x (45 -25)

= 1.06 x 1 x 20

= 21 kCal/h

Latent heat of water, h_2 = Y x 540

= 0.80 x 540 kCal/h

= 432 kCal/h

Total heat requirement, h $= h_1 + h_2$

= 21+432

= 453 kCal/h

Global radiation (k) is 600 kCal/h/m^2

Overall thermal efficiency assured 30%

Hence, drying area $= \frac{h}{K} \times \frac{100}{30}$

$= \frac{453}{600} \times \frac{100}{30} = 2.5m^2$

Considering 25 mm gap between two cubes of jaggery and other allowances

Effective area = 6.25 m^2

B. Design of air inlet and chimney

i) Input Air

Temp. = 25^oC, R.H. = 70%, Humidity ratio = 0.014 kg/kg of dry air

Specific vol. = 0.863 m^3/kg of dry air

Suppose V m^3 of air is entering in 6 hours

So, wt. of dry air $= \frac{V}{0.863}$ kg

ii) Exit Air

Temp. = 45°C, humidity ratio = 0.024 kg/kg of dry air

Now increase in humidity ratio = 0.024 – 0.014 = 0.010 kg/kg of dry air

Here, Total moisture gain by air = Total moisture lost by jaggery

$$\frac{V}{0.863 \times 0.010} = 6.38$$

$V = 551\ m^3$ in 6h

$= 91.8\ m^3$

$= 0.0255\ m^3/s$

Suppose, length 2.5 m and width of air inlet is h m

Suppose, 0.0255 m^3/sec flow rate of exit air is to go out by chimney. If flow speed is 0.4 m/s, and dia of chimney is D m,

then, $\frac{\pi D^2}{4} X\ 0.040 = 0\ .0255$

D = 0.29 say 0.30 m

2. Fabrication of the dryer

List of materials were prepared and materials were procured. List of materials required has been given in Table 1. Different parts of the dryer were made and assembled. A view of the developed dryer is shown in Fig. 1.

Table 1. Materials requirement for fabrication of Solar dryer (Year: 2010)

Sl. No	Items	Quantity	Rate /unit	Cost (₹)
1.	Angle Iron (35x5 mm)	10m	150/m	1500
2.	Aluminium Sheet (8’x4’)	3m^2	500/m^2	1500
3.	Metallic iron *Jali* (1’x1’)	6.5m^2	400/m^2	2600
4.	Wooden Board			
	(8’x4’x19 mm)	7Pc	1300/pc	9100
	8’x4’x6 mm)	1Pc	1200/pc	1200
5.	Beeding			
	Plain	100m	3/m	300
	Designed	90m	5/m	450
6.	Plain Glass (4 mm thick)	3m^2	300/m^2	900
7.	Fevicol	2kg	150/kg	300
8.	Miscellaneous items (nut bolt handle, *fanti etc.*)	-	-	1650
9.	Total			19500

3. Performance Evaluation

A. At no load condition

The drier was tested at no load condition. For the purpose, the dryer was kept in the place where there is no shadow of tree and building. The orientation of the dryer was ensured as due south. In the each tray a mercury thermometer was kept. The ambient temperature and humidity, cabinet temperature and temperature of each tray was also measured at each hours starting from morning to evening. It was observed the temperature of drying chamber was upto 21ºC higher as compared to ambient (Table 2). The temperature of each tray was also measured. It was noticed that temperature of trays of the dryer varies from 31.22-41.56ºC (Table 3).

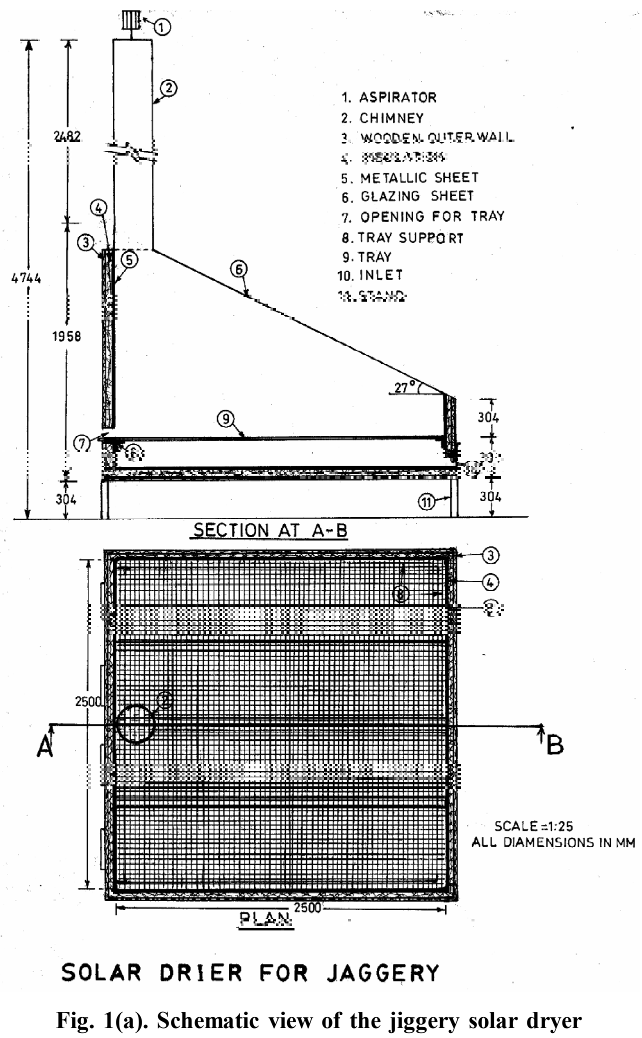

Fig. 1(a). Schematic view of the jiggery solar dryer

Fig. 1(b). A view of jaggery solar drier

Table 2. Overall temperature rise of dryer at different time of the day

Time of the day	Ambient temperature (ºC)	Humidity (%)	Cabinet temperature (ºC)	Temperature difference (ºC)
9	18	70	26	12
10	19	70	33	14
11	20	65	38	18
12	23	65	40	17
13	23	50	43	20
14	24	50	45	21
15	24	50	41	17
16	22	50	37	15
17	21	55	34	13

Table 3. Temperature of trays of the upper layer of the dryer

Time Tray	9	10	11	12	13	14	15	16	17	Average Temp. (ºC)
1	27	35	42	50	50	53	40	35	35	40.77
2	26	32	35	48	50	51	48	41	35	40.67
3	26	35	45	50	48	40	50	44	36	41.56
4	20	20	32	40	46	50	48	45	38	37.67
5	28	35	45	50	50	55	40	35	35	41.44
6	20	25	40	47	50	50	47	38	33	38.89
7	19	20	28	35	35	45	35	34	30	31.22
8	20	25	30	46	48	46	46	40	35	37.33
Average temperature										38.70

B. At load condition

Initial weight of the each tray waw taken. The trays were filled with jaggery cubes and their weight were taken again. All the tray were put in the dryer in the morning at 09.00 A M and final weight at 5.00 PM were taken again. Same procedure was adopted till it dries.The final weight after each day of each tray were measured. Total drying time was calculated as 16 hours with tempering overnight.

C. Cost of drying of jaggery

Bureau of Indian Standards (IS:9164-1979) for estimation of cost was followed for estimation of cost of operation of the solar dryer. Following assumptions were made:

Life of drier and Salvage value	=	8 years and 5% of Initial cost
Rate of interest, insurance and shelter charges	=	12%, 2% and 1.5% on average investment
Number of days of use of drier in a year	=	100
Repair and maintenance factor	=	8% on cost per year
Capacity of drier	=	100 kg per batch
Cost of drier	=	₹ 19,500
Number of man-days employed and wages of labour	=	1 per batch and ₹ 200 per man-days

The fixed cost, operating cost and total cost of jaggery drying was worked out to be ₹ 0.40, ₹ 2.15 and ₹ 2.55 per kg, respectively.

The drying rate of jaggery was found as 0.300 kg moisture per hour. It took about 16 hours with overnight tempering for drying jaggery from about 12% moisture content to about 6% moisture content. The total cost of drying was calculated as ₹ 2.55 per kg. The developed dryer is suitable for rural areas.

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Packaging and Storage of Jaggery

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Jaggery (also known as *gur*) is a natural, traditional sweetener made by the concentration of sugarcane juice. It is a traditional unrefined non centrifugal sugar consumed in Asia, Africa, Latin America and the Caribbean. It contains all the minerals and vitamins present in sugarcane juice and that is why it is known as healthiest sugar in the world. It is a concentrated product of cane juice without separation of the molasses and crystals, and can vary from golden brown to dark brown in colour. India is the largest producer and consumer of jaggery in the world. Out of the total world production, more than 70% is produced in India (Rao *et al.,* 2007).

It is consumed in almost all sections of the society as a sweetener and as a source of energy. It is also used in animal feed mixtures. In Ayurvedic way of medicine, it is used as medicine, blood purifier and base material for syrups. Jaggery and Khandsari are among the major agro processing industries found in rural sector of our country. Nearly 50 per cent of total sugarcane produced in the country is used for manufacture of about 8-10 million tonnes jaggery which is known as the most nutritious agent among all sweeteners (Madan, 2004). Even today, this sector utilizes about 38 per cent of the total sugarcane grown in the country and provides employment to about 2.5 million people (Cooperative Sugar, 2011; Nerkar, 2004).

Jaggery is manufactured between October and April but since it is marketed and consumed throughout the year a substantial part of it has to be stored. It has been estimated that one third to one half of the jaggery produced is stored for consumption during and after rainy season. Jaggery contain hygroscopic substances such as reducing sugars, dextrose , minerals like chlorides, sodium, potassium which make the jaggery liable for moisture absorption and microbial degradation, The estimates showed that 5-10% of stored jaggery is lost because of its hygroscopic nature (Narain *et al.,* 1985). It is difficult to store jaggery during the periods of high humidity and high temperature. These conditions fall during monsoon season (July to September) when the relative humidity values exceed more than 55 to 60% due to which it may lose its normal texture, colour and favour microbial growth causing compositional changes leading to undesirable, aroma, flavour and quality deterioration.

Modified Atmosphere packaging (MAP) is a well established technique in which the gases surroundings of a product is altered resulting in an atmospheric condition different from that of air (Tareq and Hotchkiss 2002). The interaction between product, barrier material and environment determines the gas composition inside the package (Rai and Paul, 2007). MAP improves the product quality, freshness and increases the shelf-life of the product as well as provides convenience to the consumer and adds value to the product. In a modified atmosphere package, the product is exposed inside the pack to the normal atmospheric gases (oxygen, nitrogen, carbon dioxide and water vapour) but in concentrations which are different from those in the ambient air. The packaging consists of polymeric film pouch or plastic container with a specified gas permeability. It uses minimum processing and little energy and maximizes nutrition and flavour. In adverse climatic conditions when deterioration accelerates, MAP slows the ongoing life processes not by changing the product but by adjusting its environment.

The estimates shows that 5 to 10% of stored jaggery valued about ₹ 1000 crore is lost during monsoon annually (Mandal *et al.,* 2006). The traditional packaging methods for storage in vogue (*e.g.*, inside a blanket of bhusa or wheat straw, cloth lined with polyethylene sheet, aluminum foil, plastic containers, earthen pots) give far from satisfactory results and in these days of acute food shortage the need for evolving an effective packaging method must be regarded as a national importance . Also at retail level the jaggery is sold in open and under unhygienic condition. Hence there is need to evolve suitable packaging technique to enhance shelf life and maintain quality of jaggery.

Shelf life of Jaggery under MAP through Nitrogen Flushing

Jaggery cubes made of cultivar CoJ 64 was packed in LDPE,PP and PET films of thickness 95, 30 and 90 microns respectively. The contol was jute package. Nitrogen was flushed in through gas flushing machine with vacuumtime 15s, inflation time 1.5s and pressure .02-0.1 MPs. All the packages were stored under ambient condition. Monthly data was recorded for moisture content, colour, reducing sugar and hardness.

Moisture content was determined by using hot air oven method by putting known weight of the sample in a dish, keeping it in preheated oven maintained at a temperature at 70°C. After 24 hours the dish was removed and transferred to desiccators, allowed it to cool and then weighed. The dish was replaced in oven for a further period of 24 hour, removed and transferred to desiccators, cool and weighed again. The process of heating; cooling and weighing was repeated after every 24 hour till consecutive weighing did not differ by more than 0.5mg.

The colour of jaggery is one of the important quality parameters, which indicates the freshness. It also affects the commercial value of the product. The basic purpose of colour measurement was to get an idea of comparative change in colour in different treatments with storage time. Conventionally, all conceivable colours can be located using Commission Internatinale de I'Enclairage (CIE) L*, a*, b* colour space system abbreviated as CIELAB (Mc Gurie, 1992), which is specified by three perpendicular axes. The L* indicates intensity of colour i.e. lightness which varies from L*=100 for perfect white to L*=0 for black. 'a*' and 'b*' are chromaticity dimensions which give understandable designations of colour i.e. the value of 'a*' measured redness when positive, grey when zero and greenness when negative and the value of 'b*' measured yellowness when positive, grey when zero and blueness when negative . These coordinates pinpoint the measured colour in a three-dimensional colour space. In the present study, on each day of observation, for different packaging treatments, L*, a* and b* values were determined at four places over the entire surface of the jaggery; using a Hunter Labscan (Model Miniscan XE plus, Hunter associated, USA,) in such a way that the sample was placed in close contact with the lens of the instrument so that the light which falls on the sample should reflect back and no light is transmitted to the surroundings and values obtained were averaged. The instrument was first calibrated with a standard white plate and black plates provided along with equipment before taking observations.

Total reducing sugars(TRS)

Reducing sugars namely glucose, fructose and others in alkaline solution have the ability to reduce cupric state to cuprous oxide. Reducing sugars having a free aldehyde/ ketone group, when reacts with alkaline copper reagent reduces its Cu^{3+} ion to Cu^{2+} ion, which forms a blue coloured complex with arsenomolybdate reagent, which can be measured at 620nm.

Phenolic content

The concentration of total phenols was determined as per McDonald *et al*. (2001), using Folin Ciocalteu reagent. One gram of jaggery sample was extracted with 10 ml of methanol: water (50:50, v/v) solution. Then 0.5 ml of diluted (1:10) extract was mixed with 5 ml of Folin Ciocalteu reagent (1:10 diluted with distilled water) and 4 ml of aqueous Na_2CO_3 (1M). The mixtures were allowed to stand for 15 min and the optical density of the mixtures was measured against the blank at 765 nm with the help of a UV-Vis spectrophotometer.

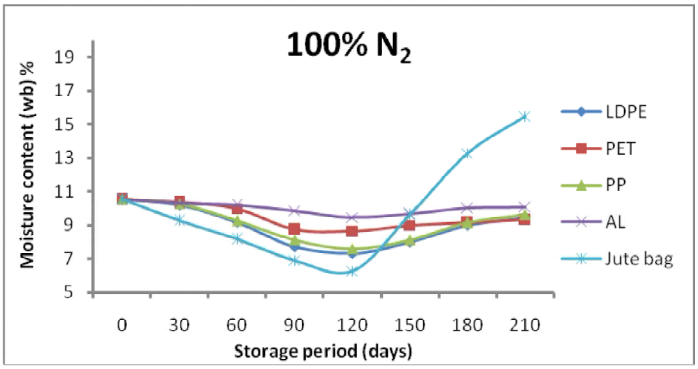
Texture analysis

Texture measurement was done using Texture analyzer (Make: Stable Micro Systems, Model: TA.HD*i*). The texture of jaggery cubes was analyzed every month during the storage study. Hardness test was performed using probe P/75 cylindrical probe. The force was measured in Newton in compression mode. The probes were attached to the load cell (50 kg) and was calibrated. The sample was placed on the mounting table and test was started. It provided the plot between the force and time. As compression proceeded fracture was observed as a peak or series of peak. The maximum value was considered to be indication of the overall hardness strength of the sample.

Effect of Jaggery storage under MAP through Nitrogen Flushing

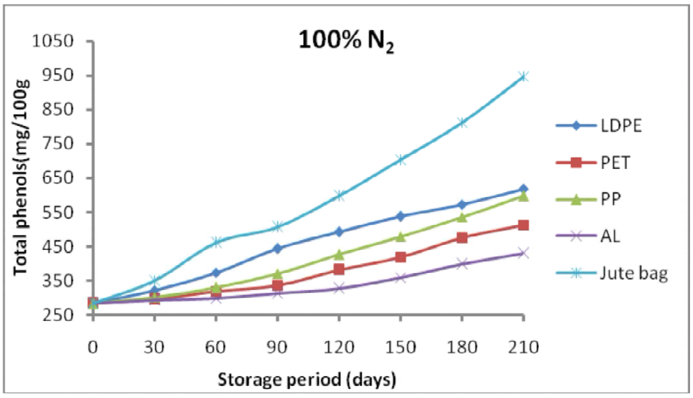
Moisture content

There was significant ($p<0.05$) effect of packaging material, storage atmosphere and duration on moisture content of jaggery. Under nitrogen packaging the moisture decrease in the jaggery samples was 3.21%, 1.87, and 2.93% for LDPE, PET, and PP films respectively after 120 days of storage. For the next 90 days the moisture increase was 2.13%,0.65%,2.03% and 0.63% for for LDPE, PET, PP and laminated films respectively. The overall change in the moisture was 1.08%, 1.22%, 0.90% and 0.44% for LDPE, PET, PP and laminated films, respectively. The overall rate of change of moisture content was minimum for laminated and maximum for PET. The final value after 210 days of storage was minimum for PET and maximum for laminated.



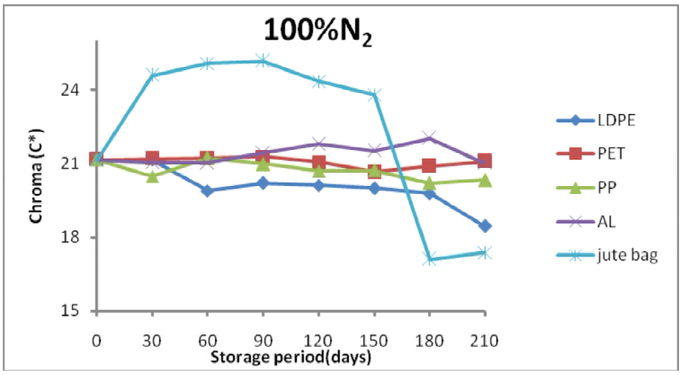
Total phenols

The overall change in total phenols was 334.69 mg/100 g, 230.32 mg/100 g, 2314.13 mg/100 g and 145.34 mg/100 g for LDPE,PET, PP and laminated film respectively. In laminated the increase in total phenols was 1.51 times as compared to 2.18 times in LDPE. The initial rate of increase of increase of total phenols was slow but increased significantly towards the end of storage duration.

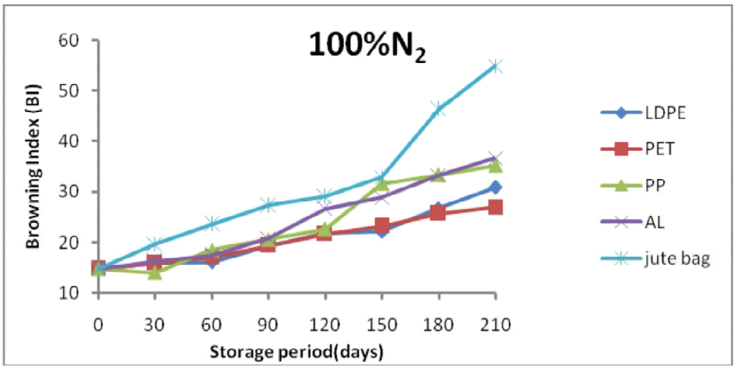


Colour

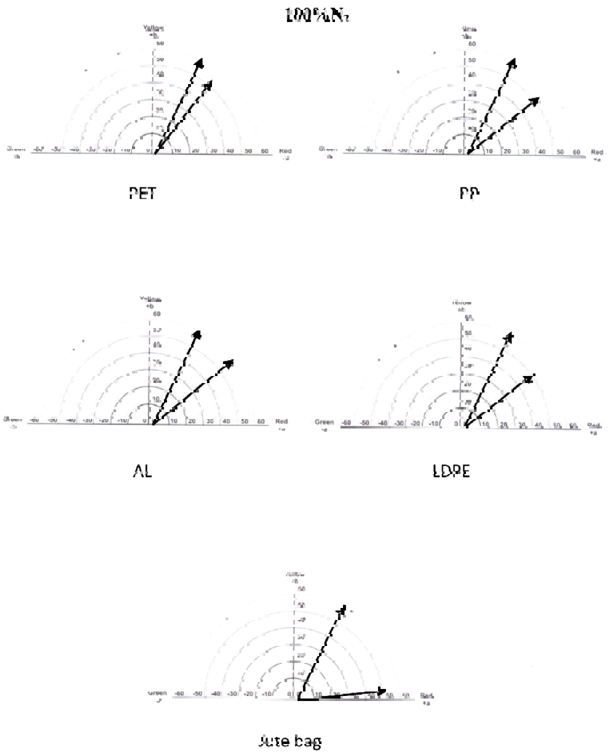
Under 100% N_2 the net decrease in ÄC* was minimum (-.007) for PET followed by LAM, PP and LDPE. Jaggery samples stored in LDPE showed a slight increase in ÄC* value on 30th day of storage. ÄC* change in PET showed increasing +ve values till 90th day of storage which indicated increase in brightness of jaggery. Similar non linear behaviour was observed in PP. In laminated film ÄC* decreased during first 60 days of storage and then it increased toward the right side of the reference till 180th day indicating increase in brightness of the jaggery samples.



The BI value increased in all th e treatments over the entire storage period. It indicated that samples became more brown on 210th day of storage compared to fresh jaggery. The rate of increase was linear till 150th day of storage followed by higher increase rate. In control a sharp increase in BI was observed after 150th day. The maximum increase in BI of 54.89 was observed in control treatment.



The direction of colour difference for different treatments with respect to fresh jaggery was evaluated by means of ΔC*, ΔL*. It lied in the third quadrant of colour space system which is indicative of darkness. The intensity of darkness was highest for control. The darkening was least for PET under 100% N_2.



Chroma hue difference on the portion of a*, b* chromaticity diagram of L* C* h* colour space system to determine the hue and its saturation after 210 days of storage under 100% N_2

Reducing sugars

Under 100% N_2 LDPE, PET and PP followed exactly similar behavior over the entire storage period. LAMINATED film showed a upward increase after 150th day of storage. The increase in reducing sugars was 13.95%, 14.45 %, 14.99% and 17.44% for PET, LDPE, PP and LAMINATED respectively. Under vacuum all the films have similar trend till 150th day of storage followed by abrupt increase in reducing sugars in Laminated film.

Hardness

An initial increase in hardness was observed after 30 days of storage in all type of packages which further decreased consistently thereafter.The hardness was retained in jute bags (316.00 N) till 120th days of storage which decreased drastically thereafter.

On the basis of storage qualities *viz.* Moisture, reducing sugar, phenol, colour and hardness it was observed that storage of jaggery under 100% nitrogen in polymeric films was more suitable in enhancing the shelf life and mantaining the quality as compared to conventional jute bags. The best packaging material was PET for maintaining the keeping quality of jaggery during and after monsoon season. LDPE films were not suitable for storing jaggery during monsoon season.

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Dr. A.D. Pathak is the Director of the ICAR-IISR, Lucknow (since 2015). Before taking the present assignment, he worked as Head, Crop Improvement Division at this Institute. He has unique experience of working with tropical and sub-tropical sugarcane based research institutes in country as Plant Breeder. He published over 200 papers in diverse disciplines of agriculture and is involved in development and release of sugarcane and sugar beet varieties in India. He is member of many professional scientific societies. He has been conferred with several prestigious awards. He is a Member of several important committees including ICAR Governing Body and ICAR Society etc. Technologies developed from the Institute under dynamic leadership of Dr. Pathak, contributed significantly in making Uttar Pradesh, the largest sugarcane and sugar producing state in India.

About the Institute

This Institute, established in 1952 and transferred to ICAR on April 1, 1969 is now an ISO 9001:2015 accredited organization. It has one regional and two specific purposes outposts for nationwide coverage of its activities. At headquarters, it is organized into five Divisions viz., Crop Improvement, Crop Production, Crop Protection, Plant Physiology and Biochemistry and Agricultural Engineering.

Besides these divisions, the Institute has central facilities for analysis of soil, water and plant samples; juice quality analysis; agro-meteorology laboratory (having A class meteorological observatory) that provides data related to weather fluctuations and climate change. The well-equipped Jaggery Unit conducts research on improving technology for juice, jaggery and other value added products on competitive costs and also on storage aspects of jaggery. The coordinating unit of All India Coordinated Research Project (AICRP) on Sugarcane, one of the Krishi Vigyan Kendra (KVK) of Lucknow district are housed at this Institute.

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ISBN 978-93-5396-574-7